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Agri-food Systems as Energy Systems: An Innovation for New Insights on Transformation to Sustainability

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***Abstract*:** Agri-food systems, indispensable but flawed institutions of the modern world, have partially accomplished their primary purpose, but in many cases, fail to reach all people. Moreover, associated environmental damages threaten future production. Climate change produces the most serious threats. Scientists have built different definitions and diagrams to guide research. Each emphasizes important points, but none have included everything. This paper offers a new diagram and definition based on displaying agri-food systems as an energy system. Agriculture is the source of biomass, one of the nine primary energy sources. With refining and processing, harvested products become food and feed, the sources of metabolic energy and nutrients. Together with other energy sources, especially fossil fuels, food and feed support the production of material wealth. Decision makers constantly direct streams of investments into perpetual production of agricultural biomass. The diagram shows that this agri-food system produces climate change, and the system is also a victim of climate change. This new perspective of agrifood systems as energy systems cannot show all components of the system, but it suggests new lines of innovation to mitigate the weaknesses of these systems.

Keywords: Agri-food systems, Climate changes, Energy systems, Sustainability, Investments

Agri-food Systems and Calls for Change

Agri-food systems, indispensable but flawed institutions of the modern world, have partially accomplished their primary purpose: producing and delivering enough food and fiber to feed and clothe people who do not farm for their livelihood or do not have sufficient land to produce enough. Unfortunately, deliveries remain uneven and, in many cases, fail to reach those most in need. Moreover, associated environmental damages, as noted below, threaten these systems.

Despite agri-food systems supporting 7.9 billion people-a number that is still growing-multiple criticisms have surrounded them for over half a century (Conti, Zanello and Hall 2021). Flaws with these systems include (1) insufficient quantities and qualities of food or (2) threats to perpetual functioning. Poverty usually contributes to the first set of flaws, a social-economic-political-cultural issue, not a physical absence of food and fiber. Other factors exacerbating poverty include inequality and insecurity of land tenure or access to water, discrimination based on gender-race-ethnicity, and geopolitical conflicts. Even in wealthier places, however, poor diets and obesity result from lack of easy access to nutritious choices.

A wide range of physical-chemical-biological problems cause the second set of concerns. For example, chemicals used to increase yields (fertilizers, pesticides, and others) unfortunately contaminate the environment and threaten the health of humans and other species (Houlton et al 2019, Sharma et al 2019). Consider just one example, a study of the herbicide glyphosate, often regarded as one of the safest pesticides to use. Recent studies, however, found that glyphosate blocked the ability of bumble bees to thermoregulate their nests. Without this ability, reproduction was likely to fail (Weidenmueller et al 2022, Crail 2022).

In the years after 1900, many scientists and social reformers began a systematic critique of industrial agriculture and its many hazards to health and sustainability. One of the most prominent examples centered on agroecology, an interdisciplinary enterprise to combine social and natural sciences. Francis et al (2003), defined agroecology as the ecology of food systems, a framework to reform many problems of industrial agriculture, both environmental and social.

Most importantly for agri-food systems, atmospheric changes caused by emissions of greenhouse gases have raised global temperatures, which have altered climatic factors, especially temperatures, precipitation, and storms. Such changes disrupt the physiology of crop plants and livestock, alter occurrences of pest populations and beneficial insects, reduce irrigation water, increase the frequency of “100-year” floods, and destroy farm infrastructure (Bezner et al 2022). Moreover, the processes of agri-food systems themselves contribute about one-third

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of the greenhouse gases causing climate change (Crippa et al 2021)

Even so, the modern world depends upon agri-food systems for security and well-being. As a result, the systems must deliver enough food *to every person*, especially enough calories and nutrients to support metabolic energy needs, sound nutrition, and health. These requirements demand more than mere prevention of starvation. Agri-food systems must also be resilient, i.e., able to withstand and recover from disruptions such as heat waves. Finally, agri-food systems must deliver food and fiber in perpetuity. The needs for metabolic energy and adequate supplies of nutrients will never end, so agri-food systems must function forever.

Sustainability of agri-food systems, in other words, rests heavily on the need to produce and deliver calories and nutrients "forever," a very demanding criterion. Given the criticisms of both socio-cultural and bio-physical dimensions of agri-food systems, many just enumerated, they currently fail to meet this criterion. For agricultural scientists, cultivating sustainable agri-food systems requires research, development, and innovation. New agricultural science, technology, and knowledge can contribute to resolving both socio-cultural and bio-physical problems of agri-food systems.

But what exactly is an agrifood system? This paper first highlights the origins of agri-food systems as a concept for scientific study. Definitions and diagrams from multiple perspectives have captured many of the components, processes, and outcomes of these systems. The paper then presents a new perspective based on seeing agri-food systems as part of energy systems. This innovation leads to revised definitions and diagrams of agri-food systems, new ways of understanding needed changes, and new possibilities and justifications for research so that agri-food systems will be better able to achieve their mission for many years to come.

Agri-food Systems: A Concept for Scientific Study

Surprisingly, the word "agri-food" did not appear in the English language until 1968 when, according to the Oxford English Dictionary, a Canadian newspaper referred to an "agri-food centre." *Fortune*, an American business magazine, referred in 1977 to the "agri-food business" as comparable to other industries, even the oil industries. With a word came a concept, subject matter rich for scientific study.

Given the intense interest in agri-food systems within the agricultural science and technology community in 2022, it is important to note that systems thinking itself developed only about 60 years ago and started to become common only about 30 years ago (Richmond 1994). As explained below, thinking of agriculture as agri-food systems developed mostly in the last 20 years.

Traditionally, before modern transportation and manufacturing, local farmers supplied their regions with the foodstuffs needed to sustain them. Energy intensive agriculture, based on cheap nitrogen fertilizer, irrigation, and mechanization, prompted development of larger farms worked by fewer people. Younger generations moved to cities in search of higher incomes and different opportunities. Food production instead of being local increasingly became far removed from population centers, dependent on well-functioning agri-food systems. Some of the new opportunities for employment were in agri-food systems (Christiaensen et al 2020). Despite these changes, the historical record clearly points to a longstanding interest in the inabilities of "modern" agriculture-i.e., developments since the early 1900s-to resolve deficiencies in food supplies, social inequities and injustices among people working in agri-food systems, and environmental degradation threatening future food and fiber production (Thompson and Scoones 2009).

Global recognition of the failures of agri-food systems came in 2002 at the Rio +10 Summit on Sustainable Development, which led the World Bank and the UN Food and Agriculture Organization to launch the International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD). Stimulated originally by concerns with the growing use of biotechnology and transgenic crops, the effort grew into a wholistic assessment of the abilities of agricultural science and technology to reduce hunger and poverty, improve rural livelihoods, and facilitate sustainable development (IAASTD 2009, Herren et al 2020).

The broad scope of IAASTD's assessment suggests that, in 2009, the assessors saw agriculture as a system with multiple components interacting to produce a wide variety of outcomes, some beneficial and some not. Nevertheless, explicit use of agri-food systems as a concept appears to have played little role in the 2009 assessment. The term appears a few times in the contexts of defining standards of quality and safety of food (p. 351) and of concerns about concentrations of economic power within a small number of companies (p. 465). Nevertheless, no definition of agri-food systems appears in IAASTD's 2009 report, and the term does not appear in the Glossary (p. 560) or Index (p. 577). Its common acronym today, AFS, stood for "agroforestry" in the report (p. 568).

In the decade following IAASTD's report, however, the concept of agri-food systems began to appear frequently and signaled recognition of a flawed, unsustainable system that, at a bare minimum, needed incremental change. Some agricultural scientists, both natural and social, called for transformational innovations, a far more ambitious target.

Thompson and Scoones (2009) criticized modern, high-input agriculture as the result of research looking at agriculture as a static entity, with yield and economic productivity as the only outputs of interest. They maintained instead that agri-food systems are dynamic, uncertain in behavior, and shaped by multiple, changing, interacting variables, which could not be managed by science based on studying one variable at a time.

Calls for transformative changes grew rapidly after 2015. The International Panel of Experts on Sustainable Food Systems called for new analytical frameworks, new transdisciplinary science, and knowledge revolutions (IPES 2015). More importantly, adoption by the United Nations General Assembly of seventeen Sustainable Development Goals in 2015 galvanized action, especially by international organizations (United Nations, 2016). Specifically, SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health), SDG 12 (new systems of production and consumption), and SDG 13 (combat climate change) each pointed to an element of sustainability of agri-food systems and set a new context for the direction of agricultural research and innovation (Hall and Dijkman 2019).

After adoption of the Sustainable Development Goals in 2015, researchers associated with CGIAR, organized in 1971 through the World Bank and UN Food and Agriculture Organization (Özgediz 2012), developed a theory of change by identifying eight specific objectives for transformative research (Campbell et al 2018). A group of 100 organizations subsequently developed a vision and agenda for this ambition (Steiner et al 2020).

Other papers also stimulated efforts for transformative research. "Sustainable Intensification" was the objective for transformed food systems that preserved both yield and livable environments (Pretty 2018). Hall and Dijkman (2019) also emphasized the need for transformative changes if agri-food systems were to continue feeding the world while preserving livable environments and fostering social justice.

In 2020, some participants from the original IAASTD assessment reviewed developments since the 2009 report. They highlighted "*. . . how a new food system narrative has been firmly established since 2008, which is distinctly different from the post-war chemical narrative that still dominates mainstream farming* (Herren, Haerlin et al 2020)." This report emphasized the need for a "paradigm shift" in agricultural science and technology, a transformation of scientific knowledge by completely new concepts and methods (Kuhn 1962), i.e., a radical shift indeed.

The themes of the 2020 report have been echoed in subsequent papers. Conti, Zanello, and Hall (2021) outlined multiple reasons for resistance to change in agri-food systems, for example, technological lock-ins, persistence of dominant technologies, patterns of power and political economic, and infrastructure rigidities. Wojtynia et al (2021) assessed the same theme of resistance to change in one country, The Netherlands. They found broad agreement in recognition of social (human health and livelihoods) and environmental problems (water quality, chemical use, and biodiversity) among Dutch stakeholders, but little consensus on possible solutions. The differences reflected adherence to an export market and economic growth model compared to the embrace of wholistic visions in agroecology.

Participants in the 5th Global Conference on Climate Smart Agriculture in Indonesia in 2019 also accepted the need for innovation to preserve and improve functioning of agri-food systems in the face of climate change. Already, the theme of Climate Smart Agriculture has attracted significant support, about $56 billion per year, but some scientists argue the focus is on incremental changes of agri-food systems, not transformational changes needed (Dinesh et al 2021).

A convenience survey of 410 participants in the 5th Global Conference in 2019 sought to measure such opinions. Of participants surveyed, 262 replied, and 66 percent of the respondents were research scientists. Collectively, the respondents identified 629 issues needing research. Top priority for the largest group of respondents (34 percent) was "climate-resilient and low emission practices and technologies," a clear indication that climate change was the top priority among those surveyed (Dinesh et al 2021).

Because the conference focused on Climate Smart Agriculture, it's not surprising that climate change preoccupied these respondents. Nevertheless, results indicated that at least a significant contingent of agricultural scientists endorsed this goal as top priority. Moreover, this target for research identically matched one of the eight targets identified a few years earlier as an integral part of a theory of change for agri-food systems (Campbell et al 2018).

But what exactly are the agri-food systems now the focus of global concern and scientific study? Unfortunately, precise definitions of them have not yet stabilized (Hall and Dijkman 2019), which complicates efforts to produce useful innovations. Examples below illustrate different efforts for both textual and diagrammatic definitions.

Textual definitions of agri-food systems: Calls for research to understand and transform the way we produce, distribute, and consume food have stimulated definitions emphasizing the scope of agri-food systems from the farm through to the consumer, and ultimately disposal of waste food and packaging (IPES 2015):

. . .web of actors, processes, and interactions involved in growing, processing, distributing, consuming, and disposing of foods, from the provision of inputs and farmer training, to

product packaging and marketing, to waste recycling. . . .

Hall and Dijkman (2019) characterized agri-food systems as a metaphor encompassing social, environmental and political processes but not emphasizing the continuum of processes from farm to waste disposal:

. . . a descriptive metaphor for the interconnected elements of food production and consumption, and the defining social, environmental and political context in which these sit.

Hall and Dijkman (2019) also pointed to a definition developed by researchers on food systems at the University of Vermont in the United States. This one included health, economics, and scale not included in the above definitions.

[A]n interconnected web of activities, resources and people that extends across all domains involved in providing human nourishment and sustaining health, including production, processing, packaging, distribution, marketing, consumption and disposal of food. The organisation of agri-food systems reflects and responds to social, cultural, political, economic, health and environmental conditions and can be identified at multiple scales, from a household kitchen to a city, county, state or nation.

Diagrammatic definitions of agri-food systems: An approach different from using words to spell out the elements of agri-food systems relies on diagrams. A few of many examples show a range of "agri-food systems images," from simple to elaborate. They differ in the density of ideas, components, processes, scales, and crops portrayed. All diagrams depend upon text to identify components and processes, and to explain their functions. Nevertheless, images can often show relationships among interacting components more clearly and easily than texts.

Perhaps the simplest diagram traces the flow of agricultural products from farm to consumption and disposal of waste (Fi. 1), quite comparable to IPES (2015), quoted above. At the end of the flow, extra illustrations and the legend draw attention to hunger, food insecurity, and food policy, issues not involving the flow of physical agricultural products from production through processing and marketing to consumption and disposal of waste. Absent from Figure 1 are (1) links between hunger/food security and policy and physical flows; (2) inputs of knowledge, water, energy; and (3) any reference to periodic and repeating passage of time. It is also unidirectional with no feed-back loops. Nevertheless, the diagram successfully conveys many of the components and processes that occur between farm and consumer.

Another simple diagram of a food system (Fig. 2) shows four main steps in movement of food from farm to consumption (Sustainable Food Center 2020). The key idea of a repeating cycle appears in the circular arrangement of the components, in which consumption leads around to the starting component, production. Periodicity of flow, typically annual, however, appears only by inference from the perpetual need for food. Icons outside the circle indicate that labor, energy, waste, policy, and climate accompany the cycle, but it's not clear how they relate to the four components. Water appears only indirectly through the icon for climate. Other components, such as inequality-hunger, policy, and knowledge-science do not appear.

Corke and Olewnik (2019) built an elaborate, information-dense diagram (Fig. 3). Primary overlapping and interacting components include Politics-Governance, Socio-cultural, Economics, and Environment, each of which also has sub-components. Like Figure 2, this diagram includes the idea of a cycle, from producers of foods to consumers and back again, but it, too, leaves the reader to infer both periodicity and perpetual functioning. One interesting difference compared to Figures 1 and 2 is the inclusion of aquatic as well as terrestrial sources of food. Also included in Figure 3 are money, water, and energy, plus issues of food security and education-training-expertise.

A final example, Figure 4, includes the idea of past time or history, explained in the text with an example, adoption of synthetic chemical pesticides after 1945. These chemicals required new skills and attitudes among the adopters. As farmers made pesticides a routine part of their production practices and increased yields, other players in the agri-food system also became accustomed to the chemicals, e.g., people involved in processing, marketing, and finance as well

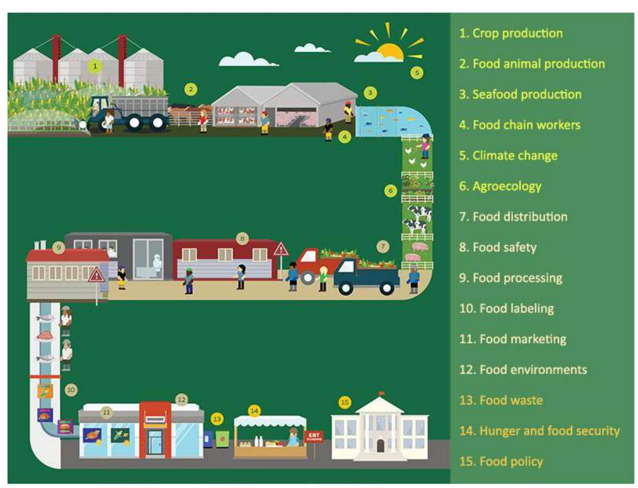


Fig. 1. Definition of an agri-food system by diagraming flow of agricultural production on the farm to consumption and disposal of waste. Hunger/food insecurity and food policy appear at the end of the flow. (Center for a Livable Future, 2022, https://www.foodsystemprimer.org/ the-food-system/, accessed 7 July).

as manufacturers making the chemicals. Consumers, too, became accustomed to cosmetically perfect fruits and vegetables at cheaper prices. Now, to suggest a new set of practices, e.g., integrated pest management (IPM) requires not only farmers learning new skills but also adjustments by other players in the system. In other words, changes in pest control practices involve not just the technology itself but also many other socio-political changes. For these reasons, use of synthetic pesticides persists or is "locked-in," even in the face of resistance to pesticides and previously unknown health hazards (Conti et al 2021, Perkins 1982).

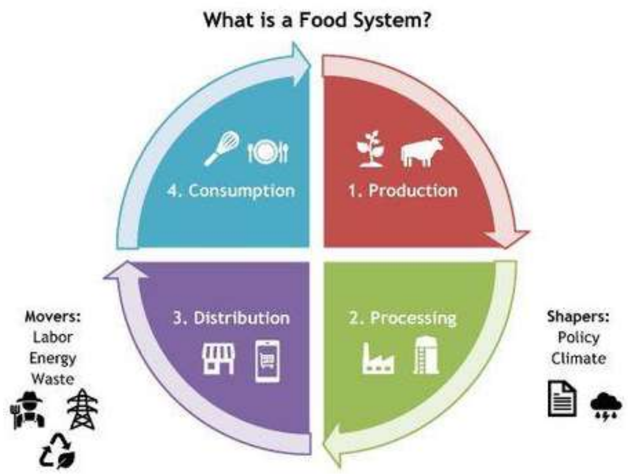
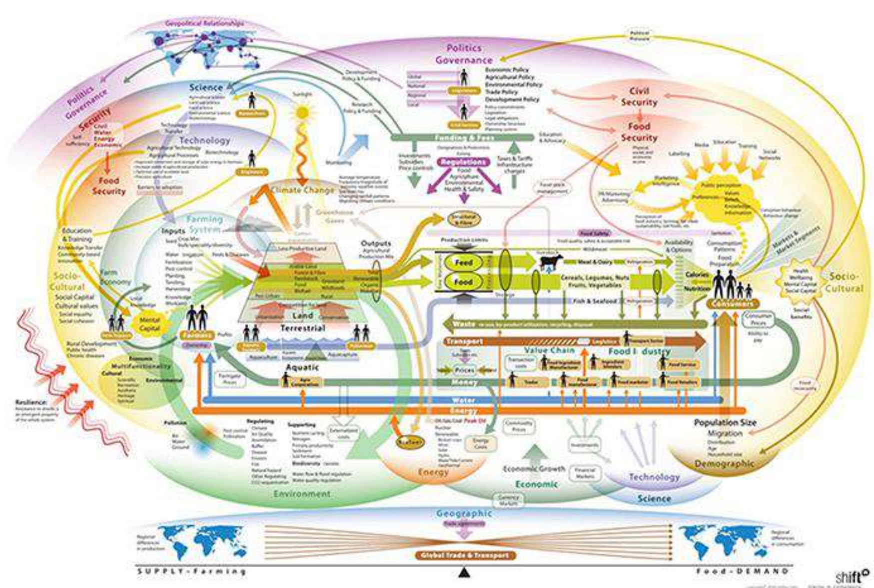


Fig. 2. A simple diagram of a food system showing four main steps in movement of food from farm to consumption. The idea of a repeating cycle appears in the circular arrangement of components surrounded by arrows showing direction of flow. Period of flow, typically annual, however, does not appear. Icons outside the circle indicate that labor, energy, waste, policy, and climate play a role in the cycle. Water appears only indirectly through the icon for climate. Other components, such as inequality-hunger and knowledge-science do not appear (Sustainable Food Center 2020)

A second line of logic from economic history also led to "history matters:" the "treadmill theory" (Cochrane 1979, Global Agriculture 2022). Early adopters of a new technology-if it works-increase yields and thus earn more income. Their peers see the benefits, and they, too, adopt the new practices. When many farmers adopt new practices, however, total yields increase enough to drive prices lower. Early adopters make money, but later adopters don't. Farmers who don't adopt see prices drop while their yields remain the same. Thus, their incomes drop, and many leave agriculture. Early adopters with extra money buy or rent the land of the leavers. The treadmill theory thus explains why farmers must adopt profitable new technology: they are on a treadmill, and not adopting risks financial failure. Abandoning the new technology isn't possible, because it, too, risks financial collapse. The new technology persists, even if turns out to be unsustainable.

Figure 5 depicts a systems science approach to an agri-food definition. Agri-food systems scientists have developed an alternative way of portraying agri-food systems, the Food-



2019 Cereal Foods World super theme: Global Food System. Source: shiftN

Fig. 3. An information-dense diagram of a food system (Corke and Olewnik 2019)

Energy-Water nexus (FEW). Systems scientists seek to describe, explain, predict, and manage systems, ". . . a set of things connected in a way that creates some unified whole) (Saundry and Ruddell 2020). Studies of FEW incorporated previous work on the interactions of human and natural systems (Liu, Dietz, Carpenter et al 2007, Saundry 2016).

Saundry and Ruddell (2020 34) defined FEW systems as a ". . . set of sources, movements, uses, and sinks that constitute a way of understanding the unified whole in the context of a particular place and time." Relationships between components could be non-linear, multivariate, and multi-scaler; boundaries of the system could be multifaceted. Where agricultural scientists studied granular connections between components of agri-food systems from farmer to consumer, systems scientists sought to understand interactions among food, energy, and water in food production.

One example of a diagram defining a FEW nexus (Fig. 5) shows four major components: food, energy, water, each affecting each other and interacting with climate change (California Department of Water Resources, 2017, as cited in Saundry and Ruddell 20206). Rather than emphasizing the actors and organizations in the annual production of food and fiber, diagrams drawn from systems science emphasize interactions among natural resources and with driving factors external to the FEW nexus. The figure incorporates water, food, energy, and climate change, but not the power and politics of Figure 3 or historical grounding of Figure 4.

In sum, the verbal and diagrammatic ways of defining agri-food systems complement each other, but neither approach has captured every dimension of these systems.

Agri-Food Systems As An Energy System: A New Perspective

Saul and Perkins (2021) developed a new diagrammatic portrayal of energy systems-the Energy Regulatory and Industrial Complex (ERIC)-to promote better education on climate change. Their argument was that resolution of the risks of climate change required an energy transition from fossil fuels to renewable energy without carbon emissions. The heart of making that transition required changing investment flows away from building and maintaining fossil fuel infrastructure toward infrastructure for renewable energy. Without perpetual streams of investment, no modern energy system can persist.

A simple change in ERIC transforms it to a portrayal of an agri-food system based on an energy system (ERIC-AFS) (Figure 6). Unlike Figures 1-5, ERIC-AFS emphasizes the production of food and feed to provide an "energy service:" metabolic energy for people and their livestock. Production of food and feed operates cyclically and perpetually if the requisite investment streams persist. As with energy systems in general, transformation of agri-food systems requires redirecting perpetual streams of investment.

Key to this new perspective is recognition that "biomass" is a primary energy source (PES), i.e., one of the nine natural resources that yield energy services. Ordinarily, biomass

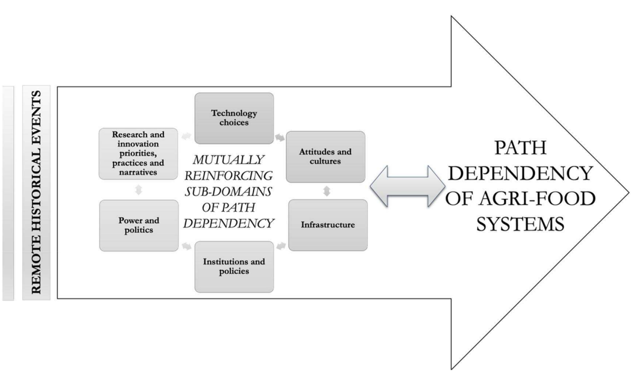


Fig. 4. A food system diagram that includes flow of time and maintains that historical changes affect the operations of current-day systems and the possibilities of changing them (Conti, Zanello and Hall 2021), i.e., "history matters"

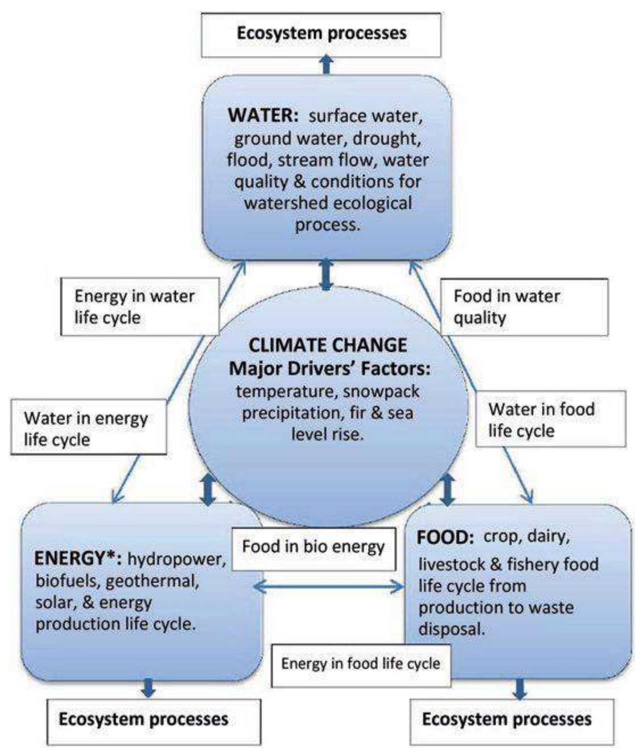


Fig. 5. One example of a diagram to define a FEW nexus emphasizes interactions among food, energy, and water, all affected by climate change. Each of the four major components changes and is changed by its interactions (California Department of Water Resources 2017; found in Saundry and Ruddell 2020)

yields energy when combusted directly (e.g., firewood) or fermented to a fuel before combustion (e.g., grain or sugar cane into ethanol). Food and feed, special forms of biomass, are sources of life-sustaining metabolic energy. Food and feed come from agri-ecosystems, and ERIC-AFS shows "Agriculture" instead of the more generic "biomass" as one of the nine PES (Figure 6).

In Figure 6, energy services produce development/ wealth/money controlled variously by companies, individuals, and governments. Decision making in turn perpetually invests some of this money into Innovation-Building-Maintaining-Operating-Rebuilding infrastructure needed to produce Pes, Fuels, and Energy Services, to again produce Development-Wealth-Money and thus continue the investment cycle.

Climate Change is the inevitable by-product of the world's current energy systems, based on production and use of fossil fuels, which emit the largest share of greenhouse gases. Fossil fuels (coal, oil, natural gas), the most widely used PES, provide about 80 percent of the world's energy services, and historically they created modern societies. These fuels also underlie the creation and operations of high-yielding, energy intensive agriculture, especially through the production of cheap nitrogen fertilizers and powering the harvesting, manufacturing, and transport processes embedded in agri-food systems. Production and use of fossil fuels release the two most important greenhouse gases, CO_2 and CH_4. Warmer temperatures and climate change from fossil fuels have already damaged agricultural yields, due to physiological harm to crops and livestock and to changes in precipitation: more floods and more droughts (Benzer et al 2022). Loss of yield has already damaged human health and ultimately will destroy the benefits from fossil fuels and high-yielding agriculture.

In addition, however, as shown in Figure 6, agriculture itself not only is damaged by climate change but it also contributes to climate change by increasing emissions of three greenhouse gases (N_2O, CO_2, and CH_4). Crippa et al (2021) estimate that agri-food systems, from production to consumption, produce 34 percent of the global emissions of greenhouse gases causing climate change. In other words, energy-intensive agriculture is both cause and victim of climate change.

Dangers to agricultural yields from climate change created the Central Dilemma: if humanity stops using fossil fuels to mitigate climate change, yields decline, and agri-food systems collapse. If fossil fuels continue in use and continue driving climate change, yields also decline and agri-food systems collapse. The Central Dilemma powerfully supports placing agriculture in a diagram of an energy system, clearly illustrating agriculture's role, along with the fossil fuels, as the source of an essential energy service and as a cause of climate change.

ERIC-AFS is a complex diagram and merits a more detailed guide to reading it (Appendix 1). Here, however, we turn to a new definition suggested by ERIC-AFS:

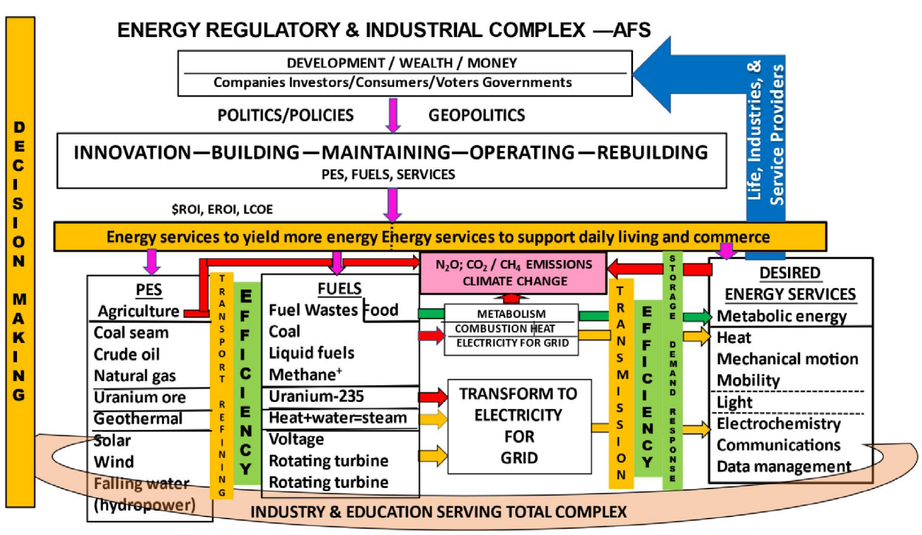


Fig. 6. The Energy Regulatory and Industrial Complex (ERIC) portrays an energy system so as to emphasize the production of the nine primary energy sources, their transformation into fuels, and the provision of energy services. Modified from Saul and Perkins (2021), ERIC-AFS shows a cyclic agri-food system in which metabolic energy services enable human activities in modern societies leading to development and wealth. In a perpetual cycle, some of this wealth must be invested to renew supplies of energy sources, one of which is agriculture, so that food and feed can again support metabolic energy essential to life

Agri-food systems are arrangements of components promoting multiple, perpetual, cyclical flows of physical materials, energy, decisions, and investments, all designed to promote agricultural production of biomass, one of the nine primary energy sources. In turn, harvested biomass undergoes refining, processing, packaging, and transport to produce and deliver food and feed, the fuels providing metabolic energy, existentially important for humans and their livestock. In collaboration with other primary energy sources providing other energy services, food and feed support the continuity of developed economies, which of necessity must allocate a perpetual flow of investments to promote continued agricultural production to provide perpetual flows of food and feed to support metabolic energy.

Discussion

As with each of the earlier textual and diagrammatic definitions of agri-food systems, neither this textual definition nor ERIC-AFS (Figure 6) captures all elements of agri-food systems. Instead, all definitions and diagrams highlight points, which authors choose to emphasize. These are points not made elsewhere or information less visible in other renditions. ERIC-AFS and the definition provide platforms for discussing agri-food systems and their needed changes.

ERIC-AFS and its associated definition emphasize several important points. Figure 6 explicitly indicates a key feature of all agri-food systems: financial investments required to produce food and feed, the fuels providing metabolic energy. Every farmer knows the sacrifice of up-front investments to purchase and plant seeds well before the payoffs of harvest sales. The risk: crop failure and no harvest, a devastating blow, especially if the farmer borrowed money at the outset. In some cases, farmers use pesticides to avoid the risks of damages to their crops, which would endanger their ability to pay debts at the end of the harvest (Perkins 1982). People not in agriculture, especially those in cities who have never seen a farm, can easily forget or underestimate this factor..

Not only are investments cyclic and perpetual for production, they aim carefully at supporting specific production practices. To put innovations into practice, the investment targets must change. For the investment targets to change, decision making by investors must change. Multiple sources currently invest annually in agriculture: individual farmers, banks, governments, and others.

Targeted investments also guide the work of agricultural scientists. Decisions about scientific investments, too, must change and might, therefore, go to different communities of scientists. for example, only 9 percent of those surveyed at the 5th biennial conference of Climate Smart Agriculture, noted earlier, identified “innovative finance to leverage public and private sector investments” as a top priority, the smallest percentage among the five groups identified as top priorities (Dinesh et al 2021). The small percentage of researchers seeing investment as a topic of low priority suggests a need to increase attention to this point. Changing the direction of investments always creates winners and losers. Accordingly, political conflict may arise because of changing investment patterns, and they must be expected.

Despite the low interest respondents had in investments, their interest in climate resilient and low emission practices was the top priority for 34 percent of respondents, essential for addressing the Central Dilemma. The Dilemma calls for two separate lines of research: one to make the systems more resilient to climate change and the other to reduce the emissions of greenhouse gases from the systems. Both avenues will change agri-food systems, some in incremental ways and others more transformational. A complete review of these lines lies far beyond the scope of this paper but consider the following examples from both lines.

To make agri-food systems more resilient to hazards of climate change

- Plant and animal breeding for resistance to heat, drought, floods, and storms
- Architectural and construction changes in farm buildings to resist heat and floods
- Policy changes to improve financing of needed research
- Institutional changes to develop needed research facilities and stimulate coordination among them
- Innovations in climate change education to assist public understanding of vulnerabilities of agri-food systems to climate change, for both urban and rural audiences
- Educational programs for financial industry and their regulators about climate change and agri-food systems

To mitigate emissions of greenhouse gases by agri-food systems

- Electrification of machines and transport serving agri-food systems, based on renewable primary energy sources, not fossil fuels; scales to include utilities, community infrastructure, and on-farm generation
- New methods for synthesis and application of nitrogen fertilizers, to increase efficiency of use, decrease emissions of nitrous oxide, and reduce runoff into waterways
- Synthesis of farm chemicals, steel, cement, and ammonia with low or no emissions of carbon
- Management of soils and agricultural wastes to reduce emissions of N_2O, CO_2, and CH_4

- Educational programs for participants and beneficiaries of agri-food systems about needed changes by companies, work forces, and consumers
- Design of policies for agri-food systems to promote lower emissions of greenhouse gases, for example, by lowering transport during production, processing, and marketing of agricultural goods

ERIC-AFS and the new definition also prompt new insights not usually associated with changes in agrifood systems. For example, seeing agriculture as an energy source indicates the centrality of the energy service, that is, metabolic energy to support human life and livestock. While a farmer will see the value of his or her activities as the harvested material, humanity as a whole values agriculture mostly for its provision of metabolic energy and nutrition. The same is true for all energy sources. For example, a coal miner values the monetary worth of the rock taken from the ground, but humanity doesn't really want coal as a rock. Instead, the value lies in the heat energy when the rock is burned.

This point may seem obvious and trivial, but in fact it carries the most radical ideas for innovation. If ways other than agriculture can produce metabolic energy for people and livestock, then commercial development of such methods may be highly useful innovations. For example, the culture of insects for livestock feed or human food may not be called "agriculture," but the metabolic energy produced may be highly prized as an energy service (Halloran et al 2018).

Another feature of ERIC-AFS is a clear emphasis on geopolitics as a factor affecting investment decision-making in agriculture. In earlier work (Perkins 1997). I reconstructed the role of geopolitics influencing decisions to support investments in the Green Revolution in South Asia as well as in the United States and the United Kingdom. These factors originated in the conflicts of the Cold War between The United States and the USSR after World War II. More recently, the invasion of Ukraine by the Russian Federation has shown that geopolitical factors can disrupt supply chains associated with agri-food systems (Economist, 2022). Russian naval forces blocked grain shipments from Ukraine to countries in northern Africa, leading to potential food shortages in countries that usually import Ukrainian wheat (Dahir and Peltier 2022).

In addition to the strengths of placing agri-food systems in an energy context, ERIC-AFS and the new definition have gaps leaving important points for supplementary discussions. To keep the diagram simple and the definition concise, essential subsystems are not included. For example, the inputs of agricultural production include steel, cement, chemicals, and water, each of which requires energy to produce and deliver to farmers. Most of this energy currently comes from fossil fuels. An agri-food system, therefore, relies on collaborative combinations of energy sources. Innovators must not forget about the important roles played by other energy sources, and, to mitigate climate change, these other energy sources must be changed from fossil fuels to sources not emitting greenhouse gases.

The diagram and the definition also do not include demography, spatial distributions, social factors, and social institutions. The population size, for example, determines the amount of metabolic energy needed but says nothing about the location of populations. As noted earlier, development of fossil fuels was essential to mechanization of agriculture. And with mechanization came a shift in where people live. Less labor was needed in the countryside, and people left rural areas for the cities. Harvested food that used to travel very short distances to consumers must now travel thousands of kilometers. The harvest must be preserved and transported to deliver metabolic energy to consumers.

Another gap in the diagram and definition lies in the lack of any information about a multitude of social factors, each of which could affect the success of achieving new investment patterns end new deployment of technology in practice. Women farmers compared to men may have more difficult pathways to investments, finance, and expertise. Small holders compared to large landowners may also be at a disadvantage in adopting new practices. Those working to reform agri-food systems must remain highly conscious of the detrimental effects of such inequalities.

Another key element of agri-food systems not directly visible in ERIC-AFS or the textual definition lies in the realm of "history matters." "Mechanical motion" and "mobility," energy services powered by fossil fuels, historically replaced animal and human muscles (Cochrane 1979), and a major portion of global warming resulted from greenhouse-gas emissions from engines in agriculture, transport, and industry. Mechanization of agriculture lay behind a profound transition in agri-foods systems. In the United States, for example, the proportion of the American population in agriculture dropped from 34.7% in 1910 to 1.8% in 1995 (Lobao and Meyer 2001). Simply put, machines made it possible for fewer people to do agricultural work, and many people left the countryside for work in industry and services in the cities. Today, fossil fuel powered transport supports both movement of food to urban centers and the supply chains of goods from cities to countryside to serve agriculture.

One additional factor results from the historical movements of people. Political support for innovation in agri-food systems depends partially on urban populations, which now house most people. Out-of-sight causing out-of-mind, however, results in injustices in agriculture that too often escape the notice of city people, who in turn neglect to support needed agricultural reforms. For example, in the United States, farmworkers have been excluded from the Fair Labor Standards Act of 1938; only in 2016 did California pass legislation to ensure farmworkers would receive overtime pay for working more than a standard 40-hour work week. Washington's governor signed similar legislation in 2021; Oregon passed its law in 2022 (AP 2022).

CONCLUSIONS

Climate change poses serious threats to the well-being of people across the globe. It doesn't matter whether they live in the cities of modern societies or whether they practice subsistence agriculture in a less industrialized country. A major part of the threat centers on the effects of a warmer climate on agriculture and agri-food systems. If yields seriously decline, then food insecurity, food shortages, hunger, famine, sickness, and death loom.

First signs of damages to agricultural yields have already occurred due to climate change. If the current level of damages, plus the more serious threats of future damages were not enough, other factors also demand innovations in agrifood systems. Given these pessimistic statements, why should anyone hold optimism for the future? Two major points from this paper, however, provide grounds for cautious optimism.

The concept of agri-food systems as an object for scientific studies has already bolstered seeing the future through an optimistic lens. Many efforts to define and diagram these systems have helped organize and fund needed research. Multiple perspectives found in the different definitions and diagrams emphasize multiple facets, all of which stimulate different useful pathways for innovation.

The value of portraying agri-food systems as part of the global energy system brings out yet more perspectives and components of these systems. Combining the energy lens with the sense that history matters points to the second major conclusion: agricultural scientists working in the traditional agricultural disciplines must pay close attention to the energy connections embedded in modern agri-food systems. They should support efforts to transition away from fossil fuels to renewable energy without carbon emissions. These transition efforts will undoubtedly affect the work and possibilities of traditional agricultural scientists. Evidence already exists that agricultural scientists are keenly aware of climate change and connections to fossil fuel energy. This awareness must translate into supportive agricultural practices that work well with energy from renewable sources.

Appendix 1: Agri-food systems in ERIC-AFS, details of a new perspective

Drawn from Saul and Perkins (2021), ERIC-AFS (Fig. 6) emphasizes investments, a key feature of energy systems they had not seen elsewhere: a perpetual cycle of investments builds, maintains, operates, and rebuilds all energy systems. ERIC-AFS acknowledges the technology and natural resources involved in energy systems and includes social, political, economic, cultural, institutional, and environmental dimensions. Science, technology, and broad political-ecological factors shape “Decision Making” about investments and innovation.

Agri-food systems both use and produce energy, but usually assessments of innovation in these systems don't picture them as energy systems. This paper modifies ERIC by placing Agriculture in the framework as a primary source of energy, ERIC-AFS (Fig. 6). ERIC-AFS depicts a cycle, so one can trace its operation starting at any point. Start with the vertical box on the left, “DECISION MAKING,” the processes upon which innovations and investments in ERIC-AFS depend.

From DECISION MAKING, move to the row of boxes at the bottom of the diagram. In the lower left-hand corner, “PES” (Primary Energy Sources) indicates the nine Primary Energy Sources, all of which originate “naturally,” i.e., without human agency, although humans can, in the case of Agriculture, augment the natural processes. These nine sources are the only energy sources available. Agriculture, more generally called “biomass,” means plant and animal products derived directly and indirectly from photosynthesis. It also includes biomass from forests, managed or unmanaged.

Move right to “Fuels,” materials or processes ready to use for energy and derived from primary energy sources; fuels exist due to human actions. For agriculture, crops can yield fuels directly, e.g., grain can be turned into ethanol for motor vehicles. Similarly, burning wood wastes and paper yields energy as heat and light, and landfills of garbage produce methane, a fuel. Most importantly, only Agriculture yields food and feed for people and livestock.

Primary energy sources and fuels are useful, but the value of energy systems lies in the box at the lower, right-hand side, “Desired Energy Services.” Simply put, people don't really want sources and fuels; instead, they want the services energy performs, usually by using an appropriate machine.

Energy services exist in eight distinct categories, one of which is to provide metabolic energy for people and other animals. Only food as a “fuel” can provide this service; the other eight primary energy sources, plus non-food biomass, cannot directly provide metabolic energy. All nine primary energy sources, however, can power each of the other seven energy services. As presented elsewhere, different fuels have unique profiles of strengths and weaknesses, and certain services generally derive from only one or a few of the primary sources (Perkins 2017). For example, fuels for transport powered by internal combustion engines currently come almost entirely from crude oil refined into diesel or gasoline fuels.

Note the boxes between PES and FUELS and DESIRED ENERGY SERVICES. These capture various human interventions making the progression possible and more efficient, e.g., transport (moving materials) and refining (chemically or physically modifying materials and processes). The most important box is "Transform to electricity for the grid." Electricity is a manufactured energy carrier, also called a secondary energy source. It does not exist in nature, at least not in a useful form, but electricity is preferable for many purposes, e.g., light, which also comes from combustion. For the bottom three listed energy services, electricity is the only source of energy to power electrochemistry, electronic communications, and data management.

The processes of moving from Primary Energy Source to Desired Energy Services cause the box depicting climate change. The two most important greenhouse gases (CO_2, CH_4) come from multiple parts of ERIC, and N_2O comes mainly from Agriculture, along with CO_2 and CH_4. Agriculture emits most nitrous oxide from degradation of nitrogen fertilizers.

Powered by the eight energy services, Life, Industries, and Service Providers-shown in the blue arrow moving up and to the left-create the products and services of modern industrial societies. Plentiful and inexpensive products and services create material prosperity and comfort in developed, wealthy societies. Virtually all modern people relish modernity and have no desire to revert to premodern conditions. Climate change clouds the future, but many remain oblivious to it as they eat and live well.

Many also remain uninformed about the origins of food in developed countries. Agriculture is an industry, courtesy of energy services. Machines, chemicals, and improved varieties yield vast quantities of food to power metabolic processes. With mechanization, very few people produce food and fiber, and transport companies move agricultural products from production on farms to consumption in cities, powered almost entirely by fossil fuels. Many people live far from farmlands, have never been on a farm, have little understanding of agri-food systems, and remain oblivious to the energy that feeds them.

From the Development/ Wealth / Money box, the perpetual investment cycle embedded in ERIC-AFS begins, with decision-points in purple arrows. Decisions-made in a context of politics/policy and geopolitics-direct money flows to innovation and to the endless building-maintaining-operating-rebuilding of energy systems.

Continually, energy industries marshal profits and borrowed funds for investments to produce more primary energy sources and fuels. For example, as oil and gas fields decline, geologists and petroleum engineers must develop new fields. As refineries wear out, companies maintain and replace them. A company making electricity from geothermal heat and steam must maintain existing equipment and replace it when needed. An electric power company using solar panels and wind turbines must buy, install, maintain, operate, and replace worn-out equipment. Farmers, too, must continually maintain, operate, and replace equipment.

In all cases, decision-makers invest "surplus money," i.e., money not needed for immediate consumption but instead used to satisfy future needs. Outside investors, financial industries, and governments also loan, subsidize, or grant money for investments.

Consumers of energy also invest in perpetual cycles, not to produce primary energy sources and `fuels but to produce energy services. They buy, operate, maintain, and replace equipment to stay in business or to live. For example, a citizen using an automobile or air conditioner must buy, operate, maintain, and replace machines, or the energy service disappears.

Investors use their own funds and borrow from financial institutions and governments. Financed by taxes and borrowing, governments provide grants and subsidies. A plethora of politics, laws, and policies surround all investments. More indirectly, each country with investment activity also has geopolitical concerns, and governments in each country shape investment processes to meet geopolitical goals.

Regardless of the source of investment funds, all investors expect a return from the expenditure, either more money, more service benefits, or some political payoff. Returns to companies producing primary energy sources come from selling sources and fuels. Failure to receive expected returns will sour decision-makers on making the same investments again in the future. Most importantly, without perpetual streams of investment, energy systems grind to a halt. Without energy services, modern societies collapse.

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Actual and Potential Effects of New Plant Breeding Technologies

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Abstract: New plant breeding technologies (NPBTs), including genetically modified and gene-edited crops, offer large potentials for sustainable agricultural development and food security, while addressing shortcomings of the Green Revolution. This article reviews potentials, risks, and actually observed impacts of NPBTs. Regulatory aspects are also discussed. While the science is exciting and some clear benefits are already observable, overregulation and public misperceptions may obstruct efficient development and use of NPBTs. Overregulation is particularly observed in Europe, but also affects developing countries in Africa and Asia, which could benefit the most from NPBTs. Regulatory reforms and a more science-based public debate are required.

Keywords: Plant breeding technologies, Food systems, Green revolution, Genetically modified organisms

More than 800 million people worldwide are chronically hungry, and 2 billion are micronutrient- deficient (FAO 2021). These numbers are currently further increasing, also as a result of the Russian attack on Ukraine. Food insecurity and low dietary quality cause huge public health problems. Malnutrition is responsible for physical and mental development impairments, various infectious diseases, and unacceptably high numbers of premature deaths (Development Initiatives 2021). Reducing these problems and achieving Sustainable Development Goal 2 “zero hunger and improved nutrition” requires major transformations in global food systems. Isolated fixes cannot solve the complex issues (Springmann et al 2018, Meemken and Qaim 2018, FAO 2021). Among other strategies, agricultural technologies have a very important role to play.

Producing enough food for a growing population has always been a challenge since humans became sedentary and started agriculture some 12,000 years ago. This challenge is not yet over, as the global population continues to grow. Fertile land and water are becoming scarce, so production increases have to come primarily from yield and productivity growth (Cai et al 2019). Plant breeding has contributed to considerable yield growth, especially during the last 100 years (Huang et al 2002, Evenson and Gollin 2003). In addition, massive increases in the use of chemical fertilizers, pesticides, irrigation water, and other yield-enhancing inputs have helped to raise food production and feed the rising population. Even though chronic hunger is still widespread in many developing countries, the global proportion of hungry people was reduced from over 50% in the first half of the twentieth century to around 10% today (FAO 2021). However, the increasing intensity of agricultural production also has its problems. The high use of agrochemicals combined with unsustainable agronomic practices has led to several environmental externalities. Agriculture also contributes to climate change, accounting for about 25% of the global greenhouse gas emissions (IPCC 2019). The climate change will likely affect agricultural production negatively through increasing mean temperatures, heat and water stress, and rising frequencies of weather extremes. Poor people in Africa and Asia will be hit hardest by climate calamities, not only because they are particularly vulnerable to price and income shocks, but also because many of them depend on agriculture for their livelihoods (Wheeler and von Braun 2013). Without new types of technologies, sustainable agriculture and food security cannot become reality any time soon.

New plant breeding technologies (NPBTs), including genetically modified organisms (GMOs) and gene-edited crops, could possibly be a game-changer (Zilberman et al 2018, Zaidi et al 2019). They could contribute to higher crop yields, lower use of chemical fertilizers and pesticides, better crop resilience to climate stress, reduced post-harvest losses, and more nutritious foods (Bailey- Serres et al 2019, Eshed and Lippmann 2019, Zaidi et al 2019). However, NPBTs are not yet widely used and accepted. Transgenic

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GMOs in particular are often seen very critically (Greenpeace 2015). Even though 30 years of research and commercial applications suggest that GMOs are not more risky than conventionally-bred crops (EASAC 2013, NAS 2016, Leopoldina 2019), there continue to be widespread concerns about possible negative health and environmental consequences. These concerns have led to safety regulations that are much stricter for GMOs than for any other agricultural technology (Qaim 2016). Given that most of the GMOs commercialized up till now were developed by large multinational companies, there are also economic and social concerns related to market power and unequal benefit distribution (Stone 2010)2. Similar concerns have also been voiced for the more recent gene-edited crops (Shew et al 2018). This paper provides an overview of the potentials, risks, and actually observed impacts of NPBTs with a particular emphasis on their role for food security and sustainable agricultural development.

Plant breeding and food security: Historical trends: Since the beginnings of agriculture some 12,000 years ago, farmers in different parts of the world have tried to increase crop production through selecting the highest-yielding plants for multiplication, developing new tools, and testing various agronomic practices. Successful innovations were adopted more widely, and some of the technologies and practices also spilled over to other parts of the world. Until the nineteenth century, this process of innovation was slow. Most agricultural production increases came from expanding the agricultural land area, not from increases in crop yields. Hunger and undernutrition were widespread. Even in Western Europe, the majority of the population was suffering from food insecurity and insufficient access to calories and nutrients until the nineteenth century (Fogel 1989). In the late eighteenth century, Thomas Robert Malthus, a British cleric and economist, predicted widespread famine, because the population and food demand grew faster than the possibility to expand the land area for food production (Malthus 1789).

The race between population growth and food production entered a new era in the second half of the nineteenth century. Agricultural research became more scientific. New insights into plant genetics, plant nutrition, and advancements in the chemical industry speeded up the process of agricultural innovation substantially. The development and spread of improved crop varieties and the use of chemical fertilizers and other modern inputs led to massive increases in agricultural productivity in the USA and Europe during the first half of the twentieth century (Qaim 2016). As a result, food insecurity and undernutrition declined rapidly in the USA and Europe. However, it took a while until modern technologies were adapted and used more widely also in poorer countries. In the 1950s and 1960s, population growth outpaced food production especially in Asia, leading to serious concerns about looming famines.

Green revolution: The Rockefeller Foundation and other development organizations were instrumental in launching several public sector research programs aimed at adapting new agricultural technologies to tropical and subtropical conditions and make them available to farmers in the developing world. Since the late-1960s, high-yielding varieties of wheat and rice, and later also maize, developed through these international programs were widely adopted by farmers in Asia and Latin America (Evenson and Gollin 2003). Combined with a rise in the use of irrigation, fertilizers, and other agrochemicals these new varieties contributed to a doubling and tripling of agricultural yields within a relatively short period of time (Qaim 2017). These technological developments and the resulting increase in food production became widely known as the Green Revolution. Due to various constraints, the Green Revolution was less pronounced in Africa (Eicher and Staatz 1984)3.

The production increases in major staple foods through the Green Revolution improved the availability and affordability of calories. This is especially relevant for poor population segments that typically spend a large proportion of their income on food. Simulations demonstrate that mean consumption levels of calories in developing countries would have been 10-15% lower had the high-yielding varieties of wheat, rice, and maize not been introduced (Evenson and Gollin 2003). Thus, the Green Revolution has contributed significantly to reducing hunger in Asia and Latin America. The predicted famines were prevented and poverty rates declined considerably (Eicher and Staatz 1984, Gollin et al 2021). Norman Borlaug, the chief wheat breeder of the Rockefeller Program in the 1960s and often referred to as "the father of the Green Revolution", received the Nobel Peace Prize in 1970 for his contribution to increasing world food supplies and food security.

Figure 1 shows developments in agricultural production and food security since the 1960s. With increasing crop yields (Fig. 1a), the proportion of undernourished people

[2] As will be argued below, public concerns about the safety of GMOs and related regulatory hurdles for their commercialization have contributed to the market dominance of a few multinationals, because only large companies can afford the costly regulatory procedures.

[3] In the early days of the Green Revolution, especially high-yielding varieties of wheat and rice were developed, both of which not among the key staple foods in large parts of Africa. In addition, roads and irrigation infrastructure, which are important to get access to needed complementary inputs and benefit from the new varieties, were less developed in Africa than in Asia and Latin America.

declined from close to 40% in 1960 to 11% today (Fig. 1b). Increasing yields did not only increase food availability, but also agricultural profits and incomes in the small farm sector, which is home to the majority of the world's poor and undernourished people (Fan et al 2005, Qaim 2017). With this close association between crop yield trends and food security in mind, it is not surprising to see that the prevalence of hunger today is still much higher in Africa than in other regions (Fig. 1c). In Africa, agricultural productivity growth was much slower than elsewhere and could not keep pace with the rising population. Africa is the only region worldwide where the number of hungry people is still increasing (FAO 2021).

The growth in cereal yields over the last few decades is the result of progress in plant breeding, more intensive use of fertilizers, pesticides, and irrigation water, and several other factors. Disentangling the contribution of individual factors to yield growth is difficult, due to synergies and complexities in establishing the correct reference trend (Olmstead and Rhodes 2008, Huffman et al 2018). However, the role of plant breeding seems to have increased over time. It is estimated that breeding contributed to around 20% of the yield growth between 1960 and 1980, and to 50% of the yield growth between 1980 and 2000 (Evenson and Gollin 2003, Qaim 2016). Given that further increases in the use of fertilizer and other inputs are associated with decreasing marginal yield effects, the role of plant breeding and plant genetics for agricultural productivity will likely continue to grow over time.

Problems with the green revolution: While the Green Revolution contributed to agricultural growth and hunger reduction, it also brought about several problems and did not sufficiently address others. Some of the problems are related to environmental effects. The high-yielding varieties of the Green Revolution were performing particularly well under irrigated conditions and were much more responsive to fertilizers than traditional landraces. Some of the new varieties were also more susceptible to certain pests and diseases. Hence, farmers' use of irrigation water, chemical

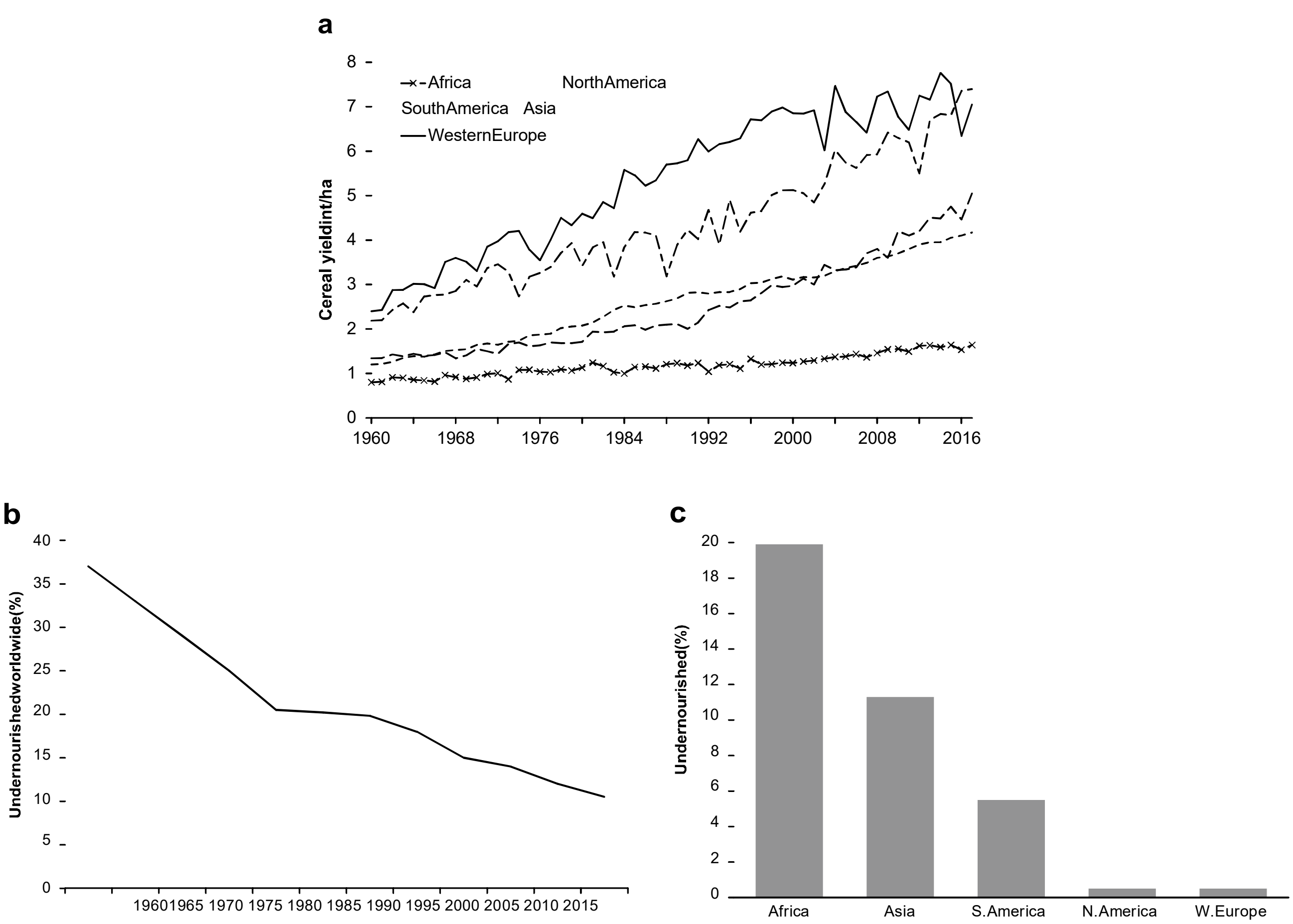

Fig. 1. Global trends in agricultural productivity and hunger. (a) Mean cereal yields by region, 1960-2017. (b) Prevalence of undernourishment worldwide, 1960-2015. (c) Prevalence of undernourishment by region, 2018. Source: Based on data from FAO (2019a,b)

fertilizers, and pesticides strongly increased. The overuse of these inputs in some regions has led to falling groundwater tables, soil and water pollution, nitrous oxide emissions, and other environmental issues (Foley et al 2011).

The effects of the Green Revolution on biodiversity are more complex. The intensive use of agrochemicals has reduced biodiversity in agricultural landscapes. Furthermore, as the productivity growth concentrated on a relatively small number of high-yielding varieties of wheat, rice, and maize, species diversity and varietal diversity in global agricultural production and food supplies declined (Khoury et al 2014, Pingali 2015). On the other hand, higher yields on the cultivated land reduced the need for additional cropland expansion, thus preserving natural biodiversity. While agricultural intensification can contribute to local cropland expansion under certain conditions, studies show that the Green Revolution's technology-driven yield growth was land saving at the global level and helped to preserve millions of hectares of forestland and other natural habitats (Villoria 2019). As land-use change is also the biggest source of greenhouse gas emissions from agriculture (IPCC 2019), land-saving technological change helps to reduce the climate change effects of agricultural production as well.

The human nutrition effects of the Green Revolution also had several dimensions. While reductions in hunger and food insecurity are undisputed, impacts on other forms of malnutrition were less positive. As mentioned, the strong focus of the Green Revolution on only a few major cereals led to lower species diversity in farming and food supplies, which also had implications for dietary diversity. Whereas prices for cereals decreased, more nutritious foods-such as pulses, vegetables, fruits, and animal source products-became relatively more expensive (Gomez et al 2013, Qaim 2017)4. In addition, plant breeders' strong attention to yield was at the expense of nutritional traits, resulting in lower micronutrient contents in high-yielding cereal varieties (DeFries et al 2015). Against this background, it is not surprising that micronutrient deficiencies declined much more slowly than calorie undernutrition in recent decades (Gödecke et al 2018). As the world population continues to grow, further food production increases will be required in the future. However, future production increases need to be more diverse and more environmentally-friendly. This will require novel agronomic and breeding approaches. The role of NPBTs in this connection is discussed in subsequent sections.

New plant breeding technologies: The last 30 years have seen a revolution in plant genetics and the development and use of new breeding technologies. In this section, we briefly describe some technical aspects of NPBTs, before discussing concrete breeding objectives and technological risks in subsequent sections.

Genetically modified organisms (GMOs): A GMO is an organism into which genes coding for desirable traits have been inserted through the process of genetic engineering (Qaim 2009). Plant breeders depend on genetic variation for the development of new, useful crop varieties. To increase genetic variability in a particular species, breeders have – for a long time – used wide crosses, hybridization, mutagenesis induced by radiation or chemical agents, and other techniques, which can lead to fairly random outcomes. GMOs have opened new horizons, as the genetic variation available for breeding has become much larger. With recombinant DNA techniques, individual genes coding for desirable traits can be introduced to the plant without simultaneously making all the other genetic changes that occur through conventional crossbreeding or traditionally induced mutagenesis. GMO crops are often referred to as transgenic crops, implying that foreign genes – so-called transgenes – were introduced (Qaim 2016). One fundamental difference between conventional and transgenic plant breeding is the product of the research. The product of conventional breeding is a new variety that has certain desirable characteristics and can be used by farmers in the particular environment for which it was developed.

The product of transgenic research in contrast is not one particular new variety, but a new trait, which can then be introduced or backcrossed into many local varieties. Thus, in principle, GMO technologies can help to preserve varietal diversity (Krishna et al 2016). With certain adjustments, the same traits can also be transferred to other species. This can be of particular advantage for vegetatively propagated crops, such as banana and cassava, which are difficult to improve through conventional crossbreeding (Qaim 2016). Transgenic GMOs have been developed since the 1980s and were first commercialized in a few countries in the mid-1990s. The most widely used GMO traits thus far involve herbicide tolerance and insect resistance. Effects of GMO adoption are discussed in more detail below.

Gene editing: Transgenic research techniques, as used since the 1980s, have increased the precision of plant breeding considerably. However, the gene transfer mechanisms used to develop the first-generation GMOs could not predetermine the exact location of the transgenes in the recipient plant. Hence, when using these first-generation transfer mechanisms, numerous transgenic events had to be created and tested in order to later select

[4]Changing relative prices have led to a substitution away from more nutritious foods. On the other hand, decreasing prices for staple foods had a positive income effect, which may also have increased the consumption of more nutritious foods. The net effects are situation-specific.

those that express the desired trait successfully without undesired off-target effects. During the last 15 years, new DNA sequencing methods have facilitated the mapping of relevant regions of the plant genome, thus contributing to a considerable further improvement in breeding precision and speed (Hickey et al 2019). Based on these methods, new breeding technologies were developed for which the term “gene editing” (also “genome editing”) is now widely used (Vats et al 2019).

Gene editing refers to techniques in which DNA is inserted, modified, replaced, or deleted in the genome of a living organism at predetermined locations. Targeted genetic scissors are used to create site-specific double-strand breaks, which are then repaired using the cell's own repair systems. Different gene-editing methods are used, including zinc finger, TALEN, and the nowadays most widely used CRISPR/Cas system that was developed in 2012 (Schindele et al 2019, Vats et al 2019). Gene-editing techniques are not only used in plants, but also in animals to breed for desirable traits, and in humans to detect and repair genetic diseases. Gene editing is a very dynamic field of research with further improved methods constantly emerging (Hickey et al. 2019). Recently, the so-called prime-editing system was developed, which builds on a single-strand break and further adds to breeding precision (Anzalone et al 2019).

The genetic changes made with gene-editing techniques may involve simple or complex mutations or also the integration of species-specific and foreign genes. Most of the gene-edited crops developed so far involve simple point mutations without the integration of foreign DNA, meaning that the resulting crop plants do not carry any transgenes (Zaidi et al 2019). Gene-edited crops with simple point mutations have new desirable traits, but it is hardly possible for outsiders to detect that they were actually gene-edited; identical point mutations could in principle also occur naturally or through traditional mutagenesis (Grohmann et al 2019).

Breeding objectives with NPBTs: The breeding objectives pursued with NPBTs are not completely different from those pursued with conventional breeding. However, the much larger genetic variation that can now be exploited and the direct integration or modification of genes and gene sequences increases breeding efficiency and the development of certain traits and plant features that were previously difficult or impossible to obtain. Specific traits always have to be combined with locally adapted germplasm, which is usually the result of conventional breeding. Hence, NPBTs are a complement, not a substitute for conventional breeding. In the following, I provide a short overview of traits that biotechnologists currently try to develop or that have already been tested and used in the field.

Pest and disease resistance: One important category of traits involves pest and disease resistance. Among the first GMOs used in agriculture were insect-resistant crops into which bacterial genes from *Bacillus thuringiensis* (Bt) were introduced. Furthermore, virus resistance, fungus resistance, and bacterial resistance are important traits that have been developed with transgenic and non-transgenic gene-editing in a number of crop species, including several cereals as well as cassava, banana, papaya and a number of vegetables (Oliva et al 2019, Zaidi et al 2019). Pest- and disease-resistant crops can reduce chemical pesticide sprays and increase effective yields through lower crop losses (Qaim and Zilberman 2003, Bailey-Serres et al 2019).

Other agronomic traits: Many research groups are also working on higher crop resilience to abiotic stress such as heat, drought, flooding, and soil salinity – traits that are particularly important to make agriculture more climate-smart (Hickey et al 2019). Transgenic and gene-editing technologies are being used to develop tolerance to abiotic stress in maize, rice, wheat, beans, and several other crop species (Eshed and Lippmann 2019, Vats et al 2019).

Substantial advances have recently also been made in developing crops with higher nutrient use efficiency (Bailey-Serres at al 2019). Crop yields are heavily dependent on sufficient availability of nutrients, especially nitrogen and phosphorous, currently provided primarily through chemical fertilizers. Higher nutrient use efficiency can increase crop yields with lower amounts of fertilizers, thus reducing energy use and the environmental footprint of agricultural production. Researchers also use transgenic and non-transgenic techniques to raise the yield potential of crop plants through increasing plant growth and photosynthetic efficiency. While the genetic mechanisms determining yield can be complex, recent studies showed that also relatively simple site-specific modifications can lead to significant yield growth regardless of the growing conditions (Wu et al. 2019).

Product quality: Researchers are also working on various traits to improve product quality. Several fruits and vegetables with CRISPR/Cas-based non-browning traits are already on the market in North and South America. Such technologies could help to reduce food losses and waste. NPBTs are also used to change the fatty acid composition of oil crops, reduce the gluten content of wheat, or increase the micronutrient content of various food crops, all of which could have positive human health effects (DeSteur et al 2012, Modrzejewski et al 2019).

New domestication and crop diversity: Gene-editing technologies can also be used to domesticate neglected crops and wild plants in a short period of time, an approach that has been termed “de novo domestication” (Fernie and

Yan 2019). Traditionally, the domestication of plants and the development of productive varieties required decades of breeding, which is also the main reason why most breeding programs during the last 100 years concentrated on the further improvement of a relatively small number of crops that were domesticated already several thousand years ago. The recent discovery of multiple key domestication genes and scientific breakthroughs in introducing multiple genomic changes in plants simultaneously with CRISPR/Cas enables the domestication of wild species within a single plant generation (Schindele et al 2019). De novo domestication can contribute to enhancing agrobiodiversity and dietary diversity with possible benefits for the environment and human nutrition (Singh et al 2019).

Gene editing can also be used for the redomestication of already domesticated crops. During the history of crop domestication, the selection and breeding for higher yield, and the international exchange of germplasm, many local resistance and resilience genes of wild species were lost or never fully integrated into breeding lines (Fernie and Yan 2019). In other words, the gene pool in wild relatives of domesticated plants is often much bigger than the genes and traits in the domesticated gene pool (Hickey et al 2019). Instead of trying to integrate certain traits from wild relatives into modern varieties retrospectively, redomestication may be a more efficient option in some cases, helping to increase genetic diversity within crop species and make agriculture more climate-resilient, locally adapted, and less dependent on chemical inputs.

Speed breeding: That gene editing is much faster than any other breeding method and that it can be efficiently applied to all kinds of species, including previously neglected and not even domesticated ones, is a key advantage against the background of global environmental change. Changing climates do not only contribute to shifting weather patterns and more frequent weather extremes but also to evolving pathogen populations, so that the ability to rapidly adapt crop plants and agricultural production to the changing conditions is crucial to ensure future food and nutrition security (Bailey-Serres et al 2019, Hickey et al 2019). Another big advantage is that gene editing is relatively cheap and easy to implement; so it can also be used by smaller labs and companies, which could contribute to more diversity and competition in seed markets.

Technological risks: Every new crop variety that is released into the environment and consumed by humans and animals may be associated with certain risks. Broadly speaking, two different types of risk can be distinguished. First, possible risks related to the breeding process. Second, possible risks related to the particular traits developed. Thirty years of risk research related to GMO crops suggest that there are no new risks related to the breeding process. While off-target effects occur, these are easily detected and can be eliminated during the testing phase. In other words, GMOs are not inherently more risky than conventionally-bred crop varieties (EASAC 2013, NAS 2016, Leopoldina 2019). This conclusion was drawn by all major science academies and by various international organizations, including the World Health Organization (WHO) and the Food and Agriculture Organization (FAO).

Based on the scientific evidence available there is no justification to regulate GMOs differently than conventionally-bred crops. In reality, however, there are huge differences in regulation. For the approval of a new GMO, many years of molecular, biochemical, and environmental testing, as well as feeding trials, are required. Some precaution when dealing with new technologies is always advisable. But GMOs are not so new anymore; they have been widely used and consumed for 25 years without a single case of harm to human health or unexpected environmental effects. GMOs are the most highly regulated and tested foods in the world. Many crop varieties that are commonly used in conventional and organic agriculture would not have been approved if the same standards that are now used for GMOs had applied (Qaim 2016).

For gene-editing technologies such as CRISPR/Cas a long safety record is not yet available, because these technologies have only been used for a few years. However, the point mutations developed so far are genetically indistinguishable from natural mutations or traditional mutagenesis (Grohmann et al 2019), so new types of risk cannot be expected. Gene editing can also lead to off- target effects, but the frequency of off-target effects is much lower than for transgenic GMOs and for traditional mutagenesis (Holme et al 2019).

The second type of risk, namely risks related to a particular new trait, is different. Such risks exist, but they cannot be assessed for GMOs or gene-edited crops in general. Each new trait can have different effects. Herbicide tolerance, for instance, will differ in its environmental and health impact from traits such as drought tolerance or increased vitamin levels. Trait-specific risks can only be assessed case by case, which is also true for conventionally-bred crops. Hence, a trait-based (also called product-based) regulatory approach would make much more sense than the process- based approach used for GMOs in most countries.

For gene-edited crops, regulatory approaches are still evolving. Many countries, including the USA and Australia, have decided to not regulate gene-edited crops as GMOs, meaning that gene-edited crops are regulated in the same way as conventionally-bred crops, unless they contain foreign DNA. This is different in the European Union (EU). The EU Court of Justice decided in 2018 that gene-edited crops are automatically considered GMOs, meaning that the same strict rules and regulatory procedures as used for transgenic crops apply (Holme et al 2019). Further implications are discussed below.

Effects of NPBTs on sustainable development: Gene-edited crops are not yet widely used in agricultural production, so effects on economic, social, and environmental development cannot yet be observed. However, GMOs have been used for 25 years, and a large number of adoption and impact studies exist.

Adoption of GMOs: The commercial application of GMOs began in the mid-1990s. Since then, the technology has spread rapidly around the world, both in industrialized and developing countries. Since 2011, the area grown with GMOs in developing countries has been larger than the area in industrialized countries. In 2019, GMOs were planted on 190 million ha, equivalent to 14% of the total worldwide cropland. These 190 million ha were grown by 17 million farmers in 29 countries (ISAAA 2019). Most of these countries are located in North and South America, followed by Asia. In Europe and Africa, very few countries have adopted GMOs, which is mostly due to limited public acceptance in these regions and unfavorable regulatory environments (Qaim 2016). The countries with the biggest shares of the total GMO area in 2019 were the USA (38%), Brazil (28%), and Argentina (13%), followed by Canada (7%), India (6%), Paraguay (2%), China (1.7%), South Africa (1.4%), Pakistan (1.3%), and a number of other countries (ISAAA 2019).

In spite of the widespread international use of GMOs, the portfolio of available crop-trait combinations is still very limited. While many different traits were developed and tested, most of them were not yet approved for commercial use. So far, only a few concrete GMO technologies have been commercialized. The dominant technology is herbicide tolerance (HT) in soybeans, which is mostly used in North and South America. In 2019, HT soybeans accounted for almost 80% of total worldwide soybean production. Other widely-used GMO crops include insect- resistant (IR) maize and cotton. The insect-resistance trait is based on Bt genes, which control stemborers, rootworms, and cotton bollworms. Especially Bt cotton is grown in many different parts of the world, including by smallholder farmers. In 2019, India had the largest Bt cotton area, followed by the USA, China, Pakistan, and various other developing countries (ISAAA 2019).

Effects of GMO adoption: Over the last 25 years, many studies have been conducted, analyzing the effects of GMO adoption on crop yield, pesticide use, farm profits, and other outcomes in different parts of the world. A meta-analysis has evaluated these existing studies, finding that GMO adoption benefits farmers in most situations (Klümper and Qaim 2014). On average, GMOs have increased crop yields by 22% and reduced chemical pesticide quantities by 37% (Table 1). GMO seeds are usually more expensive than conventional seeds, but the additional seed costs are more than compensated by savings in chemical pest control and higher revenues from crop sales. Average profit gains for adopting farmers are 68%.

A breakdown of GMO impacts by modified trait reveals a few notable differences (Table 1). IR crops lead to a significant reduction in pesticide quantity, whereas HT crops do not in many situations. Such differences are expected. IR crops protect themselves against certain insect pests, so that spraying insecticides can be reduced. HT crops are not protected against pests but against broad-spectrum chemical herbicides (mostly glyphosate), which can facilitate weed control. While HT crops have reduced herbicide quantity in some situations, they have contributed to notable increases in the use of broad-spectrum herbicides elsewhere. Average yield effects are also higher for IR than for HT crops.

A breakdown by region shows that farmers in developing countries benefit more from GMO adoption than farmers in industrialized countries (Table 1). The reasons are twofold. First, farmers operating in tropical and subtropical climates often suffer from higher pest damage that can be reduced through GMO adoption. Hence, effective yield gains tend to be higher than for farmers operating in temperate zones. Second, most GMOs are not patented in developing countries, so that seed prices are lower than in industrialized countries, where patent protection is much more common (Qaim 2016).

Beyond the benefits for farmers, GMOs have also contributed to positive environmental and health effects

Table 1. Mean impact of GMO crop adoption (meta-analysis results)

	Yield	Pesticide quantity	Farm profit
All GMO crops	+22%	-37%	+68%
By modified trait			
Herbicide tolerance (HT)	+9%	+2%	+64%
Insect resistance (IR)	+25%	-42%	+69%
By region			
Industrialized countries	+8%	-18%	+34%
Developing countries	+29%	-42%	+78%

Source: Based on data from Klümper and Qaim (2014)

(Barrows et al 2014). Reductions in the use chemical pesticides through IR crops have led to benefits for biodiversity and ecosystem functions and to a lower exposure of farmers, farm workers, and consumers to toxic substances. HT crops have facilitated the adoption of reduced- tillage practices, thus curbing erosion problems and greenhouse gas emissions (Smyth et al 2014).

Finally, without the productivity gains from GMOs during recent years, around 25 million hectares of additional farmland would have to be cultivated globally, in order to maintain current agricultural production levels (Qaim 2016). As mentioned, farmland expansion is an important contributing factor to biodiversity loss and climate change, meaning that the GMO-related yield gains contribute significantly to climate change mitigation (Kovak et al 2022).

However, especially the widespread use of HT crops in North and South America is also associated with certain environmental problems. Higher profits and easier weed control have induced many farmers to narrow down their crop rotations, now often growing HT crops as monocultures. This has contributed to resistance development in weed populations and increases in other pest and disease problems, sometimes leading to higher pesticide use (Fernandez-Cornejo et al 2014). These environmental problems are not inherent to GMOs; they are the result of inappropriate technology usage. Conventionally-bred HT crops, which are used in some countries, can lead to the same types of environmental problems if not used properly. Improved seeds, regardless of whether they were bred conventionally or with NPBTs, should never be considered a substitute for good agronomic practice, but should be integrated into sound and locally-adapted crop rotations and agricultural systems.

GMOs and smallholder farmers: New technologies that are suitable also for smallholder farmers can contribute to poverty reduction and broader rural development. Hence, it is important to understand whether crops developed with NPBTs can be used successfully by smallholder farmers. Some experience with GMOs exists. Again, it is important to differentiate by crops and traits. HT soybeans have so far been used primarily by large farms in North and South America. Soybeans are not much grown by smallholders. Moreover, weed control in the small farm sector is often conducted manually. This underlines that not every GMO crop-trait combination is well suited to the small farm sector.

However, IR crops with inbuilt Bt genes are widely grown by smallholder farmers in countries like India, China, Pakistan, and South Africa (ISAAA 2019). The example of Bt cotton in India is particularly interesting, because anti-biotech activists repeatedly claimed that GMOs have ruined smallholder cotton growers in India. These claims were shown to be wrong (Gilbert 2013, Qaim 2016). Smallholder cotton growers in India have rapidly adopted Bt cotton because the technology is very beneficial for them. Within less than 10 years after its first commercialization, more than 90% of the cotton growers had switched to GMO seeds.

Impact estimates with four rounds of panel survey data from India, spanning a time period of eight years, showed that Bt cotton adoption has significantly and sustainably reduced chemical pesticide applications, leading to large health and environmental benefits (Table 2). Smallholders typically apply pesticides manually with backpack sprayers and no protective devices. The reduction in spaying intensity has lowered the incidence and severity of pesticide poisoning considerably. Higher yields and profits through Bt cotton adoption have also contributed to income gains, raising living standards by 18% on average. As a result, improvements in dietary quality and nutrition were observed. GMO adoption has reduced food insecurity among Indian cotton growers by 20% (Table 2).

Beyond cotton growers, other rural households in India have benefited from growth in the cotton sector through additional employment. This is particularly relevant for landless laborers, who often belong to the poorest of the poor. Two-thirds of all rural income gains from Bt cotton adoption in India accrue to poor people with incomes of less than two dollars a day (Qaim 2016).

Similar to these results from India, Bt cotton adoption has also contributed to poverty reduction and other social benefits in the small farm sectors of China, Pakistan, South Africa, and several other developing countries (Qaim 2009,

Table 2. Impact of Bt cotton adoption in India (Panel data evidence)

	Mean effect
Economic effects	
Effect on cotton yield	+24%
Effect on cotton profit	+50%
Effect on farm household living standard	+18%
Environmental effects	
Effect on chemical insecticide use	-44%
Effect on pesticide environmental impact	-53%
Nutrition and health effects	
Effect on pesticide poisoning incidences	-28%
Effect on calorie consumption	+5%
Effect on micronutrient consumption	+7%
Effect on food insecurity	-20%

Source: Based on data from Kouser and Qaim (2011), Kathage and Qaim (2012), Krishna and Qaim (2012), Qaim and Kouser (2013), and Veettil et al (2017)

Huang et al 2010, Qiao 2015, Kouser et al 2019). Bt maize has been used successfully for many years by smallholders in South Africa and the Philippines (Smyth et al. 2014). A more recent application of GMO technology in a local food crop is Bt eggplant in Bangladesh, which also contributes significantly to lower insecticide use and higher yields and incomes among smallholder vegetable growers (Ahmed et al 2021).

Future NPBT applications: In addition to HT and IR crops, various other GMO applications are being used commercially, so far on smaller areas, including virus-resistant beans in Brazil, virus-resistant papaya in Hawaii, and drought-tolerant maize in the American mid-west. Transgenic drought-tolerant maize has also been tested for several years in Africa, but was not yet commercially approved. Field trials with a number of other GMO crops and traits have been carried out on various continents, including nitrogen- efficient rice, fungus-resistant potato, and sorghum and cassava with higher micronutrient contents (Qaim 2016, Wesseler et al 2017).

Transgenic Golden Rice with high contents of provitamin A has been tested for many years and was recently – after multiple delays – approved for seed multiplication and use in the Philippines. Golden Rice may soon also be commercialized in Bangladesh and other countries of Asia, where vitamin A deficiency is a serious health issue. Ex ante impact studies show that Golden Rice – if widely consumed – could significantly reduce child mortality, infectious diseases, and eyesight problems in developing countries (Stein et al 2008, Wesseler and Zilberman 2014). Golden Rice is probably the technology that has been blocked most intensively by anti-biotech groups, because these groups fear that a GMO that helps the poorest of the poor in particular could undermine their narrative of biotech only serving the interests of large multinational companies (Regis 2019).

Examples of gene-edited crops at or near the end of the research pipeline are manifold, including fungus-resistant wheat, rice, banana, and cacao; drought-tolerant rice, maize, and soybean; bacterial-resistant rice and banana; salt-tolerant rice; and virus-resistant cassava and banana, among others (Hickey et al 2019, Tripathi et al 2019, Zaidi et al 2019). Many of these technologies could contribute significantly to sustainable agricultural development and food security.

Regulation and public perceptions: As explained in the previous section, the cultivation of GMOs haze increased rapidly since the mid- 1990s. However, of the 192 million ha grown with GMOs in 2018, over 95% were grown with only four different species (soybean, maize, cotton, and canola) and two modified traits (HT and IR). This narrow focus of already commercialized GMO applications has different reasons. One reason is that many crop traits are somewhat more complex to develop than HT and IR, meaning that more research and testing is required. However, a much more important reason for the narrow crop and trait focus in commercialized applications is the low public acceptance of GMOs and, related to this, the complex biosafety and food safety regulatory procedures. As mentioned, several other GMOs were extensively tested but not yet approved for commercial use, because of overly precautious regulators, highly politicized policy processes, and extensive lobbying efforts of anti- biotech activist groups (Herring and Paarlberg 2016).

Public perceptions: Especially in Europe, GMOs – when used in food and agriculture – have a very negative image. Many Europeans are deeply convinced that transgenic GMOs are very risky for human health and the environment. There is a widespread notion that the foreign genes introduced to the crop plants may lead to unexpected negative effects, either immediately or in the long run. Furthermore, as most GMOs were developed by large multinational companies, many in the wider public are also concerned about a monopolization of seeds and food supply chains with negative social consequences, especially in developing countries. And, as several of the biotech multinationals have a history of producing and selling chemical pesticides, it is also widely believed that GMOs would promote and perpetuate unsustainable agricultural systems with increasing pesticide use.

Where do these negative attitudes stem from? When the work with recombinant DNA started in the 1970s (at that time mostly with viruses, not plants), little was known about the safety of the resulting transgenic organisms. Scientists themselves recommended a precautious approach, and this suggestion was adopted in the design of regulatory policies (Fagerström et al. 2012). Many countries developed specific policies for GMOs, which are much stricter than for other types of technologies. When the first open field trials with transgenic plants started in the late-1980s and early-1990s, environmental NGOs became active in opposing GMOs, sometimes with spectacular campaigns. These NGO campaigns reinforced public fears of uncontrollable risks.

But why do these fears persist 30 years later, in spite of the mounting scientific evidence that GMOs are not more risky than conventionally-bred crops? One of the reasons is that scientists are often not the ones who the public trusts most. Environmental NGOs are often trusted more, as it is believed that they are fighting for the good without any hidden agenda. But for some of the NGOs, campaigning against GMOs has become a business model and a good source of donation revenues. As a result, the NGO narratives about GMOs never changed, even when it became clear that many of the arguments used are completely wrong.

The mass media also played their role in perpetuating negative public attitudes about GMOs. In their approach to provide a "balanced picture", journalists often contrast findings by researchers with statements by NGO representatives. For media users, hearing the same types of NGO arguments and narratives again and again can perpetuate beliefs and contribute to confirmation bias up to a point where new scientific evidence is hardly entering the public debate anymore.

A manifest example of the strong role of environmental NGOs in forming and perpetuating public beliefs about GMOs and of the difficulty to enter science into the debate is an open letter that more than 100 living Nobel laureates wrote to Greenpeace in 2016 (Roberts 2018). In the letter, the Nobel laureates urged Greenpeace to end its opposition to GMOs because the arguments used for so many years had all been debunked by scientific evidence. Greenpeace's simple answer was that the Nobel laureates were not experts in the field of food and agriculture. The instance was hardly covered in the mass media. As mentioned, attitudes towards GMOs are particularly negative in Europe, but Europeans attitudes have spilled over also to other parts of the world, including Africa and Asia (Herring and Paarlberg 2016). Policymakers and the wider public in Africa and Asia are not only influenced by NGO narratives, but also by concrete concerns of losing export markets when adopting GMOs that are not approved for import in the European Union.

Gene-edited crops are still much newer. Up till now, most of them do not contain foreign DNA, which means that public attitudes may, in principle, be much more positive (Zaidi et al 2019). Many of the public reservations against GMOs are related to the fact that they contain foreign genes. However, public knowledge about gene-edited crops is still quite limited, and several environmental NGOs have started to frame these new technologies as the industry's attempt to introduce GMOs through the backdoor. These NGO activities are not helpful for forming public opinions based on objective information.

Safety regulation: As mentioned, GMOs are more heavily regulated than any other agricultural technology. The regulation focuses primarily on the assessment and management of biosafety and food safety risks. Risk assessment and risk analysis is governed by internationally accepted guidelines developed by the Codex Alimentarius. Nevertheless, significant differences in the regulatory approaches exist between countries. Differences between the US American and the EU approaches are particularly pronounced (Qaim 2016). In the USA, GMOs – while requiring additional tests – are regulated under the same laws that are also used for conventional agricultural technologies. If the required tests for known risks have been passed successfully, there is no further regulatory hurdle for commercialization of the GMO in question. In contrast, in the EU specific laws were introduced, requiring a separate testing and approval process for GMOs that is overseen by institutions especially established for this purpose. And there is no automatism for approval when all tests have been passed. Instead, politicians from the EU Commission and the EU member countries have to finally approve all GMO applications. Following the precautionary principle, EU politicians can refuse to approve GMO crops on grounds of uncertainty alone, even without any evidence of risk (Qaim 2016).

As EU politicians know how unpopular GMOs are in many of the member countries, the scientific risk assessments are regularly ignored and approvals are delayed or denied. Only one single GMO crop event is currently authorized in the EU for commercial cultivation, namely a Bt maize event that was approved back in 1998 (for comparison, around 200 GMO crop events were approved in North and South American countries during the last 25 years). And even this old Bt maize technology was later prohibited in several of the EU member countries (Smyth et al. 2016). In other words, the process-based regulatory approach, together with the precautionary principle and the heavily politicized regulatory practice, is effectively a ban on GMO crop technologies in Europe. The approach does not only suppress commercial use, but also the development of new GMO crops, as also field trials need to be authorized. When such approvals are not issued on time, or when field trials are vandalized, as happened repeatedly in the past, GMO crop and trait developments can be seriously delayed or thwarted altogether. In July 2018, the EU Court of Justice ruled that all gene-edited crops fall under the same GMO laws and procedures (Holme et al 2019). Science academies have urged politicians to reform the EU GMO legislation (Leopoldina 2019), but the political will to do so seems limited.

The EU regulatory procedures stifle the development and use of NPBTs in Europe and elsewhere. Many countries in Africa and Asia have copied European-style regulatory approaches for GMOs. And GMO events also need approval when not intended for cultivation in Europe but only imported as food or feed. As the EU is a big importer of agricultural commodities, the slow and politicized approval procedures hamper the use of GMOs also in exporting countries. Even in India and China, where Bt cotton has been used successfully for many years, major GMO food crops have not yet been approved and used commercially (Pray et al 2018).

The reluctance of policymakers to approve GMOs is largely driven by low consumer acceptance. On the other hand, the fact that GMOs are not approved by policymakers reinforces widespread public beliefs that the technology is inherently dangerous (Herman et al 2019). The lengthy procedures also make the commercialization of GMOs unnecessarily expensive, thus contributing to consolidation and market power in the seed industry and discouraging the use of NPBTs to develop crops and traits with smaller commercial market potentials. Some of the societal resistance against GMOs is based on the argument that the promises are oversold, because so far only very few concrete technologies are actually available on the market. Fears are also related to GMO seeds being dominated by a few multinationals. The mutually reinforcing combination of false NGO narratives, public misperceptions, and costly overregulation is clearly the main reason for the observed industry concentration and the fact that many of the exciting technological potentials have not yet materialized.

Other regulations for NPBTs: Beyond biosafety and food safety, a number of other regulations are relevant for NPBTs. Especially in Europe, the approach of singling out GMOs as something very different requires a number of rules that enable the coexistence of GMO systems, conventional systems, and organic systems in agricultural production, trade, processing, and retailing. GMO foods have to be labeled as such. In addition to this mandatory labeling, voluntary labels to declare that foods were derived from GMO- free supply chains also exist in Europe and elsewhere. More details about the economics of GMO labeling and coexistence can be found in McCluskey et al (2018) and Zilberman et al (2018). Another important area of biotech regulation is the protection of intellectual property rights (IPRs). The ability to obtain patent protection on biological inventions differs between countries. In the USA, patents on genes, genetic processes, and GMO plant varieties have proliferated since the 1980s (Clancy and Moschini 2017). Most of these patents are held by a few multinational companies, which is also one of the reasons for the public opposition to GMO crops. First, there are widespread ethical concerns with patenting life and genetic materials that exist in nature. Second, there are social concerns, because it is feared that patents lead to seed monopolies and corporate control of the food chain. Indeed, too strong and far-reaching patent protection on genes and enabling technologies reduces the freedom to operate in research and can contribute to market concentration (Deconinck 2020). Efficient forms of IPR protection for NPBTs, which properly balance research incentives, freedom to operate, and social benefits, may still have to be developed, also taking into account that many gene-edited varieties are genetically indistinguishable from conventionally-bred crops. However, widespread fears that patents will inevitably hurt developing countries and lead to exploitation of smallholder farmers seem to be overrated, because patent protection is part of national law, and so far most plant biotechnologies are not patent-protected in developing countries (Qaim 2016).

CONCLUSION

NPBTs offer large potentials to contribute to sustainable agricultural development and food security. Plant breeding and the adoption of high-yielding varieties played a key role in reducing hunger over the last 100 years. However, the Green Revolution technologies of the past focused on a small range of cereal crops and performed particularly well under favorable environmental conditions and high input regimes. This has led to narrowing agricultural and dietary diversity and – in some situations – also to environmental problems associated with excessive agrochemical input use. NPBTs, including GMOs and gene-edited crops, can help to further increase yields, while addressing the shortcomings of Green Revolution technologies. NPBTs can help to increase crop diversity, raise yield potentials, provide better resistance to pests and diseases, increase nutrient use efficiency, make crops more resilient to climate shocks, and improve nutritional quality, just to name a few of the types of technologies that plant biotechnologists have already worked on extensively. A few GMO crops were already widely adopted with clear economic, social, and environmental benefits, including in the small farm sector of developing countries.

Of course, sustainable food and nutrition security requires more than NPBTs. But against the background of further population growth, climate change, and a dwindling natural resource base it would be irresponsible to not harness the potentials that modern plant biotechnology offers. Currently, overregulation and public misperceptions stirred and perpetuated by consistently false NGO narratives about risks obstruct the way for more efficient development and use of NPBTs. Especially in Europe, serious regulatory reforms and a more honest and science-based public debate are required. The European skepticism has also influenced many developing countries in Africa and Asia, which could benefit the most from using NPBTs. Developing countries are well advised to disregard European attitudes and use GMOs and gene-edited crops more confidently for the benefit of their farmers and consumers.

This plea in favor of NPBTs does not mean that everything will be fine without public regulation and policies. Like any transformative technology, NPBTs raise certain questions that need to be addressed to avoid undesirable side-effects. Some of these questions are correctly raised by biotech critics, but the conclusion that any potential issue would justify a technology ban is certainly inappropriate. Unfortunately, in many countries the entrenched fundamental debate about banning or allowing GMOs has overshadowed more detailed discussions about suitable technology management.

Relevant questions, for which policy responses and institutional adjustments will be required, include the following. How can we ensure that newly developed crop varieties with desirable traits are used sustainably as part of diverse agricultural systems and not as substitutes for proper agronomy? How can market power by a few multinationals be prevented? How can we facilitate the development of new crops and traits that may not have huge commercial potential but may be particularly beneficial for poor farmers and consumers? How can we ensure that suitable new crop technologies will actually reach the poor through favorable technology transfer mechanisms? What is the appropriate level of IPR protection in industrialized and developing countries? Finding answers to these and other relevant questions will require more research and a more constructive public and policy dialogue.

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Climate Change and its Impact on Agricultural Pests

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***Abstract*:** Climate change is the most dynamic global environmental issue and most discussed issue. Climatic factors viz., rising temperatures, atmospheric CO_2 levels, and change in precipitation patterns have significant impacts on agricultural production. Climate change can affect food security by changing physiology of crop plants and associated environment. As insects are cold blooded animals, climate change impacts insects significantly, and displays various and complex effects on crop pests worldwide. Changes in climate can affect insect pests in several ways. They can result in an expansion of their geographic distribution, increased survival during over-wintering, increased number of generations, altered synchrony between plants and pests, altered interspecific interactions, increased risk by invasive and migratory pests, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control agents. These all result into serious risk of crop economic losses challenging food security. Climate change requires adaptive management strategies to deal with the changing status of pests. In this review, the role of the climatic factors and changes that might have direct or indirect impacts on insect pests are discussed. Changes in these parameters are likely to favour or to limit pest species, depending on their ecological context. Climate change effects should be studied in the context of local climate and local ecological interactions. Several priorities can be identified for future research on the effects of climatic changes on agricultural insect pests. These include modified integrated pest management tactics, monitoring climate and pest populations, and the use of modelling prediction tools.

***Keywords*:** Climate change, Agriculture, Insect pests, Risks impacts, Adaptation and mitigation

Agricultural production has undergone many major changes-agricultural revolution which has been influenced by the development of civilization, technology, and general human advancement. The exceptional population growth in the last 100 years has had many undesirable consequences which along with changes in environmental conditions impacted the security of the food supply. The growing world population has rising demands for crop production and accordingly, by 2050, global agricultural production will very likely need to be doubled to meet that kind of increasing demand (Tilman et al 2011). Climate change is a worldwide threat that is unavoidable and immediate which encompasses a combination of natural and anthropogenic changes in the environment. Worldwide attention has been attracted by recent changes in global climate phenomena and consequent losses. Climate change, according to the Intergovernmental Panel on Climate Change (IPCC), is described as “any change in climate over time, whether due to natural variability or as a result of human activity.” Human activities are responsible for much of the warming that has been observed over the last 50 years. According to Intergovernmental Panel on Climate Change (IPCC) projections, the global annual temperature will increase by 1°C by 2025 and it may increase up to 3°C by the end of the next century and CO_2 is expected to increase up to 445-640 ppm by 2050 due to increase in greenhouse gas emissions (Kumar et al 2020).

Insects constitute over half of the estimated 1.5 million organism species of the biodiversity identified so far on the planet and are fundamental to the structure and function of ecosystems. At the same time, insects are among the most susceptible groups of organisms to climate change as they are ectothermic, so thermal changes have strong direct effect upon their growth, reproduction and existence (Bale et al 2002). The effects of climate change on insect pests are of greater significance because insects are involved in many biotic interactions, such as plants, natural enemies, pollinators and other organisms, which play a major role in the ecological functioning of insect pests (Moore et al 2008). Nowadays, more attention is focussed on abiotic factors which have the tendency to reduce yield loss due to increase of such conditions.

The rise in temperature directly affects pest's reproduction, survival, spread and population dynamics as well as the relationships between pests, the environment, and natural enemies (Prakash et al 2014). This paper will review the impact of some of the predicted climate changes, especially increasing temperatures, atmospheric carbon dioxide concentrations and changeable precipitation pattern effects on the biology and ecology of harmful insects.

Indian scenario of climate change: The footprint of climate change can already be seen in every corner of the planet. Erratic weather patterns, rising sea levels and melting glaciers due to climate change, are reshaping societies across the globe. India is one of the world's most climate vulnerable countries. In India, climate change is already affecting human health, wildlife, food production, clean water access and the economy at large. The country's average temperature is expected to rise by 4.4 degree Celsius by the end of the year 2100 (Blog on climate change 17.5.2022). The warming may be more pronounced in the northern parts of India. The extremes in maximum and minimum temperatures are expected to increase under changing climate; few places are expected to get more rain while some may remain dry. Number of rainy days may come down but the intensity is expected to rise at most of the parts of India. Gross per capita water availability in India will decline from 1820 m^3/ year in 2001 to as low as 1140 m^3/ year in 2050. Over 50% of India's forests are likely to experience shift in forest types, adversely impacting associated biodiversity, regional climate dynamics as well as livelihoods based on forest products. Even in a relatively short span of about 50 years, most of the forest biomass in India seems to be highly vulnerable to the projected change in climate (Mahato 2014).

Being a tropical country, India is more challenged with impacts of looming climate change (Chahal et al 2008). Productivity of Indian agriculture is limited by its high dependency on monsoon rainfall which is most often erratic and inadequate in its distribution (Chand and Raju 2009). Country is experiencing declining trend of agricultural productivity due to fluctuating temperatures (Aggarwal 2008), frequently occurring droughts and floods, problem soils, and increased outbreaks of insect pests (Srikanth 2007, Dhawan et al 2007, IARI News 2008 and 2009) and diseases. These problems are likely to be aggravated further by changing climate which put forth the major challenge of attaining food security.

Risks: Climate-related risks are higher with global warming of 1.5°C compared to the current risks, but the risks are significantly more severe if the global warming reaches 2°C. Risks depend on the degree and pace of warming, geographical location, levels of regional and local development and vulnerability, and realized adaptation and mitigation activities. Global food and fibre production, plant protection and plant biosecurity, which include all strategies to assess and manage the risks posed by infectious diseases, quarantine regulated pests, invasive alien species and living modified organisms in natural and managed ecosystems, will also be adversely impacted (IPCC 2018).

Impacts: Climate-change impacts are already emerging for natural and human systems, including changes in water quantity and quality, and shifts in geographical ranges, seasonal activities, migration patterns, species abundance and interactions for many with more negative than positive impacts on the yields of most crops (Porter et al 2019). There is evidence that climate change is affecting biological systems at multiple scales, from genes to ecosystems (Sutherst et al 2011). According to Scheffers et al (2016), anthropogenic climate change has impaired 82 percent of 94 core ecological processes recognized by biologists, from genetic diversity to ecosystem function. According to IPCC (2018), if temperatures rise by about 2°C over the next 100 years, negative effects of global warming would begin to extend to most regions of the world and directly affect most of the organisms on the earth. Climatic variability, together with increase in atmospheric temperature and carbon dioxide, change in precipitation pattern, extended period of drought do have lot of implications in agriculture sector. Climatic changes also profoundly affect the population dynamics and the status of insect pests (Woiwod 1997). These effects could either be direct, through the influence of weather on the insects physiology and behaviour (Samways 2005), or may be mediated by host plants, competitors or natural enemies (Harrington et al 2001 and Bale et al 2002). In addition, the impacts include changes in phenology, distribution and community composition of ecosystem that finally leads to extinction of species (Walther et al 2002).

For species to survive in the changing climates, they must either adapt *in situ* to new conditions or shift their distributions in pursuit of more favourable ones. Many insects have large population sizes and short generation times, and their phenology, fecundity, survival, selection, and habitat use can respond rapidly to the climate change. These changes to insect life-history may in turn produce rapid changes in their abundance and distribution. Increased temperature will cause insect pests to be more abundant and almost all insects will be affected by changes in temperature (Bale et al 2002). In-season effects of warming include the potential for increased levels of feeding and growth, and the possibility of additional generations in a given year (Cannon 1998). This will alter the crop yield, and also influence the effectiveness of insect-pest management practices. Increased global temperature will also influence the phenology of insects including early arrival of insect pests in their agricultural habitats and emergence time of a range of insect pests (Dewar and Watt 1992; Whittaker and Tribe 1998), which in turn requires early and more frequent application of insecticides to reduce the pest damage. Increased temperatures will also increase the pest populations as water stressed plants at times result in increased insect populations and pest outbreaks.

Climate change will also result in increased problems of insect transmitted diseases. These changes will have major implications for crop protection and food security, particularly in the developing countries, where the need to increase and sustain food production is most urgent. Long-term monitoring of population levels and insect behaviour, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. The impact of climate change will vary across regions, crops and species. Many models and protocols have been designed to measure the effects of climate change for different species and in different disciplines.

Impact of rising temperature: Temperature is one of the dominant abiotic factors affecting directly the insects. Temperature can affect the insect species in several complex ways. Species which cannot adapt and thrive in increased temperature tend to have hard times in maintaining its population while others may thrive and multiply rapidly. Temperature has roles in metabolism, metamorphosis, mobility, host availability etc. which determines the possibility of change in insect pest population and dynamics. Laboratory and modeling experiments support the notion that the biology of insect pests are likely to respond to increased temperatures (Cammell and Knight 1991). With every degree rise in global temperature, the life cycle of insect will get shorter. The quicker the life cycle, the higher will be the population of pests. In temperate regions, most insects have their growth period during the warmer part of the year because of which, species whose niche space is defined by climatic regime, will respond more predictably to climate change while those in which the niche is limited by other abiotic or biotic factors will be less predictable (Bale et al 2002). In the first case, the general prediction is that if global temperatures increase, the species will shift their geographical ranges closer to the poles or to higher elevations and increase their population size (Samways 2005). Given the distribution and behaviour of insect pests, it can be hypothesised that an increase in temperature should be associated with increased herbivory as well as changes in the growth rate of insect populations (DeLucia et al 2008 and Deutsch et al 2018). Thus, insect populations in tropical zones are predicted to experience a decrease in growth rate as a result of climate warming due to the current temperature level, which is already close to the optimum for pest development and growth, while insects in temperate zones are expected to experience an increase in growth rate. The same authors confirmed this theory by estimating changes in the growth of pest populations in the production of the world's three major grain crops (wheat, rice and maize) under different climate change scenarios. According to the study wheat, which is normally grown in temperate climates, warming will accelerate the growth of pest populations. For rice grown in tropical zones, they predict a decrease in the growth of pest populations, and for maize grown in both temperate and tropical regions. Effects of increased temperatures are greater for aboveground insects than for those that spend most of their life cycle in the soil, because soil is a thermally insulating medium that can buffer temperature changes and thus reduce their impact (Bale et al 2002).

Future changes in insect population dynamics depend on the level of global temperature increase in coming years. Climate models predict that the average temperature of the globe will increase by 1.8-4°C by the end of the current century (Karl and Trenberth 2003). The increase in temperature associated with climatic change, would impact crop pest insect populations in several complex ways like (a) extension of geographical range, (b) increased over-wintering, (c) changes in population growth rate, (d) increased number of generations, (e) extension of development season, (f) changes in crop pest synchrony, (g) changes in interspecific interactions, (h) increased risks of invasions by migrant pests, and (i) introduction of alternative hosts and over-wintering hosts.

Response of insect pests to increased CO_2 concentration: Elevated concentrations of atmospheric CO_2 can affect the distribution, abundance, and performance of herbivorous insects. Such increases can affect consumption rates, growth rates, fecundity, and population densities of insect pests. Currently available data suggest that the effects of elevated atmospheric CO_2 on herbivory are not only highly specific to individual insect species, but also to insect pest–host plant systems. The effects of increasing CO_2 levels on insect pests are highly dependent on their host plants. Increased CO_2 levels would have a greater impact on C3 crops (wheat, rice, cotton, etc.) than on C4 crops (corn, sorghum, etc.). Therefore, these differential effects of elevated atmospheric CO_2 on C3 and C4 plants may result in asymmetric effects on herbivory, and the response of insects feeding on C4 plants may differ from that of C3 plants. C3 plants are likely to be positively affected by elevated CO_2 and negatively affected by insect response, whereas C4 plants are less responsive to elevated CO_2 and therefore less likely to be affected by changes in insect feeding behaviour (Skendžic et al 2021).

Impact of precipitation on insects: Distribution and frequency of rainfall may also affect the incidence of pests directly as well as through changes in humidity levels. It is predicted that under the climate change, frequency of rainfall would decline while its intensity would increase, which would lead to heavy showers and floods on one hand and drought spells on the other. Under such situations, incidence of small pests such as aphids, leafhoppers, whiteflies, mites, etc. on crops may be reduced as these get washed away by the heavy rains (Pathak et al 2012). The deviation of rainfall during monsoon and November and its relationship with level of *Helicoverpa armigera* (Hub.) damage severity showed higher November rainfall favoured higher infestation. Average rainfall is predicted to decrease in several regions and the occurrence of summer droughts is likely to increase. Lever (1969) analysed the relationship between outbreaks of armyworm, *Mythimna separata* (Walker) and to a lesser extent *Spodoptera mauritia* (Boisd.) and rainfall from 1938 to 1965 and observed that outbreaks occurred when rainfall exceeded the average 89 cm. The effect of rainfall on pests can be studied by simulating various rainfall intensities through sprinklers (Karuppaiah and Sujayanad 2012).

Invasive insect pests: Many authors predict expanded geographic range and increased population densities and voltinism under climate change scenarios, which could soon lead to potentially severe consequences for sustainable agricultural production (Ziska et al 2011). However, it is important to state that climate change is not the predominant driver of biological invasion. To become invasive, alien insects must successfully arrive in a new habitat, survive the given conditions, and thrive. Climate change could positively or negatively influence the components of this invasive pathway. The process of insect invasion involves a chain of events that include the transport, introduction, establishment, and dispersal of invasive alien insects (Ricciardi 2013). Once a new species arrives in a new habitat, the other stages of the invasion process could be positively or negatively influenced by existing climate and climate change. Climate change can directly affect the transport and introduction of invasive insects. Extreme climate events (storms, high winds, hurricanes, currents, and swells) could shift pests to new geographic areas where they may find environmental conditions favourable for establishment (Food and Agriculture Organization 2020). Since 1889, a total of 24 insect species have been reported to invade India (Naveena et al 2020). In recent times, many exotic pests invaded India, such as papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink (Muniappan et al 2008); cotton mealybug, *Phenacoccus solenopsis* Tinsley; tomato leaf miner *Tuta absoluta* (Meyrick), fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and rugose spiraling whitefly, *Aleurodicus rugioperculatus* Martin established very successfully in different parts of India. The reason behind this may due to climate change, where congenial environment has developed for their survival and reproduction (Vinod Kumar et al 2020).

Impact on pest population dynamics and outbreaks: Abiotic environment resulting due to climate change will affect significantly the diversity and abundance of insect-pests through geographic range expansion, increased overwintering survival and a greater number of generations per year, thereby increasing the extent of crop losses. It may result in upsetting ecological balance because of unpredictable changes in the population of insect-pests along with their existing and potential natural enemies (IPCC 2007). Changes in climatic variables have led to increased frequency and intensity of outbreaks of insect-pests viz., sugarcane woolly aphid *Ceratovacuna lanigera* Zehntner in Karnataka and Maharashtra states during 2002-03 (Srikanth 2007), rice plant hoppers *Nilparvata lugens* (Stal) and *Sogatella furcifera* (Horvath) on rice in North (IARI News 2008 and 2009), mealybug, *Phenacoccus solenopsis* Tinsley in cotton growing belt of the country (Dhawan et al 2007), papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink on papaya in Tamil Nadu, Karnataka, and Maharashtra (Tanwar et al 2010).

Impact of climate change on pollinators and pollination: Climate change is reported to impact insect pollinators at various levels, including their pollination efficiency. According to Millennium Ecosystem Assessment report (2005), pollination is one of the 15 major ecosystem services currently under threat from mounting pressures exerted by growing population, depleting natural resource base and global climate change (Costanza et al 1987, Sachs 2008). Earlier studies have clearly shown that the population abundance, geographic range and pollination activities of important pollinator species like bees, moths and butterflies are declining considerably with changing climate (FAO 2008). The climatic factors like temperature and water availability have been found to affect profoundly the critical events like flowering, pollination and fruiting in the life cycle of plants (Cleland et al 2007). The quality and the quantity of pollination have multiple implications for food security, species diversity, ecosystem stability and resilience to climate change (FAO 2008). The pollination services and associated risks are not addressed properly in determining the actions needed for conserving pollinators.

Impact of climate change on agricultural chemicals: Agricultural chemicals are basically chemical compounds and thus their properties may vary based on change in climate, i.e. temperature, atmospheric moisture, wind velocity, rainfall pattern, etc. Generally, after spraying, a pesticide undergoes degradation or persists in the environment for a longer time. Degradation of pesticide molecule depends upon the chemical structure, its formulation type and the intensity of factors responsible for its degradation. Major factors which contribute to degradation of a pesticide molecule are sunlight and temperature. Temperature plays a role in breaking the pesticide molecule by increasing the heat around the molecule, thus, the molecule breaks down into either a toxic or a non-toxic molecule. Breakdown of molecules or the metabolites may persist longer than the parent molecule, and may possess more leaching potential than other metabolites or parents too. Sometimes pesticide toxicity increases due to synergistic effect from the presence of environmental contamination Dosage of the pesticide formulation will have to be changed as it may become effective at a lower dose due to enhanced temperature and vice-versa. Sometimes due to increase in temperature penetration of pesticide molecule into the insects and crops becomes faster as compared to low temperature (Vinod Kumar et al 2020). Temperature is a major factor affecting insecticide toxicity either positive or negative and, thus, efficacy. The response relationship between temperature and efficacy has been found to vary depending on the mode of action of an insecticide, target species, method of application, and quantity of insecticide ingested or contacted. Increased temperature will increase the activity of some of the insecticides. Natural plant products, entomopathogenic viruses, fungi, bacteria, nematodes, and synthetic pesticides are highly sensitive to the environment (Pareek et al 2017)

Effectiveness of biological control agents/ natural enemies: Climate change is likely to have severe impacts on the abundance, distribution, and seasonal timing of pests and their natural enemies, which will alter the degree of success of biological control programs (Thomson et al 2010). Phytophagous insect species are naturally controlled by top-down (natural enemies) and bottom-up (host plant availability and quality) mechanisms. These mechanisms interact to influence insect population dynamics, performance, and behaviour, and are affected by climate change (Jamieson et al 2012). Temperature changes can affect the biology of host and natural enemy differently, destabilizing their population dynamics (Hance et al 2007) and causing temporal desynchronization. Natural enemies, being at the third trophic level, are expected to be significantly affected by climate change (Furlong and Zalucki 2017). If tropically connected species respond variously to climate change, the trophic interaction between them could be perturbed, resulting in decoupling of the synchronized dynamics between insect pests and their natural enemies and potentially negatively affecting the performance of biological control (Welch and Harwood 2014). All these species are affected by the effects of global warming and could respond differently to temperature changes (Harington et al 1999). Hance et al (2007) reported that if a natural enemy starts to develop at a slightly lower temperature than the prey and develops faster than the prey when the temperature rises, a too early and warm spring leads to its early emergence and a high probability of death from lack of prey. If this phenomenon is repeated over several years, it may lead to the extinction of the natural enemy.

Adaptation and mitigation strategies for pest management: Climate change adaptation can be viewed as an ongoing process of implementation of existing risk management strategies and reducing the potential risk from climate change impacts (Howden et al 2007). Climate change is widely expected to make pest infestations more unpredictable and increase their geographic range. Coupled with the uncertainty of how climate change will directly affect crop yields, the interactions between insects and plants in ecosystems remain unclear (Gregory et al 2009). The adaptive capacity of agricultural production systems will depend on several biological, economic, and sociological factors. The ability of local communities to adapt their pest management practices will depend on their physical, social, and financial resources (Sutherst et al 2011). With climate change and the acceleration of global trade, uncertainties, and frequency of occurrence of existing and new pests will increase. Increasing the ability to adapt rapidly to disturbances and climatic changes will therefore become all the more important (Barzman et al 2015). Potential adaptation strategies have been identified by many scientists to reduce the risks of spreading new pests and diseases, and to mitigate the negative impacts of existing pests. Most commonly mentioned strategies are modified integrated pest management practices, monitoring climate and insect pest populations and the use of modelling predictions tools (Skendžic et al 2021).

CONCLUSIONS

Climate change now a day is a globally acknowledged fact. Different aspects of climate change that are relevant to insect pests include small-scale climate variability such as temperature increase, increase in atmospheric CO_2, changing precipitation patterns, relative humidity, and other factors. It has serious impacts on diversity, distribution, incidence, reproduction, growth, development, voltisim and phenology of insect pests. Climate changes also affect the activity of plant defence and resistance, biopesticides, synthetic chemicals, invasive insect species, expression of Bt toxins in transgenic crops. Considering such declining production efficiency due to depleting natural resource base, serious consequences of climate change on diversity and abundance of insect-pests and the extent of crop losses, food security for 21st century is the major challenge for human kind in years to come. Being a tropical country, India is more challenged with impacts of looming climate change. In India, pest damage varies in different agro-climatic regions across the country mainly due to differential impacts of abiotic factors such as temperature, humidity and rainfall. This entails the intensification of yield losses due to potential changes in crop diversity and increased incidence of insect-pests due to changing climate. It will have serious environmental and socio-economic impacts on rural farmers whose livelihoods depend directly on the agriculture and other climate sensitive sectors. Dealing with the climate change is really tedious task owing to its complexity, uncertainty, unpredictability and differential impacts over time and place. Understanding abiotic stress responses in crop plants, insect-pests and their natural enemies is an important and challenge ahead in agricultural research. Impacts of climate change on crop production mediated through changes in populations of serious insect-pests need to be given careful attention for planning and devising adaptation and mitigation strategies for future pest management programmes. Using different pest models for forecasting the insect outbreaks, creating farmers network, pest diagnosis, pest surveillance and pest management services in real time using ICT tools critical for insect pest management in the climate change scenario is the need of the hour. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection, and devise appropriate measures to mitigate the effects of climate change on food security.

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Comparative Models of *Quercus* spp. and *Tilia* spp. Biomass for Remote Sensing in Climatic Gradients of Eurasia

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Abstract: Forest ecosystems play an important role in climate stabilization, and continuous monitoring of their biomass is of paramount importance. The airborne laser scanning technology has become widely used in assessing the biomass of trees by remotely registering the taxation indicators of trees. The author's database of harvest data of 397 and 138 sample trees of *Quercus* spp. and *Tilia* spp., respectively, growing on the territory of Eurasia is used in this work. The data contain values of tree height, crown width and length, as well as the biomass of trunk, foliage, branches and roots. For all components of aboveground biomass, a positive relationship with the crown width and the tree height was established. At a statistically reliable level, it was found that the biomass of components of equal-sized oak trees is 52-65 % higher than that of linden. In warm regions, as precipitation increases, aboveground biomass increases, but as one moves to cold regions, it is characterized by an opposite trend. As the temperature increases in humid regions, the biomass increases, but as the transition to dry conditions begins to decrease. The contribution of tree taxation indicators, species affiliation and climate variables to the explanation of the variability of the biomass components is 73.9, 7.7, and 18.4 %, respectively. The results obtained can be useful in laser monitoring of forest biomass and in predicting possible changes in the structure of tree biomass under climatic deviations.

Keywords: Oak, Linden, Hydrothermal gradients, Components of biomass, Laser sensing of trees, Allometric models, Average January temperature, Annual precipitation

Forests play a vital role in the global carbon cycle, accounting for approximately 80% of terrestrial biomass carbon (Tian et al 2023). The carbon stored in forests exceeds the carbon content in the atmosphere, underscoring the significance of understanding forest dynamics and biomass accumulation (Pan et al 2011, He et al 2021). To effectively manage and conserve these valuable ecosystems, it is crucial to employ remote sensing techniques for accurate assessment of forest characteristics. Among these techniques, airborne laser sensing has emerged as a valuable tool, providing high-precision information on the spatial and temporal characteristics of forests (Xie et al 2008, Engler et al 2013, Zharko and Bartalev 2014, Chopping et al 2022).

The information on airborne laser sensing is significantly increased when using ground–based laser sensing devices (for example, RIEGL VZ-400, Austria), which allow us to determine with high accuracy not only the tree height, the stem diameter, the width and length of the crown, the density of the stand, but also to isolate its components from the structure of the tree: foliage, branches and trunks (Béland et al 2011, 2014, Côté et al 2012, Olsoy et al 2014, Vicari et al 2019, Lau et al 2019, Calders et al 2020). But the problem is the limited possibilities of obtaining these characteristics over large areas.

Accurate estimation of forest biomass is crucial for understanding carbon sequestration potential and ecosystem dynamics. Allometric equations are commonly used to estimate biomass, but they often underestimate the biomass of trees due to the limited variables considered. For instance, tropical forest allometric equations that include tree height but neglect crown size can underestimate tree biomass by 11-14% (Goodman et al 2014, Santoro et al 2020, Martínez Cano et al 2020). Inclusion of crown width as an independent variable in allometric models has shown to improve biomass estimation for specific tree species, such as Pinus massoniana and Dahurian larch, resulting in increased determination coefficients (Fu et al 2016, Dong et al 2018).

Quercus spp. and *Tilia* spp. are two prominent tree genera found in the forests of Eurasia, exhibiting distinct biomass dynamics in response to climatic conditions. Quercus spp. trees are known for their strong growth and adaptability, while Tilia spp. trees are recognized for their shade tolerance and unique physiological characteristics

(Zarzosa et al 2021, Wang et al 2022). Understanding the biomass differences between these two genera can provide valuable insights into their ecological roles, carbon sequestration potentials, and responses to climatic changes. Moreover, the diverse environmental conditions across Eurasia, ranging from humid to arid regions, are shaped by temperature and precipitation variations, creating climate gradients that significantly influence the growth patterns and biomass accumulation of tree species (Storozhishina and Reshetnikov 2017).

Forests are usually represented by combinations of different tree species, different tree ages, and different physiological health conditions. This results in significant intraspecific spectral variability. On the one hand, many trees will be similar in their characteristics within the spectrum. On the other hand, differences in age, physiological state, or the number of voids in the crowns may cause the same species to be recognized in different spectra (Jensen 2005). The solution can be provided by artificial intelligence methods, such as fuzzy set logic and neural networks. They are widely used in multispectral analysis of laser imagery (Mas and Flores 2008, Hyyppä et al 2008, Voss and Sugumaran 2008, Rodríguez-Puerta et al 2022). In the United States, a neural network based approach has been developed to identify tree species at the level of individual trees from lidar and hyperspectral images. This approach is able to capture spectral differences between species using an externally supervised system. It is shown that lidar data combined with hyperspectral imagery can not only detect individual trees and determine the size of tree crowns, but also identify each of the 10 species using the developed algorithm. The consequence of integrating these two data sources is that they can replace traditional field studies (Zhang and Qiu 2012).

In the proposed study, we intend to: (1) determine whether there are statistically significant differences in the biomass of oak and linden trees, (2) find out how the components of biomass relate not only to the taxation indicators of trees, but also to temperature and precipitation fluctuations in the territory of Eurasia, and (3) what contribution to the explanation of the variability of the components of biomass is made by the taxation indicators of trees, species affiliations and climate variables.

MATERIAL AND METHODS

To solve these problems used the author's database of harvest data on the biomass of forest-forming species of Eurasia in the amount of 15,200 sample trees (Usoltsev 2020). From it, 397 and 138 trees of *Quercus* spp. and *Tilia* spp., respectively, with measured taxation and biomass indicators were selected (Table 1). The genus *Quercus* is mainly represented by the species *Q. robur* L. and to a lesser extent by species of *Q. acutissima* Carruth., *Q. crispula* Blume and *Quercus mongolica* Fisch. ex Ledeb. The genus *Tilia* spp. is mainly represented by the species *T. cordata* Mill. and to a lesser extent the species *T. amurensis* Rupr. and *T. parvifolia* Ehrh. The experimental material was processed

Table 1. Statistics of database samples for *Quercus* spp. and *Tilia* spp. in Eurasia

Statistic designation*	Indices analyzed**								
	H	Lcr	Dcr	Ps	Pb	Pf	Pa	Pr	Pr/Pa
Quercus									
Mean	14.6	6.3	4.2	161.2	32.9	4.2	198.4	154.3	0.24
Minimum	2.20	0.60	0.60	0.40	0.01	0.01	0.42	1.40	0.12
Maximum	32.6	24.4	15.5	3147.1	1091.8	52.4	4291.3	843.5	0.6
SD	6.8	4.1	2.6	277.5	91.6	5.8	367.5	230.7	0.14
CV (%)	46.4	64.6	62.1	172.1	278.2	138.7	185.3	149.5	58.5
n	397.0	393.0	397.0	397.0	397.0	397.0	397.0	14.0	14.0
Tilia									
Mean	18.0	12.6	3.9	150.0	22.2	2.9	175.2	29.2	0.17
Minimum	4.80	3.90	0.50	1.07	0.35	0.09	1.96	19.5	0.11
Maximum	23.8	19.6	9.2	466.9	112.9	14.1	572.5	45.6	0.3
SD	4.7	3.8	2.0	114.7	23.0	2.8	137.0	14.3	0.08
CV (%)	26.0	30.2	49.7	76.5	103.6	95.9	78.2	48.9	47.7
n	138.0	128.0	138.0	138.0	138.0	138.0	138.0	3.0	3.0

*Min=minimum, Max=maximum, SD=standard deviation, CV=coefficient of variation, n= number of observations.
**H = tree height, m; Lcr = crown length, m; Dcr = crown birth, m; Ps, Pb, Pf, Pa, Pr = biomass of the trunk over bark, branches, foliage, aboveground and roots in a dry condition, correspondingly, kg.

according to the program of multiple regression analysis using Statgraphics software (http://www.statgraphics.com/).

RESULTS AND DISCUSSION

To realize the first task of the study, the allometric model having the form (1) is used. In order to establish the difference between oak and linden in terms of tree biomass (or its absence), the binary variable *X* is introduced in the model (1) as an additional independent variable, which encodes data for oak (X = 0) and linden (X = 1):

$\ln P_i = a_0 + a_1 \ln D_{cr} + a_2 \ln H + a_3 X,$ (2)

where P_i = the biomass of the i-th component of the tree.

Ground-based laser scanning of a forest stand can produce a value of the crown length, which, with a known value of the tree height, characterizes the change in the tree's biomass due to its physiological state, coenotic position in the canopy, and the density of a stand (Carvalho 2003, Fu et al 2015, Dong et al 2018). When the crown length was included in the two-factor model of aboveground biomass as the third independent variable, the explanatory power of the model increased from 78% to 84%, i.e. by 6% (Ubuy et al 2018). The crown length (L_{cr}) was introduced as an additional independent variable in the model (2) having the structure:

$\ln P_i = a_0 + a_1 \ln D_{cr} + a_2 \ln H + a_3 \ln L_{cr} + a_4 X$ (3)

Results of calculation of equations (2) and (3) are shown in Table 2.

When comparing the characteristics of models (2) and (3), it can observe that involving crown length increased the determination coefficients of the model (3) with respect to (2) for trunk, foliage, branch, and aboveground biomass by 0.6, 6.0, 6.9, and 1.3%, respectively. It would seem that the increase in the adequacy of the model (3) with respect to (2) is not very large, so the question arises whether it is worth considering crown length as another independent variable in the allometric biomass model? According to the results of the regression analysis, this contribution to the explanation of the variability of the trunk, foliage, branches, and aboveground biomass was 11.0, 24.1, 25.7 and 14.1%, respectively. In this case, the need to take it into account in the model becomes obvious. But there is another side of the problem: if can get the values of the crown width and tree height, as well as to distinguish between oak and linden, by means of an airborne laser in real time over quite large areas, then can measure the crown length only with a ground-based laser device and only in local conditions. Since the assessment of the structure of tree biomass by an airborne laser device is a priority in study used the model (2) as a basis for further presentation of results. The binary variable *X* in models (2) and (3) is significant at the level of p<0.001. It has a "minus" sign, which means that at the same values of tree height and crown width, the biomass of all aboveground components in oak is significantly greater than in linden.

Table 2. Results of calculation of equations (2) and (3)

	Dependent variables			
	ln Ps	ln Pf	ln Pb	ln Pa
Model (2)				
a_0^*	-4.1538	-3.9923	-4.3692	-3.4990
ln Dcr	0.3241	0.7023	0.7527	0.3967
lnH	3.0416	1.5904	2.3242	2.8493
X	-0.2869	-0.5082	-0.2582	-0.2989
adjR^2	0.940	0.694	0.755	0.924
SE	0.43	0.73	0.85	0.47
Model (3)				
a_0^*	-3.9581	-3.5937	-3.9575	-3.2608
ln Dcr	0.3964	0.9138	1.0259	0.5012
ln H	2.7056	0.8155	1.3575	2.4100
ln L_{cr}	0.3424	0.7770	0.9909	0.4487
X	-0.4677	-0.9575	-0.8498	-0.5468
adjR^2	0.945	0.754	0.824	0.937
SE	0.41	0.65	0.72	0.42

* The intercept hereafter is adjusted according to Baskerville's (1972) logarithmic transformation; adjR^2= the coefficient of determination, adjusted for the number of variables; SE = the standard error of the equation

To answer the second question, the available data of the geographical coordinates of the sample trees are plotted on the maps of the average January temperature (https://store.mapsofworld.com/image/cache/data/map_2014/currents-and-temperature-jan-enlarge-900x700.jpg) and average annual precipitation (http://www.mapmost.com/world-precipitation-map/free-world-precipitation-map/) (World Weather Maps, 2007) (Fig. 1 and 2) and were simultaneously combined with the taxation and biomass indicators of trees in the one initial matrix (Usoltsev et al 2020a,b), which was then included in the regression analysis procedure (Usoltsev et al 2019b). The refusal to use the average annual temperature in favor of the average temperature in January was justified earlier (Usoltsev et al 2019 a,b; 2020a).

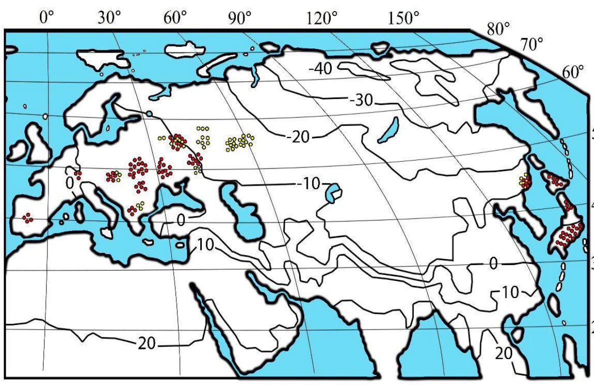

Fig. 1. Allocation of the harvest biomass data of 397 and 138 oak (Red circles) and linden (Yellow circles) sample trees, respectively, on the map of January isotherms, °C (World Weather Maps 2007)

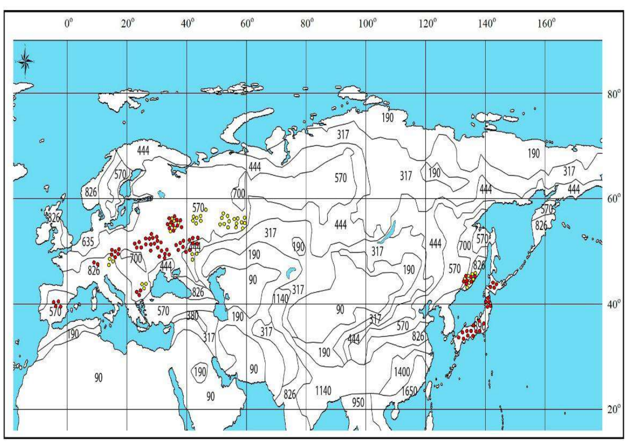

Fig. 2. Allocation of the harvest biomass data of 397 and 138 oak (Red circles) and linden (Yellow circles) sample trees, respectively, on the map of annual precipitation, mm (World Weather Maps 2007)

Based on the preliminary analysis, the model structure is proposed, which includes both morphometric characteristics of trees and climatic indicators as independent variables:

$$\ln P_i = a_0 + a_1(\ln Dcr) + a_2(\ln H) + a_3 X + a_4[\ln(T+20)] + a_5(\ln PR) + a_6[\ln(T+20)]\cdot(\ln PR) \quad (4)$$

where T is the average January temperature, °C; PR is the average annual precipitation, mm; $[\ln(T+20)]\cdot(\ln PR)$ is a combined variable that characterizes the combined effect of temperature and precipitation. Since the average temperature of January in high latitudes has a negative value, for its logarithm in the model (4), it is reduced to the form (T+20).

The amount of harvest data on the root biomass of oak and linden is 11 and 36 times less, respectively, compared to the data on aboveground biomass, and a similar disparity is typical for published databases on the biomass of trees and stands (Cannell 1982, Falster et al 2015, Schepaschenko et al 2017). Of the available 79 trees with measured oak root biomass, only 14 trees had their crown width measured, and out of a total of 11 linden trees with measured root biomass, only 3 trees had their crown width measured. Accordingly, the calculation of models (4) for the biomass of linden roots could include only 3 trees, which is not enough to ensure the stability of the model. Due to the insufficient representation of data on root biomass, were calculated models (4) for a relative indicator, namely, for *Pr/Pa*, and linked both species in one general model by encoding they with the binary variable X. The results of the calculation of the models (4) are shown in Table 3.

All the regression coefficients of the models presented in Table 3 are reliable at the level of $p < 0.001$. In the model for *Pr/Pa*, only the regression coefficient at $\ln D_{cr}$ ($t = 2.5 > t_{98} = 2.33$) was significant, and there are no differences between oak and linden in this relative indicator. The geometric interpretation of models (4) (Fig. 3) for oak biomass is

Table 3. Results of calculating models (4)

ln(*Y*)	a_0	ln*Dcr*	ln*H*	*X*	ln(*T*+20)	ln*PR*	[ln(*T*+20)]× (ln*PR*)	adjR^2	SE
ln(*Ps*)	25.7243	0.3289	3.0201	-0.7341	-13.4823	-4.4954	2.0466	0.946	0.41
ln(*Pf*)	40.4019	0.7094	1.5496	-0.8211	-18.6915	-6.8316	2.8876	0.716	0.70
ln(*Pb*)	39.8481	0.7067	2.2274	-1.0534	-21.1570	-6.5791	3.2040	0.778	0.77
ln(*Pa*)	28.7736	0.4019	2.8228	-0.8109	-14.7082	-4.8428	2.2293	0.933	0.44
ln(*Pr/Pa*)	-0.8515	-0.3752	-	-	-	-	-	0.136	0.45

obtained by substituting in (4) the average values of *H* and D_{cr} for oak taken from Table 1. Since compare the biomass of two species under the condition of equal tree sizes, these sizes should be the same for both species. The choice fell on oak for the reason that data on it in comparison with linden are presented in greater quantity (397 vs 138). The dependence of all the components of the biomass of equal-sized oak trees on temperature and precipitation is described by a propeller-shaped 3D surface (Fig. 3). In warm regions (*T* = 5°C), as precipitation increases, the biomass of all components increases, but in cold regions (*T* = -10°C), the biomass of trees practically does not respond to increased precipitation. As the temperature increases in wet regions, the biomass increases, but as the transition to dry conditions it decreases. For linden trees, Figure 3 is repeated, but the 3D surfaces for the biomass of foliage, branches, trunks, and aboveground are descend down the ordinate axis according to models (4) by 56, 65, 52, and 55%, respectively.

In other tree species, in particular, two-needled pines, spruce, fir and larch, the patterns sometimes differ in some components from those shown in Figure 3, and sometimes are opposite in all components (Usoltsev et al 2019b; 2020 a,b). This is probably due to the different biological properties of tree species and the distribution of assimilates of a tree into its various components (Zanotelli et al 2013, Xiong et al 2021, Liu et al 2021, Rehling et al 2021).

The variability of the ratio (*Pr/Pa*) is explained by the independent variable to the least extent (14%) compared to the components of aboveground biomass (72-95%), and these 14% are accounted for by the crown width, while the remaining independent variables are not statistically significant (Fig. 4).

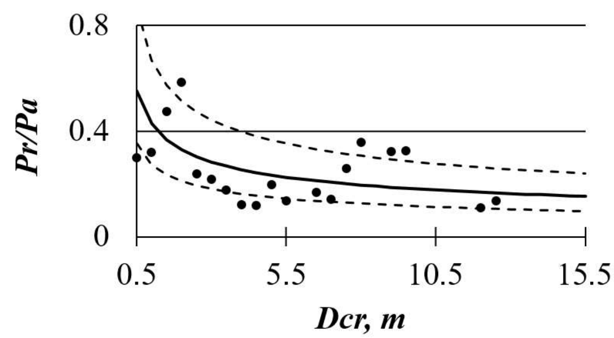

Fig. 4. Dependence of the *Pr/Pa* ratio of oak and linden trees on the crown width (*Dcr*). The solid lines show the average values of the regression, the dotted lines show the standard deviations

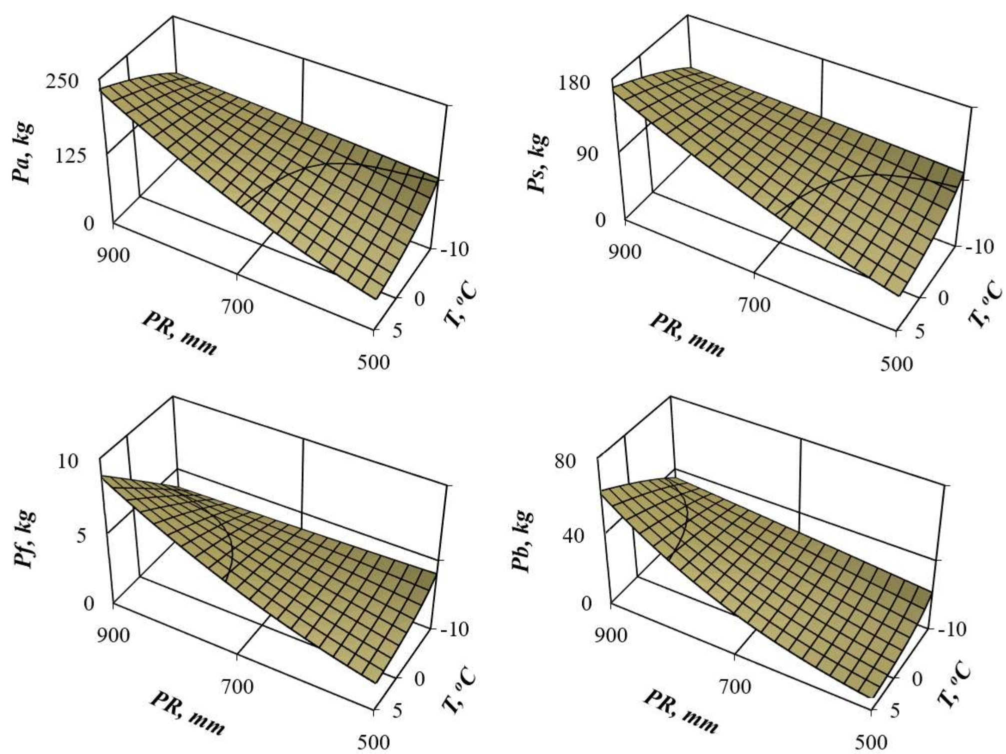

Fig. 3. Relationships of *Quercus* spp. biomass components with average January temperature (*T*) and average precipitation (*PR*). See Table 1 for the designations

Table 4. Contribution of the independent variables of equations (4) to the explanation of the variability of the dependent variables (%)

ln(*Y*)	Independent variables							
	ln*Dcr* (I)	ln*H* (II)	I+II	X	ln(*Tm*+20) (III)	ln*PRm* (IV)	[ln(*Tm*+20)] × (ln*PRm*) (V)	III+IV+V
ln(*Ps*)	9.1	70.9	80.0	6.3	4.9	4.0	4.8	13.7
ln(*Pf*)	23.0	44.5	67.5	8.6	8.3	7.3	8.3	23.9
ln(*Pb*)	18.7	51.3	70.0	9.0	7.7	5.8	7.5	21.0
ln(*Pa*)	10.8	67.2	78.0	7.0	5.4	4.3	5.3	15.0
X ± σ(*)	15.4±6.6	58.5±12.6	73.9±6.1	7.7±1.3	6.6±1.7	5.4±1.5	6.5±1.7	18.4±4.9

(*)X ± σ – mean value ± standard deviation

As a result of multiple regression analysis, the answer to r third question was obtained (Table 4). The contributions of tree taxation indicators, species affiliation, and climate variables to the explanation of the variability of biomass components are 73.9, 7.7, and 18.4 %, respectively. Climate variables explain the variability of trunk and aboveground biomass to the least extent (14 to 15 %) and foliage and branches to the greatest extent (21 to 24 %).

CONCLUSIONS

This study provides insightful findings regarding the biomass differences between *Quercus* spp. and *Tilia* spp. trees in Eurasia. The data suggests that oak trees exhibit a substantial biomass advantage, with their components, such as stems, leaves, and branches, being 52-65% more abundant compared to linden trees of equal crown width and tree height. Results highlight that temperature variations in wet regions tend to increase biomass, while transitioning to drier conditions leads to a decrease in biomass. The diversity of biomass components shows tree taxation indicators, including crown width and tree height, emerge as the most influential variables, accounting for 73.9% of the variability. Climate variables, such as temperature and precipitation, contribute 18.4% to the explanation, while species affiliation (*Quercus* spp. or *Tilia* spp.) has a relatively smaller influence of 7.7%. The outcomes can be helpful for tracking forest biomass using laser sensors.

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Integrated Pest Management: Innovations, Implementation and Impact in EU

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Abstract: Integrated Pest Management is one of the cornerstones of the EU pesticide legislation and viewed as vital for reaching the overall objective of reducing the risk and impact of pesticides. However, the uptake of IPM by EU farmers has been very slow. In this paper the causes for the slow uptake are discussed and examples are provided on EU supported activities intended to overcome the lack of uptake. Finally, the recent initiatives to reduce the use and potential impact of pesticides on human health and the environment are discussed.

Keywords: Sustainable use directive, IWMPRAISE, Green deal, IPM principles

The pesticide legislation in the European Union (EU) is generally considered to be the among the most rigorous in the world. This statement was recently substantiated by Donley (2019) who reported that 72 pesticides approved for outdoor agricultural use in the United States are banned or in the process of being phased-out in the EU. These pesticides are still widely used in the United States accounting for more than 25% of the total pesticide use. Nonetheless, pesticide authorities in the EU are under constant scrutiny for not providing a sufficient level of human and environmental safety.

Besides regulation setting the criteria for authorization of pesticides in the EU (Regulation (EC) No. 1107/2009), the EU pesticide legislation also includes a directive on the sustainable use of pesticides (Directive 2009/128/EC known as the Sustainable Use Directive (SUD)). The key objectives of the SUD are to reduce risk and impact, promote integrated pest management (IPM) and reduce the reliance on pesticides by promoting alternative approaches and technology. The directive stipulates several obligations for EU countries such as compulsory training for professional users of pesticides, distributors and advisors, regular inspection of spray equipment and raising public awareness. The SUD highlights the importance of IPM to reach the overall goals of the directive and by 1. January 2014 all professional users of pesticides were supposed to follow the eight principles of IPM laid out in Annex 3 of the directive (Barzman et al. 2015). All EU Member States are obliged to draw up National Action Plans to ensure the implementation of the SUD. More specifically, the Member States shall propose goals, targets and indicators to reduce the potential adverse effects on human health and the environment and take initiatives that stimulate the adoption of IPM and the use of alternative methods.

Bajwa and Kogan (2002) listed 67 definitions of IPM and since 2002 more definitions like 'true' and 'false' IPM reflecting the dependence on pesticides have been introduced (Ehler 2006). It has been argued that the many definitions of IPM focusing on different features of IPM has led to confusion and partly can explain the lack of uptake of IPM (Deguine et al 2021). The EU has largely adopted the FAO definition with one significant addition namely the word 'ecologically', i.e., the use of pesticides and other forms of intervention should be kept to levels that are economically and ecologically justified' highlighting the increasing emphasis on ecological processes in crop protection (Barzman et al 2015). The FAO/EU definition does not *per se* consider the hierarchy of different intervention technologies reflected in the 'IPM pyramid' but this is partly amended by the eight IPM principles. The eight principles and their numbering follow the passing of year in the field beginning with preventive and suppressive measures followed by monitoring/ forecasting, direct control and ending with evaluation with a view to improve the process (Table 1). Regarding direct interventions, it is clearly stated that non-chemical methods should be preferred to pesticides and that pesticide use, if required, should be kept at a minimum. Nonetheless, they are only principles and not guidelines and for farmers to successfully implement IPM strategies and giving up what most farmers consider to be a cost-effective approach based on a high reliance on pesticides, validated IPM control tactics and strategies are needed. Moreover, IPM

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emphasises a system approach building on agronomic, mechanical, physical, and ecological principles and only resorting to pesticide use when pests cannot be successfully managed with other tools. IPM is therefore a more knowledge-intensive approach than the traditional pesticide-based approach adopted by most European farmers.

In recent years the most important drivers for farmers to implement IPM have been the steadily increase in the number of cases of pesticide resistance and, in some crops, also the loss of key pesticides due to stricter regulations. This made many farmers realizing that heavy dependence on a constantly narrower supply of pesticides is not sustainable and led to changes in crop rotation and other farming practices focussing more on prevention and suppression. Not surprisingly, so far, all evaluations of the adoption of IPM among EU farmers have been negative whether conducted by the EU Commission (European Commission 2017) or third parties (Traon et al 2018, European Court of Auditors 2020). Studies conducted in individual EU countries add to this picture (Piwowar 2021). In a recent study, Helepciuc and Todor (2021) concluded that the lack of success could be attributed to very different approaches in the EU countries developing National Action Plans and proposing measures and timetables. It should, however, be stressed that because IPM is only defined by the eight principles and not rules, it is difficult to assess the degree of IPM implementation, as Matyjaszczyk (2019), conducting as assessment of IPM implementation in Poland, also concluded.

EU and national initiatives to promote the uptake of IPM: At EU member state level, many IPM activities were initiated. One initiative has been demonstration farms or farm networks where focus has been on reducing the use of pesticides by adopting IPM approaches and sharing the experiences among farmers. One example is the German project 'Demonstration Farms Integrated Plant Protection' which at one point included more than 60 farms covering most parts of Germany. The purpose of the demonstration farms was to demonstrate IPM tactics and strategies and to facilitate this; the farmers were supported by farm advisors and researchers. Another example is the DEPHY network created in France in 2010 now consisting of 3,000 farms who, supported by their advisors, are committed to adopt low pesticide use strategies. The network has seen farmers reducing pesticide use (expressed as the Treatment Frequency Index) but rather than adopting IPM this was achieved by substituting pesticides, reducing doses and more efficient pesticide application (Fouillet et al 2022). The project IPMWORKS was recently supported by the EU. The project builds on the principles of the DEPHY network but rather than building a French farm network, IPMWORKS will establish a pan-European farm network. The ambition is to promote a holistic IPM approach incorporating preventive and non-chemical control methods ('holistic IPM) (https://ipmworks.net/).

In recent years the EU has supported several IPM related research projects. The objective of many of the projects has

Table 1. IPM principles as laid out in ANNEX III of the SUD

1. The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:
   - crop rotation,
   - use of adequate cultivation techniques (e.g., stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
   - use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
   - use of balanced fertilisation, liming and irrigation/drainage practices,
   - preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of machinery and equipment),
   - protection and enhancement of important beneficial organisms, e.g., by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.
2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.
3. Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms, threshold levels defined for the region, specific areas, crops and particular climatic conditions must be considered before treatments, where feasible.
4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.
5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.
6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g., by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.
7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.
8. Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures.

been to develop novel IPM tools and assist the implementation of IPM through education and training of farmers and advisors. Earlier, most EU projects were developed and run mainly by researchers from universities and applied research institutes and dissemination and involvement of end-users was a minor activity in the last part of the project. Recently, the EU decided that research projects addressing IPM should adopt a 'multi-actor approach', i.e., that all stakeholders should be involved in the planning, execution and evaluation of the research activities thereby promoting a 'co-innovation' approach. One of the rationales behind the multi-actor approach is that it is more likely that farmers will adopt IPM tactics they were involved in developing, adjusting and evaluating than IPM tactics developed by researchers. In the following an example of an ongoing multi-actor project will be presented (Kudsk et al 2020).

Case study: IWMPRAISE

IWMPRAISE is addressing integrated weed management (IWM) in a broad range of crops (arable, horticultural and perennial herbaceous and woody crops). In contrast to the crop specificity of most herbicides, IWM tends to be more generic in the sense that IWM control tactics can often be applied in crops with similar growth habit, growing season and/or grown with the same spatial arrangement. This inspired us to adopt a categorical approach with four management scenarios: annually drilled crops in narrow rows (e.g., wheat and oilseed rape), annually drilled crops in wide rows (e.g., maize and field vegetables), perennial herbaceous crops (e.g., grassland and alfalfa) and perennial woody crops (e.g., pome fruit and olive). This allows for extrapolation of the eight IPM principles between regions of Europe with due consideration of differences in climatic and agronomic conditions. IWMPRAISE adopted the multi-actor approach, i.e., all stakeholders including end-users are involved in all steps of the project from the planning to the execution and evaluation. In each of the eight participating countries, 'national clusters' consisting of all stakeholders were formed. The national clusters were involved in the planning, execution and evaluation of the experimental trials. In the case of an unfavourable evaluation, the experimental design was adjusted for the following years. A similar approach was used in the second year prior to the third and last year of experimentation. By adopting this 'design-assessment-adjustment' approach it is anticipated that the IPM solutions developed will be more acceptable to the farmers and adopted faster. A range of dissemination activities were conducted to promote the visibility of the IWMPRAISE activities including a website in the local language in each of the eight countries.

The IWMPRAISE framework for IWM is built around the life cycle of weeds (Fig. 1). To manage weeds effectively farmers should either: 1) limit weed establishment in the crop from the soil seed bank or subterranean vegetative organs, 2) limit competition for resources such as light, nutrients and water by removing weeds or manipulating the weed flora to

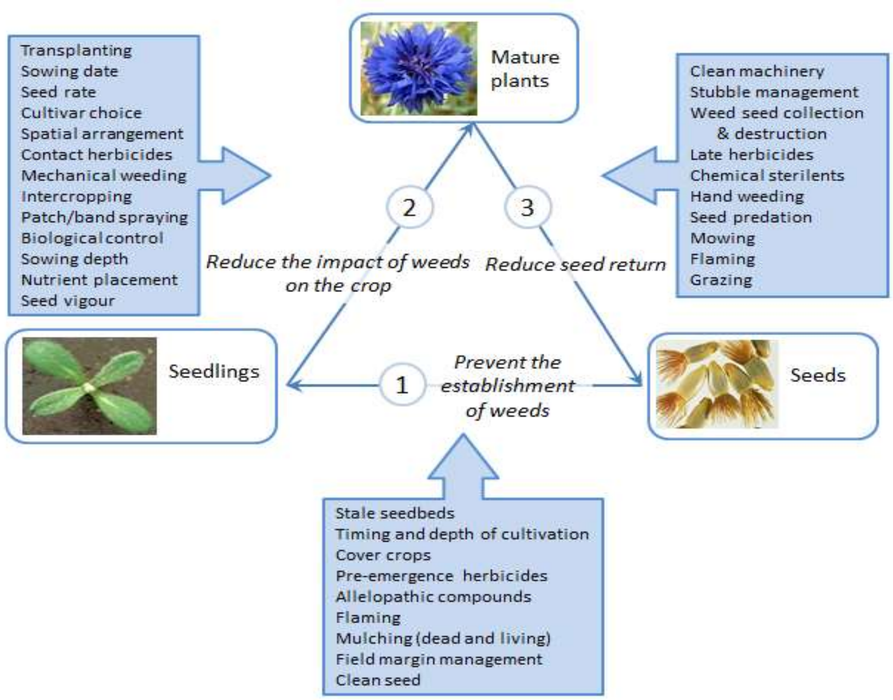

Fig. 1. Weed life cycle (Kudsk et al 2020)

reduce their competitive impact or 3) limit return of seeds or vegetative organs to the soil seed/vegetative organ bank. A sustainable approach should possibly combine control tactics impacting on different steps of the life cycle. Examples of tactics interfering at the three stages of the life cycle are shown in Figure 1.

One of the first activities in IWMPRAISE was a mental modelling exercise. Weed experts and end-users were interviewed to determine the knowledge, beliefs, perceptions and attitudes to IWM. The outcome of these interviews was used to develop an IWM framework. Based on the interviews, it was concluded that in the mindset of weed experts and end-users IPM control tactics could be allocated to one of the following five IPM pillars: 1) diverse cropping systems, 2) cultivar choice and establishment, 3) field/soil management, 4) direct control and 5) monitoring and evaluation. Combining the outcome of the interviews with the concept of categorising control tactics according to what stage of the life cycle they interfere with, led us to develop the general IWM framework shown in Figure 2 (Riemens et al 2022). Although the framework was developed in an European context, we believe it can be applied in other parts of the world in other cropping contexts but it may then be necessary to exclude or add control tactics.

The IWM framework is also available as an online version (https://framework.iwmtool.eu/). Using the online version, the first step is to select crop (annual narrow row, annual broad row or perennial) and weed (annual or perennial) groups. When pressing a hexagon, a factsheet will pop up providing further information on the use and experiences with that particular IWM control tactic.

DISCUSSION

Previous surveys have shown that there are a number of barriers constraining the uptake of IPM by farmers and advisors (Lefebvre et al 2015, Moss 2019). These barriers are based on both experiences and perceptions. An increased risk of inadequate pest control, higher costs, more labour intensive and investments in new equipment are among the reasons mentioned. Another issue, which is often mentioned, is limited evidence of the efficiency of IPM strategies. Although IPM is not a new invention, the focus on IPM in the EU is of recent date and there is little evidence that IPM strategies are cost-effective and as efficient as pesticide-based strategies.

Another constrain is lack of knowledge among farmers. IPM is more knowledge-intensive (Swanton et al 2008) and

Fig. 2. Framework for designing IWM strategies combining individual IWM control tactics from each of the 5 pillars of IWM. Colour codes refer to the weed life cycle shown in Figure 1 (Riemens et al 2022)

for IPM to be successful, a spatial and temporal scale has to be considered, which is different from the one crop – one pest approach that is currently practiced by most farmers. A spatial scale considering landscape instead of fields may be necessary to control insect pests without or with a minimum use of insecticides and a temporal scale considering, e.g., crop rotation is pivotal to manage weeds due to the close association between composition of the weed flora and the crop sequence. Hence, training of farmers and advisors is crucial to ensure that IPM becomes truly integrated pest management and not just 'Integrated Pesticide Management' (Peshin and Zhang 2014) or 'Intelligent Pesticide Management' (Nicholls and Altieri 2004). In this context, bringing groups of farmers together in hubs together with an advisor where farmers can share their experiences and receive advise on recent innovations seems to be one of the most promising ways forward. This approach was adopted in the ongoing EU project IPMWORKS and the ambition is that this project can serve as an inspiration in all EU countries. However, the success of this approach depends on the existence of an independent advisory service which is not the case in all European countries.

The development of IPM control tactics has unfortunately been lagging behind the political ambitions of implementing IPM. This is true for weeds, diseases and insect pests. For example, effective physical weed control methods are not available for all cropping situation but the use of cameras and other sensors for guiding machines will most likely promote the use of these methods. The EU project IWMPRAISE (see above) has provided numerous examples on how physical weed control methods can be part of an IWM strategy. The increased interest among farmers in precision farming including weed mapping may promote the use of integrated weed management approaches (Riemens et al 2022).

Biologicals have for many years been seen as a key component of IPM strategies (Lamichhane et al 2016) but the number of products available to European farmers are still limited (Helepciuc and Todor 2022). This has been attributed to a slow and rigoristic authorisation procedure in the EU (Sundh and Eilenberg 2020) and it is true that the time to authorise a biological in the EU is much longer than, e.g., in the United States or Canada (Gwynn, https://4458b165-2d60-4788-8442-b7e2057eceb6.usrfiles.com/ugd/4458b1_bc 95f91b705d41b889847504cd647290.pdf.). However, the efficiency of most of the commercially available biologicals is not comparable to that of synthetic pesticides and an increased use of biologicals will require that they are seen as one component of a an IPM strategy rather than a 'stand-alone' product. This change in perception has not been well communicated and the use of biologicals are a good example of how complexity increases when adopting IPM.

MacRae et al (1990) proposed the ESR (Efficiency, Substitution and Redesign) paradigm for describing the transition towards sustainability in farming. The development and implementation of IPM may benefit from leaning on this paradigm. 'Efficiency' is the improvement of the currently used methods such as optimising the application of pesticides thereby improving the performance and possibly allowing for dose reduction. Site-specific application of pesticides is another example. 'Substitution' is replacing the currently used methods by, e.g., environmental more benign methods. Examples are physical weed control methods and biologicals instead of pesticides. As mentioned, compared to pesticides many substitutes are not as effective and should not be regarded as a one-to-one substitution. This is where 'Redesign' comes in. To be successful with IPM and reduce/replace the use of pesticides with non-chemical methods, farmers will often have to apply more than one IPM tactic (referred to as 'the many little hammers' by Liebman and Gallandt (1997)). Often these tactics also involve a change in agronomic practices, i.e., in reality a redesign of the cropping system. Accepting that successful implementation of IPM may require redesign of the cropping system could provide a fresh start for the IPM concept. Recently, Jacquet et al (2022) took it a step further by suggesting that the agricultural research community in Europe need to adopt a pesticide-free paradigm to achieve a significant impact on pesticide use.

In 2020, the EU presented the European Green Deal (https://ec.europa.eu/info/strategy/ priorities-2019-2024/european-green-deal_en). One of the goals of the Green Deal is to create a sustainable food system and to achieve this the EU Commission recently launched the Farm to Fork strategy (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0381&from=EN). Some EU countries have set targets for pesticide reductions but for the first time, the EU Commission is suggesting a pesticide reduction target of 50% before 2030.

Adoption by all farmers in the EU of 'true' or 'holistic' IPM is the current political goal but, so far, the adoption is progressing very slowly, as reflected in the overall pesticide use in EU which has not gone down since the implementation of the SUD (Buckwell et al 2020). It will require significant investments in research and establishment of independent advisory services in many EU countries to reach the goals of the SUD. Maybe economic incentives such as a restructuring of the EU subsidies to also focus on IPM implementation or pesticide taxes (Kudsk et al 2018) will be needed too.

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Breeding and Deploying Climate Resilient Maize Varieties in the Tropics

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Abstract: Building climate resilience in the smallholder farming systems warrants implementation of an intenisve multi-disciplinary and multi-institutional strategy, including deployment of genetic inovations and sustainable agronomic practices, together with enabling policies. Experiences of CIMMYT over the past 15-20 years in the Global South demonstrate that accelerated breeding and delivery of climate resilient maize varieties in the tropics is possible through: (a) carefully undertaken field-based phenotyping both on-station and on-farm in the target population of environments; (b) utilization of modern breeding tools/strategies, including doubled haploid (DH) technology, precision phenotyping, breeder-ready marker deployment, and genomic selection, to achieve rapid breeding cycles and development of improved products; (c) multi-institutional efforts, especially public-private alliances, to ensure that the climate resilient varieties effectively reach the farming communities. In the last 15 years, CIMMYT and partners in sub-Saharan Africa and South Asia have released more than 300 climate-resilient maize varieties, including drought and heat tolerance, disease resistance, and other farmer-preferred traits. In Sub-Saharan Africa, more than 181,000 tons of certified seed of CGIAR-related multiple stress-tolerant maize varieties were produced in 2022, and commercialized by over 100 seed companies, covering an estimated 7.5 million hectares. Scaling of high-yielding, and drought and heat tolerant maize varieties is the need of the hour in the tropics of South Asia, following the example of sub-Saharan Africa. It must also be recognized that the changing climate is one of the major factors for the increasing incidence of devastating transboundary pests and diseases, especially in the tropics. Therefore, intenisve deployment of improved varietes with host plant resistance, as a part of integrated pest and disease management strategies, is important for sustainably protecting maize crops, and protect food security and livelihoods of millions of smallholder farmers.

Keywords: Maize, Climate resilient, Tropics, Agri-food systems, Pathogens and insect-pests

Achieving sustainable food and nutritional security, i.e., the basic right of the people to produce and/or purchase the nutritionally balanced food they need, without harming the social and biophysical environment, has to be the funadememtal goal of any nation. Over the last seven decades, India made immense progress towards food security of the population. Since 1950, the population almost tripled, but foodgrain production had more than quadrupled. India is now among the largest producers of rice, wheat, pulses, fruits, vegetables, milk, cotton, horticultural crops, dairy andpoultry, aquaculture, and spices. Agricultural production in India is valued at US$401billion in 2017, which is more than that of the USA (US$279 billion).

Despite this impressive progress, there is no scope for complacency. It is estimated that by 2030, India's population would be1.52 billion; by 2050, it would be approximately 1.7 billion, which will be the highest in the world and about 400 million more thanChina, the most populous nation today (Singh 2019). By 2050, India needs to step up production of all agricultural commoditiesby around 30 per cent in food grains and to more than 300 percentin vegetable oils to meet the needs of increased population and risingliving standards (Singh 2019). Also, by 2050, to meet the diverse demands of the population, it has been estimated that land productivity has to be increased by 4 times, water productivityby 3 times, and labour productivity by 6 times (Chand 2012). All this hasto be achieved in the context of changing climates, more fargile natural resources, and by staying within the planetary boundaries i.e., without major environmental and ecological footprints.

Climate change is for real, and certainly not fiction, as is unfortunately still believed by some in the world! The negative impacts of frequently occuring climatic extremes/variabilities on agricultural production are most often felt by the resource-constrained smallholders in the tropics, be it in Africa, Asia or Latin America.Abiotic stresses, especially drought, heat, flooding/waterlogging, soil acidity, and combinations of various abiotic stresses have a huge negative impact on the rainfed crop yields. For instance, in South and South East Asia, more than 80 percent of the

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maize-growing area is rainfed and prone to various climatic extremes/variabilities. While we tend to focus mostly on abiotic stresses in the context of climate change, it is equally important to consider the changing spectrum of pathogens and insect-pests, due to increase in temperature (Deutsch et al 2018, IPPC Secretariat 2021, Skendžic et al 2021).

Building climate resilience in the smallholder farming systems, therefore,requires implementation of an intenisve multi-disciplinary and multi-institutional strategy. This should include extensive awareness creation and widespread adoption of climate-resilient crop varieties and climate-smart agronomic management practices, strengthening of local capacities, and much stronger focus on sustainability. An array of agricultural production technologies and practices, including stress-tolerant improved crop varieties, conservation agriculture practices, and agroforestry systems, that aim to mitigate climate-induced risks and foster resilience have been developed through national and international AR4D initiatives over the past two decades. In addition, institutional interventionsthat seekto mitigate risk and build resilience through other mechanisms could play a complementary role to climate-smart agricultural productiontechnologies/practices (Hansen et al 2019).

Breeding Multiple Stress-tolerant Improved Maize Varieties for the Tropics

The International Maize and Wheat Improvement Center (CIMMYT) and partners in Africa, Latin America and Asia are intensively engaged in developing and deploying climate-resilient improved maize varieties adapted to the tropics (Cairns and Prasanna 2018, Prasanna et al 2021, Chivasa et al 2021). CIMMYT has used two major approaches for developing sources of abiotic stress tolerance that have been widely used in maize breeding programs in SSA, Asia and Latin America. The first was constitution of drought-tolerant populations for undertaking recurrent selections and derivation of elite inbred lines. The DTP-Y, DTP-W, and La Posta Sequia are examples of such populations. The second approach was full-sib recurrent selection under managed drought stress within elite populations to increase the frequency of drought tolerance alleles in germplasm already adapted to the lowland tropics (Edmeades et al 1999, Prasanna et al 2021a). Both approaches have generated several inbred lines that have become important sources of drought and heat tolerance in maize, especially in the tropics(Cairns et al 2012). Thus, population formation and improvement have resulted in an increase in the frequency of drought-adaptive alleles and identification of superior sources of drought tolerance (Edmeades et al 2017).

Besides constitution of appropriate maize populations for implementing recurrent section for improving drought stress tolerance, CIMMYT also has established an extensive phenotyping network for maize breeding in the tropics along with managed stress screening protocols (Prasanna et al 2021a); identified and used suitable secondary traits (e.g., anthesis-silking interval or ASI); and implemented focused breeding programs to continuously develop products (inbred lines, improved OPVs, and hybrids) that can perform well under both optimal and stressed environments (Cairns and Prasanna 2018, Prasanna et al 2021a). CIMMYT's maize product advancement process typically includes not only regional on-station trials of promising pre-commercial hybrids coming out of the breeding pipeline vis-à-vis internal genetic gain checks and commercial checks but also extensive regional on-farm varietal trials to ascertain the performance of the promising pre-commercial hybrids under farmer-managed conditions. This also provides opportunity for the socioeconomics team to assess farmers' product as well as their trait preferences. The best entries coming out of this rigorous process are then announced on the CIMMYT website, and further allocated to interested public/private sector partners for varietal registration, scale-up, and delivery in the target geographies.

Accelerating Improved Varietal Development using Modern Tools/Technologies

CIMMYT-Maize Teams in Africa, Asia and Latin America use an array of modern tools/technologies for accelerating improved varietal development and for increasing genetic gain for grain yield in stress-prone tropical environments (Prasanna et al 2021a). These tools include the doubled haploid (DH) technology (Prasanna et al 2012, Chaikam et al 2019), low-cost and high-throughput phenotyping using proximal and remote sensors (Makanza et al 2018a,b), genomics-assisted breeding (Nair et al 2018), and breeding information management system, including decision-making tools. With the rapid reduction in genotyping costs, new genomic selection technologies have become available in several crops that allow the crop breeding cycle to be greatly reduced, facilitating inclusion of information on genetic effects for multiple stresses in selection decisions (Xu et al 2017).

Through dedicated maize DH facilities in Kenya and Mexico, CIMMYT Global Maize Program produces annually over 100,000 DH lines (up from less than 5000 in 2011) and selects the best out of these lines in breeding pipelines. CIMMYT team has also developed and deployed superior second-generation haploid inducers for tropics using marker-assisted breeding (Chaikam et al 2018). In December 2021, CIMMYT has established a Maize Doubled Haploid Facility at ARS-Kunigal in Karnataka, India, in partnership with UAS-Bangalore. This facility will provide DH development service not only to CIMMYT maize breeders, but also to those from the NARS and small- and medium-enterprise (SME) seed companies in South Asia.

Deploying Climate-resilient Maize Varieties in the Tropics

An array of elite maize varieties with drought tolerance, disease resistance and other farmer-preferred traits have been developed by CIMMYT and deployed by seed companies across sub-Saharan Africa (SSA), Asia and Latin America. Between 2007 and 2021, CIMMYT and partners in SSA released more than 300 climate-resilient maize varieties in 13 African countries. In 2021, more than 171,000 tons of certified seed of CGIAR-dericed multiple stress-tolerant maize varieties were produced and commercialized by over 100 small- and medium-enterprise seed company partners across SSA, covering an estimated 7.2 million hectares, and benefiting about 7 million farm households.

Tesfaye et al (2017, 2018) highlighted the potential benefits of incorporating drought, heat and combined drought and heat tolerance into improved maize varieties in the climate-vulnerable tropical environments.Asia is now beginning to emulate the success story from Africa in terms of extensive deployment of drought-tolerant and drought + Heat-tolerant improved maize varieties through intensive public-private partnerships. Through the USAID-funded Heat Tolerant Maize for Asia (HTMA) project, a large heat-stress phenotyping network, comprising 23 sites in four Asian countries (India, Bangladesh, Nepal and Pakistan) has been established. Several CIMMYT-derived drought-tolerant and heat-tolerant CIMMYT-derived elite maize varieties have been released during 2016-2018 through public and private sector partners in South Asia, and several more are in pipeline.

For new climate-resilient crop varieties to contribute towards smallholders' adaptation to climate variability, it is important to further strengthen the seed systems. Delivering low-cost improved seed to smallholder farmers with limited purchasing capacity and market access requires stronger public-private partnerships, and enhanced support to the committed local seed companies, especially in terms of information on access to new products, adequate and reliable supplies of early-generation (breeder and foundation) seed, and training on quality seed production, quality assurance/quality control (QA/QC),and seed business management. Proactive managementof product life cycles by seed companies benefits both the farmers and businesses alike, contributing to improvedfood security and adaptation to the changing climate (Chivasa et al 2021).

Protecting Agri-food Systems from Devastating Pathogens and Insect-Pests

Pathogens and insect-pests have severe and cross-cutting negative impacts, particularly affecting farmers' incomes, and livelihoods. Their capacity to rapidly evolve and proliferate pose a huge challenge. There is a significant need for implementation of development and implementation of multi-disciplinary, multi-institutional, and sustainable strategies for devastating crop diseases and pests, to counter the threat to food and nutritional security, and the livelihoods of populations (Prasanna et al 2022b).

Two most recent examples of transboundary pests/pathogens severely affecting maize smallholders are the maize lethal necrosis (MLN) in Africa, and the fall armyworm (*Spodoptera frugiperda*) in Africa and Asia.MLN is a complex viral disease, emerging as a serious threat to maize production and thelivelihoods of smallholders in eastern Africasince 2011, primarily due to the introduction of maize chloroticmottle virus (MCMV). CIMMYT, in close partnershipwith national and international partners, implemented a multi-disciplinary and multi-institutional strategy tocurb the spread of MLN in sub-Saharan Africa, and mitigate the impact of the disease (Prasanna et al 2020, Prasanna 2021).

Fall armyworm (FAW) has been prevalent in the Americas for several decades but was reported for the first time in West Africa in 2016. Within two years, FAW incidence had already been reported in more than 40 countries across Africa, and over 15 countries across the Asia-Pacific (Prasanna et al 2021b). The pest was reported for the first time in India in mid-2018, and subsequently reported in several other Asian countries. FAW attacks primarily the maize crop and has potential to feed on more than 80 other crops, including sorghum and sugarcane. Indiscriminate and unguided use of toxic synthetic pesticides is reported across Africa and Asia for FAW control, which poses serious threat to environment, animal and human health, besides affecting the natural enemies of the pest. Therefore, it is extremely important to develop, test, and urgently deploy science-based, integrated pest management (IPM) technologies/management practices, including host plant resistance (both native genetic resistance and transgene-based resistance) to FAW (Prasanna et al 2022), environmentally safer synthetic pesticides, biopesticides and botanicals, besides low-cost cultural control and agro-ecological approaches (Prasanna et al 2018, 2021b). A set of three first-generation FAW-tolerant CIMMYT maize hybrids have been announced in 2021 for Africa (https://maize.org/cimmyt-announces-fall-armyworm-tolerant-elite-maize-hybrids-for-africa/). While South Sudan has recently released these three hybrids, several more countries are expected to release the FAW-tolerant maize hybrids in 2022-2023. Breeding for native genetic resistance to FAW has also been initiated by CIMMYT and partners in South Asia.

CONCLUSIONS

We need to collectively address an array of challenges, including adaptation to the changing climates, alleviating extensive malnutrition, improving soil health, and protecting agrifood systems from devastating diseases and insect-pests. Intensive multi-institutional and multi-disciplinary efforts are required to cocreate and deploy innovative and sustainable technologies that can improve crop productivity, reduce production costs, and improve the incomes and livelihoods of smallholder farmers. Building climate resilience warrants effective integration of climate-resilient crop varieties, climate-smart agronomic management practices, and effective implementation of policies to help reduce environmental and ecological footprints of agricultural practices. Scientific institutions must enhance the the pace, precision and efficiency of breeding programs through judicious and effective integration of modern tools/strategies, including high-density genotyping, high throughput and precision phenotyping, speed breeding, molecular marker-assisted and genomic selection-based breeding, and knowledge-led decision-support systems.Seed systems need to be further strengthened to become more market-oriented and dynamic, and for providing smallholders with greater access to affordable climate-resilient and nutritionally enriched improved seed. Understanding the smallholder farmers' constraints for adoption of modern technologies, enhancing affordability and access to quality agricultural inputs, and improving their linkages to the input and output markets should be accorded top priority.

Technologically, we are living in exciting times. Genomics-assisted breeding, genome editing, speed breeding, remote sensors, satellite imagery, drones, artificial intelligence, machine learning, decision support tools, and information and communication technologies, are only a few of the innovations that one can mention that are impacting various spheres of life, including agriculture. Breeding programs should be constantly appraised and revised by incorporating new innovations. Furthermore, the efficiency and effectiveness of the breeding programs should be monitored by employing metrics designed to measure the impacts of breeding outcomes (= improved varieties) on the ultimate users – the farmers.

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Energy Use Patterns and Econometric Models of Capsicum (*Capsicum annuum* L.) as Influenced by Automated Sensor-Based Irrigation and Fertigation

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Abstract: The energy input, output and utilization studies provide evidence that the total input energy was reduced during *kharif* season crop when compared to *summer* season and ranged between 71810 to 81501 MJ ha^{-1} and 84396 MJ ha^{-1} to 93952 MJ ha^{-1}, respectively. Among the different energy inputs plastic, chemical and fertilizers had higher energy utilization with notable reduction in *kharif* season., energy from indirect sources played a major role with a consumption of 75.9 to 81.7%, renewable energy resources had more share with 29.6 % in *kharif* season when compared to *summer* season (23.7 %). Econometric model evaluation showed the positive impact of Direct and Renewable Energy on yield of capsicum. Return to scale values were more than 1 for both modules, thus, there prevailed an increasing return to scale of capsicum for estimated model. Automated scheduling irrigation at 75 % available soil moisture along with 125 % recommended dose of fertilizers application through fertigation exhibited higher returns, output energy (301874 MJ ha^{-1}), energy use efficiency (3.32) and energy productivity (0.64) during *summer* season and notable increase in *kharif* season (327557 MJ ha^{-1}, 4.18 and 0.79, respectively). Hence it is economically viable, environmentally sustainable and energy efficient for cultivation of capsicum.

Keywords: Automation, Energy balance, Econometric model, Renewable energy, Sensor

India is an agrarian country with 139.4 million ha of net cultivated land and 200.2 million hectares of gross cropped area with a cropping intensity of 143.6 per cent. The net area sown area accounts to 42.4 per cent of the total geographical area (Annual Report 2021.). The estimates report that global food production must increase by 70 % to meet the food demand of the population projected to around 9 billion by 2050 (CTA-CCAFS 2011). With the increasing population and changing land usage pattern, improved and modern agricultural technologies like protected cultivation is necessary to use cultivated land intensively to meet the growing demand. The protected cultivation under controlled environment aid in high quantity of fresh and quality vegetable and fruits, fetching higher returns to the farmers (Santosh Nagappa Ningoji et al 2023). Sensor based moisture detection and scheduling automated irrigation is a way in addressing the real time challenge of precise soil moisture-based irrigation schedule. Irrigation scheduling based on soil moisture on real time basis provide optimum micro-climate in utilizing the available resources efficiency. Further, application of water soluble fertilizers through drip provides an added advantage in precision nutrient supply as per crop demand (Biwalkar et al 2015).

The economic returns and resource use efficiency are synonymous to the farmers (Kuswardhani et al 2013). Presently, energy, environment and economic returns are interrelated and are key parameters to evaluate any agricultural production system. The inputs such as electricity, fuel, machinery, fertilizer, seed and plant protection chemicals take major share of the energy supplies in the modern agriculture production system. The efficient use of energy resources are required to enhance the production, productivity and profitability of agriculture as well sustainability of rural livelihood (Hatirli et al 2005). Preparing energy balance is the best approach to examine energy use efficiency and environmental impact of the agricultural production system. It also aids researchers to calculate net energy produced, energy use efficiency, energy productivity, specific energy required and energy use patterns in an agricultural production system. Moreover, the energy audit provides sufficient data to establish functional forms to investigate the relationship between input and output energy. Estimating these functional forms is very useful in terms of determining elasticities of inputs on yield and production (Oren and Ozturk 2006).

Considerable work has been carried out on the use of energy in protected cultivation with respect to efficient and economic use for sustainable production in different countries (Heidari and Omid 2011, Ozkan et al 2011 and Kuswardhani et al 2013). However, studies related to energy usage and relations in protected cultivation is meager in India. Hence, the present study was carried out to know the influence of automated sensor-based irrigation and fertigation on energy use patterns and econometric models of capsicum. In addition to these, the study had also aimed to calculate output-input ratio, energy productivity, and specific energy used in greenhouse capsicum production in India.

MATERIAL AND METHODS

Experimental site and treatment details: The greenhouse experiment was conducted for two seasons during 2020-21 at reduced runoff farming block, University of Agricultural Sciences, GKVK, Bengaluru**,** India situated in the Eastern Dry Zone of Karnataka at 12° 58' N latitude and 75° 35' E longitude at an altitude of 930 meter above mean sea level. The experiment was laid out in completely randomized block design with factorial concept (3×4) and replicated thrice during *summer* (February to June) and *kharif* (July to December) 2020-21. The experiment was carried out with two different factors *viz*., Automated Sensor based irrigation (I_1: 75 % available soil moisture (ASM), I_2: 50 % ASM, I_3: 25 % ASM) and Fertigation levels (F_1: 75 % recommended dose of fertilizers (RDF), F_2: 100 % RDF, F_3: 125 % RDF, F_4: 150 % RDF). Control was maintained with 100 % RDF (150: 112.5: 150 kg NPK ha^{-1} + 25 t FYM ha^{-1}) with surface irrigation in open field condition.

Cultural practices: Beds of 7m × 120cm × 15cm (L × W × H) with 45 cm inter bed space were prepared and basal fertilizer dose of 37.5:37.5:30 NPK and 25 t FYM ha^{-1} was applied uniformly. The beds were covered with silver coloured polythene mulch having 30-micron thickness and 1.20 m width. Seedlings of Hybrid Delisha were raised in portrays and transplanted to greenhouse after 30-35 days of sowing at recommended spacing (60 cm x 45 cm). The experiment was designed to harvest rain water from roof top. Six greenhouse having roof area of 200 m^2 each and storage tank having 3,00,000 liters capacity. During 2020, water harvested was 7,74,000 liters from a roof top of 1200 m^2 green house. The harvested water was used to irrigate capsicum that met 100 % water requirement of capsicum during both the seasons.

Scheduling of irrigation and fertigation: The double drip lateral line laid for each bed, and inline emitters with discharge rate of 2 l h^{-1} were spaced at 30 cm interval on the lateral drip. Irrigation was scheduled according to moisture regime of the treatment with automated sensor and fertigation system (Smart flow) based on volumetric soil moisture content. The VH400 moisture sensors were used during the study, which uses superior transmission line techniques (Time-Domain Reflectometry) as does to measure the moisture content of the soil. The threshold limit for each irrigation regimes were fixed and when the soil moisture content drops below the threshold limit, the sensors will transmit signal to control system to start irrigation until the soil moisture content reaches the desired limit (Field capacity at 27.5% volumetric basis and 18.5, 21.5 and 24.5 % threshold limit in 25, 50 and 75 % ASM, respectively). Water soluble fertilizers are given through fertigation with venturi-type applicators as per treatments (75, 100, 125 and 150 % of RDF) during the entire crop growth period, initiated from third week after transplanting. A total 16 fertigation schedules were given at weekly interval according to the calibrated schedule based on the crop demand.

Energy balance: The agricultural inputs *viz*., seeds, labour, fertilizers, organic manures, irrigation water, electricity, animals, machinery, *etc.* and every agricultural outputs like fruits, vegetables and stalk have their own equivalent energy (Mega Joules) values (Table 1). The energy balance sheet was calculated by talking input energy used in production and output energy produced. Further related parameters *viz.,* net energy, energy use efficiency, energy productivity and specific energy were calculated (Heidari and Omid 2011).

$$Net\ energy\ returns\ (MJ\ ha^{-1}) = Output\ energy - input\ energy$$

$$Energy\ use\ efficiency = \frac{Output\ energy\ (MJ\ ha^{-1})}{Input\ energy\ (MJ\ ha^{-1})}$$

$$Energy\ productivity\ (kg\ MJ^{-1}) = \frac{Grain\ yield\ (kg\ ha^{-1})}{Input\ energy(MJ\ ha^{-1})}$$

$$Specific\ energy\ (MJ\ kg^{-1}) = \frac{Input\ energy(MJ\ ha^{-1})}{Grain\ yield\ (kg\ ha^{-1})}$$

Production functions: Cobbe Douglass (CD) production function was used for assessing statistical significance and expected signs of parameters. The influence of direct, indirect, renewable and nonrenewable energies on production was modeled s (Mobtaker et al 2010).

$$Model\ I: lnY_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$$

$$Model\ II: lnY_i = \gamma_1 lnRE + \gamma_2 lnNRE + e_i$$

where Yi is the ith treatment yield, βi and γi are coefficient of exogenous variables. DE and IDE are direct and indirect energies, respectively, RE is renewable energy and NRE is non-renewable energy.

The concept of returns to scale (RTS) provides the input and output relationship when one or other is changed. It refers to change in efficiency of production system based on extent of change in inputs or outputs (Manzoni and Islam 2009). If doubling of fertilizers (inputs) results in doubling of output, then it is called as constant RTS or CRS. If increase in inputs results in increase in outputs greater proportion than input use, then it is called as increasing RTS or IRS. The production function is called as decreasing RTS or DRS, when proportionate increase in all inputs results in less than proportionate increment in output. In this paper RTS values were calculated for Model I and II by adding the elasticities, derived in the form of regression coefficients in the CD production function. The sum of regression coefficients more than, equal to, or less than unity, imply IRS, CRS, or DRS, respectively.

Economics: The variable cost inclusive of fertilizers and other inputs in the prevailing local markets of Karnataka (India) were considered for cost of cultivation per hectare. Gross returns from the economic produce of the capsicum was calculated by multiplying existing price with fruit yield and expressed on hectare basis (Rs. ha^{-1}). Net return (on hectare basis) was calculated by subtracting the total cost of cultivation from the gross returns (Rs. ha^{-1}). Benefit: cost ratio (B: C ratio) was calculated as the ratio of gross return to the cost of cultivation (Rana et al 2014).

RESULTS AND DISCUSSION

Analysis of input output energy use: Total energy requirements in producing capsicum under automated sensor based irrigation at 75 % ASM with 125 % RDF through fertigation during *summer* and *kharif* were 90965.3 MJ h^{-1} and 78451.1 MJ h^{-1}, respectively (Table 2). Among different energy sources plastic used highest input energy *i.e.,* 44.1 per cent during *summer* (40140 MJ h^{-1}). The plastic includes plastic threads used for staking the capsicum plants at regular intervals and plastic mulch used to cover the beds in the greenhouse. Due to higher share of plastic among energy inputs during *summer*, the plastic threads are reused during *kharif* to reduce the input energy of plastic. The, energy share of plastic reduced 32.4 per cent (25380 MJ h^{-1}). Hence, using the reusable plastic mulch and threads or jute threads are highly recommended to cut down the energy consumption as well as cost. After plastic, chemical fertilizers (14179.7 MJ h^{-1}) and plant protection chemicals (9239.4 MJ h^{-1}) recorded higher chemical energy in total energy consumption. Since high and frequent usage of pesticide for plant protection, the

Table 1. Energy equivalents of inputs and output in cultivation of capsicum crop

Energy source	Energy equivalent (MJ)	Units	Reference
Human (Head)			
Man	1.96	MJ hr^{-1}	(Shahan et al 2008)
Woman	1.57	MJ hr^{-1}	(Shahan et al 2008)
Chemical fertilizer (Kg)			
Nitrogen	60.6	MJ. kg^{-1}	(Shahan et al 2008)
Phosphorus	11.1	MJ. kg^{-1}	(Shahan et al 2008)
Potassium	6.7	MJ. kg^{-1}	(Shahan et al 2008)
Chemicals			
Pesticide (Kg)	199	MJ. kg^{-1}	(De et al 2001)
Pesticide (l)	196	MJ. ltr^{-1}	(Ortiz and Hernanz 1999)
Fungicide (l)	168	MJ. ltr^{-1}	(Djevic and Dimitrijevic 2009, Ozkan et al 2007)
Fungicide (Kg)	92	MJ. kg^{-1}	(Djevic and Dimitrijevic 2009)
Herbicide (l)	238	MJ. ltr^{-1}	(Djevic and Dimitrijevic 2009)
Machines (h)			
Power tiller	2.74	MJ hr^{-1}	(Alam et al 2005)
Knapsack sprayer	1.4	MJ hr^{-1}	(Gezer 2003)
Electricity (kwh)	11.93	MJ kWh^{-1}	(Shahan et al 2008)
Manure (Kg)	0.3	MJ. kg^{-1}	(Yaldiz et al 1993)
Diesel (l)	56.31	MJ. ltr^{-1}	(Heidari and Omid 2011, Shahan et al 2008)
Water irrigation (m^3)	0.63	MJ m^{-3}	(Heidari and Omid 2011, Ozkan et al 2007)
Out put			
Capsicum fruit	0.80	MJ. kg^{-1}	(Canakci and Akinci 2006, Naderi et al 2019)
Capsicum stalk	7.5	MJ. kg^{-1}	(Yelmen 2019)

chemical energy of capsicum had higher values among input energy. Apart from plastic and chemical energy, energy consumption through human labour in the both season was more than $^{1}/_{10}{}^{th}$ of total energy consumption (10983.8 MJ h^{-1} and 12856.0 MJ h^{-1}, respectively), which implies labour force is essential for capsicum cultivation.

Energy sources: The energy can be classified as Direct and Indirect as well as Renewable and Non-renewable energy resources (Ozkan et al 2007). The inputs used in production of capsicum according to the direct, indirect, renewable and non-renewable sources of energy (Table 3 and 4).

Direct energy and Indirect energy: The direct energy includes diesel and electricity, human and animal efforts. the indirect energy source includes plant protection chemicals, manure, fertilizer and machinery. About 42 to 45% of total energy input was in the form of indirect energy for tomato under glasshouse and more than 50% energy used was in form of direct energy for lettuce in greenhouse production (Kuswardhani et al 2013). Cultivation of capsicum in green house consumed only 18.3 % as Direct and 81.7 % as indirect energy during *summer* season and 24.1 and 75.9 % in *kharif* season. In open field conditions (Control) was 21.1 % and 78.9 % during summer season and 29.6 and 70.4 % during *kharif* season, respectively (Table 3).

Renewable and non-renewable energy inputs: The total inputs used in both greenhouse as well as open field condition are mostly dependent on nonrenewable energy (NRE) resources. In green house, the share of renewable energy (RE) resources was only 23.7 % during *summer* and 29.6 % during *kharif* reuse of plastic threads from *summer* season has enhanced share of renewable resources by 5.9 %, like wise reuse of nonrenewable resources like plastic threads, mulching paper and use of solar energy will enhance the share of renewable resources in green house (Table 4). Kuswardhani et al (2013) reported dependency on the nonrenewable form of energy up to 54 to 66% under greenhouse and 59 to 64% in open field vegetable production. Heidari and Omid (2011) observed that non-renewable energy is mostly constituted energy for tomato and cucumber, (94 and 90%, respectively) in greenhouse vegetable production. In open field cultivation has consumed comparatively less nonrenewable energy resources in both the seasons (67.8 and 59.0 %, respectively) might be attributed due to reduced usage of plastic threads and not using plastic mulch to cover the beds.

Econometric model estimation of cultivation of capsicum: The relationship between DE, IDE, RE and NRE and capsicum yield were estimated using CD production

Table 2. Energy use patterns for cultivation of capsicum with automated sensor based irrigation with fertigation and control

Input (Unit)	Summer season				*Kharif* season			
	Automated sensor-based irrigation and fertigation (I_1F_3)		Control		Automated sensor-based irrigation and fertigation (I_1F_3)		Control	
	(MJ h^{-1})	%	(MJ h^{-1})	%	(MJ h^{-1})	%	(MJ h^{-1})	%
Human labour	10983.8	12.1	8654.0	12.6	12856.0	16.4	10611.0	18.5
Diesel	4617.4	5.1	5011.6	7.3	4955.3	6.3	5574.7	9.7
Electricity	1034. 3	1.1	813.6	1.2	1075.1	1.4	851.8	1.5
Machinery	153.4	0.2	169.9	0.2	676.6	0.9	707.0	1.2
Seedling	720.0	0.8	720.0	1.1	720.0	0.9	720.0	1.3
Plastic	40140.0	44.1	17640.0	25.7	25380.0	32.4	5040.0	8.8
Manure	7500.0	8.2	7500.0	10.9	7500.0	9.6	7500.0	13.0
Fertilizers	14179.7	15.6	11343.8	16.5	14179.7	18.1	11343.8	19.7
Plant protection chemicals	9239.4	10.2	11486.5	16.8	8963.3	11.4	10412.9	18.1
Irrigation water	2397.2	2.6	5207.3	7.6	2145.2	2.7	4733.2	8.2
Total	90965.3	100	68546.7	100	78451.1	100	57494.3	100
Direct energy	16635.6	18.3	14479.2	21.1	18886.4	24.1	17037.5	29.6
Indirect energy	74329.7	81.7	54067.5	78.9	59564.7	75.9	40456.9	70.4
Renewable energy	21601.0	23.7	22081.3	32.2	23221.2	29.6	23564.2	41.0
Nonrenewable energy	69364.3	76.3	46465.3	67.8	55230.0	70.4	33930.2	59.0

I_1F_3: Automated Scheduling of irrigation at 75 % ASM coupled with application of 125 % RDF through fertigation function (Model I) and using ordinary least square (OLS) estimation technique was assessed. The yield of capsicum (endogenous variable) was assumed to be a function DE, IDE and RE and NRE (exogenous variables). Autocorrelation test was performed using Durbine Watson (DW) test (Hatirli et al 2005). The regression coefficients of DE and RE forms were positive and significant (Table 5). The regression coefficients of NRE for were also significant. Among all the regression coefficients, the coefficient of IDE for capsicum cultivation was non-significant (The impacts of DE was higher in both the seasons (6.55 and 8.99, respectively) compared to IDE (0.50 and 0.36), which shows that an additional use of 1% of direct energy input would lead to 6.55 % increase in capsicum yield during *summer* season and 8.99 % increase during *kharif* season. RE also showed higher impacts during both the seasons compared to NRE.

Table 3. Direct and Indirect energy sources of capsicum (MJ. ha^{-1}) as influenced by irrigation regimes and fertigation levels

Type of energy	Direct energy (MJ. ha^{-1})			Indirect energy (MJ. ha^{-1})		
Treatments	Summer	*kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	15781.5	18421.7	17101.6	68657.8	53932.8	61295.3
I_1F_2	15831.8	18471.9	17151.9	71493.8	56728.8	64111.3
I_1F_3	16635.6	18886.4	17761.0	74329.7	59564.7	66947.2
I_1F_4	16786.3	19099.9	17943.1	77165.7	62400.6	69783.2
I_2F_1	15706.2	17894.2	16800.2	68771.2	53955.8	61363.5
I_2F_2	15731.3	18296.1	17013.7	71607.2	56791.8	64199.5
I_2F_3	16221.1	18622.7	17421.9	74443.1	59627.7	67035.4
I_2F_4	16497.4	18899.0	17698.2	77279.1	62463.6	69871.4
I_3F_1	15530.3	17718.3	16624.3	68865.7	54091.3	61478.5
I_3F_2	15630.8	18032.3	16831.6	71701.7	56927.2	64314.5
I_3F_3	16083.0	18446.8	17264.9	74537.6	59763.2	67150.4
I_3F_4	16309.0	18672.9	17491.0	77373.6	62599.1	69986.4
Control	14479.2	17037.5	15758.4	54067.5	40456.9	47262.2

I: Automated Sensor based irrigation (I_1: 75 % Available Soil Moisture (ASM), I_2: 50 % ASM, I_3: 25 % ASM)

F: Fertigation levels (F_1: 75 % Recommended Dose of Fertilizers (RDF), F_2: 100 % RDF, F_3: 125 % RDF, F_4: 150 % RDF). Control was maintained with 100 % RDF (150: 112.5: 150 kg NPK ha^{-1} + 25 t FYM ha^{-1})

Table 4. Renewable and non-renewable energy sources of capsicum (MJ. ha^{-1}) as influenced by irrigation regimes and fertigation levels

Type of energy	Renewable energy (MJ. ha^{-1})			Non-renewable energy (MJ. ha^{-1})		
Treatments	Summer	*kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	20746.9	22796.4	21771.7	63692.4	49558.1	56625.3
I_1F_2	20797.2	22806.7	21802.0	66528.4	52394.0	59461.2
I_1F_3	21601.0	23221.2	22411.1	69364.3	55230.0	62297.2
I_1F_4	21751.7	23434.7	22593.2	72200.3	58065.9	65133.1
I_2F_1	20785.0	22291.9	21538.5	63692.4	49558.1	56625.3
I_2F_2	20810.1	22693.8	21752.0	66528.4	52394.0	59461.2
I_2F_3	21299.9	23020.4	22160.2	69364.3	55230.0	62297.2
I_2F_4	21576.2	23296.7	22436.5	72200.3	58065.9	65133.1
I_3F_1	20703.6	22251.5	21477.6	63692.4	49558.1	56625.3
I_3F_2	20804.1	22565.5	21684.8	66528.4	52394.0	59461.2
I_3F_3	21256.3	22980.0	22118.2	69364.3	55230.0	62297.2
I_3F_4	21482.3	23206.1	22344.2	72200.3	58065.9	65133.1
Control	22081.3	23564.2	22822.8	46465.3	33930.2	40197.8

See Table 3 for treatment details

As can be seen, increase in 1 % of RE sources enhance yield by 4.03 and 5.70 % compared NRE sources (2.56 and 2.12 %, respectively). The whole analysis suggests that. Direct and Renewable sources play key role in enhancing the output of capsicum cultivation rather than NRE and IDE. Hatirli et al (2006) also observed similar trend in greenhouse tomato production. Presented in capsicum fruit yield under greenhouse situation increased as a function of the energy inputs Figure 1. The coefficients of determination (R^2) between yield and total energy input was 0.91 in first and 0.89 in *kharif* season. It implies that the variation in total energy input sources had a major influence (91 % and 89 %) on the fruit yield of capsicum in both seasons.

Returns to scale results: The return to scale (RTS) values for Models I to II Eqs. were calculated by gathering the regression coefficients (Table 5). RTS values of Model I, for capsicum yield in both seasons were 7.06 % and 9.36 %, respectively. This shows that 1% increase in the total energy inputs utilize would lead in 7.06 % and 9.36 % increase in the capsicum yield for this model. Similarly, RTS values of Model II, for capsicum yield in both seasons were 6.59 % and 7.82 %, respectively. This shows that 1% increase in the total energy inputs utilize would lead to increase in capsicum yield by 6.59 % and 7.82 %, respectively for this model. In the study of (Mobtaker et al 2010) and (Heidari and Omid 2011) the sum of the regression coefficients (i.e. values for RTS in Table 5) of energy inputs was calculated more than unity.

Influence of automated sensor-based irrigation and fertigation on energy balance: Energy auditing is one of the most common method to examine energy efficiency and

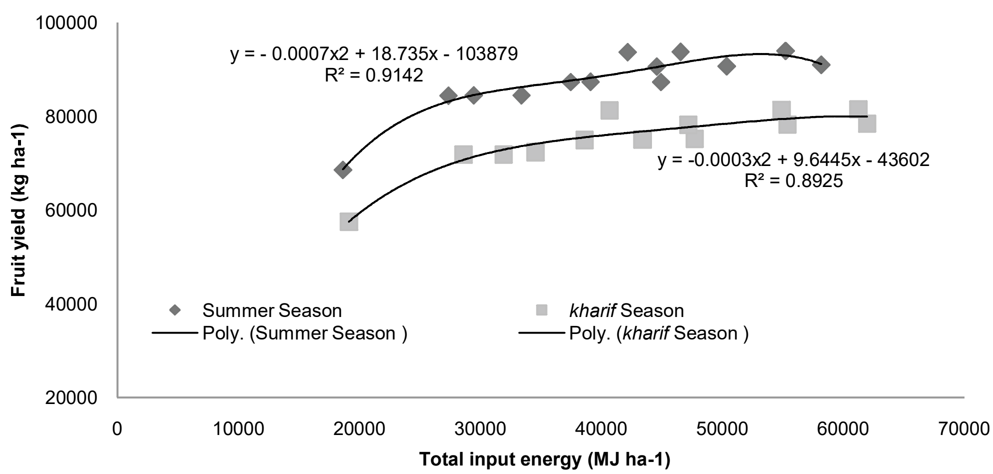

Fig. 1. Fruit yield versus total energy input for capsicum crop cultivation

Table 5. Econometric estimation of direct (DE) vs. indirect (IDE) based on Model I, and renewable (RE) vs. non-renewable (NRE) based on Model II

Endogenous variable	Summer		*Kharif*		Pooled	
Exogenous variables	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
DE (β_1)	6.55	2.53*	8.99	3.47**	8.645368	3.40**
IDE (β_2)	0.50	0.48	0.37	0.52	0.148117	0.18
Durbine Watson	2.11		1.94		2.47	
R^2	0.86		0.89		0.89	
RTS	7.06		9.36		8.79	
RE (γ_1)	4.03	2.14*	5.70	2.45*	4.985487	2.40*
NRE(γ_2)	2.56	7.20**	2.12	7.12**	2.365395	7.38**
Durbine Watson	1.46		1.51		1.49	
R^2	0.83		0.84		0.84	
RTS	6.59		7.82		7.35	

environmental impact of the production system. The influence of different irrigation regimes and fertigation levels on input energy, output energy, net energy, output to input ratio, energy productivity and specific energy was calculated (Table 6). The output energy of capsicum cultivation ranged from 139452 MJ ha^{-1} to 307015 MJ ha^{-1} during *summer* season and 144509 to 328803 MJ ha^{-1} during *kharif* season. Automated scheduling of irrigation at 75 % ASM coupled with the application of 150 % RDF through fertigation resulted in higher output energy (317909 MJ ha^{-1}) and net energy (238966 MJ ha^{-1}). It was followed by scheduling of irrigation at 75 % ASM coupled with the application of 125 % RDF through fertigation was also attributed due to higher fruit yield (60090 kg ha^{-1}) and stalk yield (35553 kg ha^{-1}). The energy consumed was less with control (59358 MJ ha^{-1}), since it will not include energy consumed for construction, maintenance, automation system and other practices in the greenhouse. Among different treatments in greenhouse application of 75 % RDF through fertigation with all irrigation regimes consumed less energy due to reduced energy consumption in fertilizers as compared to higher doses of fertilizers application. Energy use efficiency was higher with scheduling irrigation at 75 % ASM with 125 % RDF through fertigation in both seasons (3.32 and 4.18, respectively) and lower was recorded with control (2.03 and 3.20, respectively). Ghorbani et al (2011) reported an energy use efficiency of 1.44 for wheat, while Heidari and Omid (2011) found a value of 1.48 for tomatoes. The enhanced energy use

Table 6. Energetics of capsicum as influenced by irrigation regimes and fertigation levels

Treatments	Input energy (MJ ha^{-1}) (1)	Yield (kg ha^{-1}) (2)	Stalk yield (kg ha^{-1}) (3)	Output energy (MJ ha^{-1}) (4)= 2*0.8+3*7.5	Net energy 5= (4-1)	Energy use efficiency 6= (4/1)	Energy productivity (kg MJ^{-1}) 7= (2/1)	Specific energy (MJ kg^{-1}) 8= (1/2)
Summer season								
I_1F_1	84439	33408	26337	224252	139813	2.66	0.40	2.53
I_1F_2	87326	44934	29878	260030	172704	2.98	0.51	1.94
I_1F_3	90965	58199	34042	301874	210909	3.32	0.64	1.56
I_1F_4	93952	55248	35042	307015	213063	3.27	0.59	1.70
I_2F_1	84477	29451	24542	207625	123148	2.46	0.35	2.87
I_2F_2	87338	39108	27494	237494	150155	2.72	0.45	2.23
I_2F_3	90664	50383	30432	268546	177882	2.96	0.56	1.80
I_2F_4	93776	46550	30904	269020	175243	2.87	0.50	2.01
I_3F_1	84396	27381	21619	184045	99649	2.18	0.32	3.08
I_3F_2	87332	37479	24987	217385	130052	2.49	0.43	2.33
I_3F_3	90621	44600	27376	240998	150378	2.66	0.49	2.03
I_3F_4	93683	42184	26151	229879	136196	2.45	0.45	2.22
Control	68547	18651	16604	139452	70905	2.03	0.27	3.68
Kharif season								
I_1F_1	72355	34562	30034	252901	180546	3.50	0.48	2.09
I_1F_2	75201	47721	33232	287414	212214	3.82	0.63	1.58
I_1F_3	78451	61980	37063	327557	249106	4.18	0.79	1.27
I_1F_4	81501	61257	37306	328803	247302	4.03	0.75	1.33
I_2F_1	71850	31927	27584	232420	160570	3.23	0.44	2.25
I_2F_2	75088	43405	30977	267052	191964	3.56	0.58	1.73
I_2F_3	78250	55392	33866	298306	220056	3.81	0.71	1.41
I_2F_4	81363	54893	34654	303816	222454	3.73	0.67	1.48
I_3F_1	71810	28603	25342	212946	141137	2.97	0.40	2.51
I_3F_2	74960	38624	27943	240471	165512	3.21	0.52	1.94
I_3F_3	78210	47191	30180	264103	185893	3.38	0.60	1.66
I_3F_4	81272	40685	27776	240872	159600	2.96	0.50	2.00
Control	57494	19143	17226	144509	99361	3.20	0.42	2.36

See Table 3 for treatment details

efficiency was primarily attributed to the increased output energy resulting from a higher capsicum yield. Energy productivity scheduling of irrigation at 75 % ASM with the application of 125 % RDF through fertigation produced 0.64 and 0.79 kg fruits by consuming 1 MJ energy whereas control took the same energy to produce only 0.27 and 0.42 kg of capsicum fruits in both seasons. The higher yield per unit energy was mainly attributed by higher absolute growth rate, crop growth rate, net assimilation rate and relative crop growth throughout the crop growth stage which might have resulted in rapid dry matter production and partitioning into reproductive parts. The specific energy required to produce 1 kg of fruit was also lesser (1.56 and 1.27 MJ kg^{-1}) with 75 % ASM coupled with 125 % RDF through fertigation. The higher specific energy was required in control (3.68 and 2.36 MJ kg^{-1}) in both seasons.

In total, energy auditing showed that, irrigation at 75 % ASM and application of 125 % RDF through fertigation was more energy efficient compared to other combinations and also with open field conditions (control). Similar results were reported by Hatirli et al (2005) in tomato; Heidari and Omid (2011) in cucumber and tomato; Kuswardhani et al (2013) in tomato, lettuce and chili and Naderi et al (2019) in bell pepper.

Influence of automated sensor based irrigation on yield of capsicum: Scheduling of irrigation at 75 % ASM coupled with application of 125 % RDF through fertigation resulted in significantly higher capsicum fruit yield during both seasons compared to control (open field condition). Irrigation at 75 % ASM with 125 % RDF registered 217 per cent higher yield compared to control (Table 6). Application of 125 % RDF through fertigation coupled with optimum moisture distribution around root zone resulted in uniform distribution of required quantity of nutrients in the rhizosphere throughout the crop growth period. This further enhanced the physiological processes and efficient translocation of photosynthates towards reproductive organs might resulted in higher fruit yield in capsicum. Split application of fertilizers through fertigation in solanaceous vegetables enhanced nutrient use efficiency, crop productivity and higher availability of N, P and K nutrient in the root zone of drip fertigated plot. Biwalkar et al (2015) also reported similar results with application of 120 per cent targeted dose of fertilizer with scheduling of irrigation at 100 per cent replenishment of $ET_{c.}$

Economics: The total cost of cultivation in capsicum and gross return was calculated treatment wise. The recurring and non-recurring cost incurred in the production were calculated separately. The total expenditure of capsicum cultivation ranged from Rs. 592204 to Rs. 1325376. Scheduling irrigation at 75 % ASM with the application of 125 % RDF through fertigation resulted in higher gross return (Rs. 2618946 and 2789090 ha^{-1}, respectively) and net return (Rs. 1315949 and Rs. 1481512 ha^{-1}, respectively) in both seasons (Table 7). The higher net return was mainly attributed to higher fruit yield during both the seasons. The lower gross and net returns were recorded with scheduling irrigation at 25 % ASM with the application of 75 % RDF through fertigation might be attributed to lower fruit yield in both seasons (28381 and 28603 kg ha^{-1}, respectively). The lower cost of cultivation with control (Rs. 594581 ha^{-1}) was due to growing of capsicum in open field condition, which eliminated the cost of

Table 7. Economics of capsicum as influenced by irrigation regimes and fertigation levels

Treatments	Cost of cultivation (Rs. ha^{-1})			Gross returns (Rs. ha^{-1})			Net returns (Rs. ha^{-1})			B:C ratio		
	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	1258069	1262650	1260359	1503366	1555280	1529323	245297	292631	268964	1.19	1.23	1.21
I_1F_2	1280533	1285114	1282823	2022020	2147424	2084722	741487	862310	801898	1.58	1.67	1.63
I_1F_3	1302997	1307578	1305288	2618946	2789090	2704018	1315949	1481512	1398731	2.01	2.13	2.07
I_1F_4	1320795	1325376	1323085	2486161	2756576	2621368	1165366	1431200	1298283	1.88	2.08	1.98
I_2F_1	1258069	1262650	1260359	1325313	1436712	1381012	67244	174062	120653	1.05	1.14	1.10
I_2F_2	1280533	1285114	1282823	1759873	1953245	1856559	479340	668131	573735	1.37	1.52	1.45
I_2F_3	1302997	1307578	1305288	2267232	2492638	2379935	964235	1185059	1074647	1.74	1.91	1.82
I_2F_4	1320795	1325376	1323085	2094763	2470179	2282471	773969	1144803	959386	1.59	1.86	1.73
I_3F_1	1258069	1262650	1260359	1277138	1287138	1282138	19070	24489	21779	1.02	1.02	1.02
I_3F_2	1280533	1285114	1282823	1686545	1738081	1712313	406012	452967	429489	1.32	1.35	1.33
I_3F_3	1302997	1307578	1305288	2007004	2123601	2065302	704006	816023	760015	1.54	1.62	1.58
I_3F_4	1320795	1325376	1323085	1898286	1830819	1864552	577491	505443	541467	1.44	1.38	1.41
Control	596957	592204	594581	839286	861429	850357	242329	269224	255777	1.41	1.45	1.43

See Table 3 for treatment details

greenhouse construction, automated sensor based irrigation set up and drip layout. Higher cost of cultivation was recorded with scheduling irrigation at 25, 50 and 75 % ASM with 150 % RDF through fertigation was mainly due to higher cost incurring on fertilizers. The results are in line with earlier workers Choudhary and Bhambri (2014), Rekha et al (2017) and Sanjeev Kumar et al (2018). The benefit cost ratio was calculated and Scheduling irrigation at 75 % ASM with the application of 125 % RDF through fertigation recorded higher values in both seasons (2.01 and 2.13, respectively). Similar findings have been documented by other researchers, including 0.86 for cotton (Manzoni and Islam 2009), 1.74 for strawberries (Banaeian et al 2011) and 2.09 for canola (Unakitan et al 2010).

CONCLUSIONS

Among the different energy inputs plastic, chemical and fertilizers had higher energy utilization with notable reduction in *kharif* season. Direct and Non-renewable resources were the main source of energy in cultivation of capsicum. Renewable energy sources ranged from 23.7 to 29.6 per cent in green house cultivation and 32.2 to 41.0 in open cultivation. The use of renewable resources of energy like solar energy, roof water harvesting and reuse of inputs should be practiced to improve energy use efficiency. Automated sensor based irrigation at 75 % ASM with 125 % RDF through fertigation maintained higher productivity, higher energy output and higher profitability. Total energy input in greenhouse cultivation of capsicum was higher than the open field, which was mainly due increased use of fertilizers, plant protection chemicals and mulch paper. Whereas, output energy and energy productivity were higher with greenhouse cultivation. Even greenhouse cultivation found financially productive and energy efficient than open field.

AUTHORS CONTRIBUTION

Santosh Nagappa Ningoji: Conceptualization, Methodology, Data curation, Investigation, Project administration, Formal analysis, Writing. M. N. Thimmegowda: Conceptualization, Data curation, Project administration, Editing. Mudalagiriyappa: Conceptualization, Data curation, Project administration. B.G. Vasanthi: Project administration, Editing. Tulja Sanam: Data curation, Writing, Editing. H.S. Shivaramu: Project administration.

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Delineation of Groundwater Potential Zones in Low-hills of Himachal Pradesh using Remote Sensing and GIS

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Abstract: Over-exploitation of groundwater for industrial and developmental activities over the years has imposed immense pressure on groundwater resources in low-hills of Himachal Pradesh. For this reason, delineating the groundwater potential zone is highly essential for meeting future demands. Therefore, the current study utilizes remote sensing (RS) and Geographic Information System (GIS) by using weighted overlay method to prepare a groundwater potential zone map of two districts lying in low-hills of Himachal Pradesh. A total of 8 thematic layers viz. slope, geology, aspect, soil, land use land classification, drainage density, and lineament were integrated and weightage values were assigned to each of these factors. The groundwater potential zones thus obtained were divided into five categories: very high, high, moderate, low and poor. In Sirmaur district, very high zone comprises 3.76% of the area, high zone covers 3.05%, 3.83% of the region comes under moderate zone, low zone covers 15.27% of the area and 74.62% of the area was under poor zone. In Una district very high zone covers 1.24% of the area, 1.80% falls under high zone, moderate zone comprises 15.61% of the area, low zone covers 63.83% while poor zone comprises of 17.52%. The results of the current investigation may be useful for future groundwater potential zones plans and for evaluating groundwater potential zones in similar low-hill regions.

Keywords: Groundwater, Remote sensing, GIS, Groundwater potential zones

Groundwater is necessary to sustain various forms of life and is one of the important water sources for agriculture, industry, and domestic use worldwide (Singh et al 2019). Occurrence, distribution and movement of groundwater are highly influenced by terrain features such as geology, lithology, tectonic framework and geomorphology of the area (Srivastava 2002). Knowledge about the status of groundwater is as important as to its quantity, as it helps in determining the suitability of water for various purposes. The groundwater quality variation in any area is a function of physicochemical quality parameters which is greatly influenced by its geological formations and anthropogenic activities of the area (Subramani et al 2005). Groundwater potential mapping (GPM) can be defined as a tool for the systematic development and planning of water resources (D´ıaz-Alcaide and Mart´ınezSantos 2019). It can classify the areas of a given watershed or a region based on the possibility of groundwater occurrence (Jha et al 2010). Groundwater occurrences in a region depend on the characteristics of rocks, soils, and geological structures (Maniar et al 2019).

Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish the base line information for groundwater potential zones (Chowdhury et al 2010). Thus, since the past few decades, geospatial techniques have become a useful tool for groundwater mapping (Murthy 2000). Remote sensing (RS) and geographical information system (GIS) have benefited from joining together primary and numeral data-set (Shailaja et al 2019). Remote sensing has played a vital role to map and analysis at synoptic scales (Chen et al 2019). A combination of geospatial technologies datasets was processed in the RS and GIS software and used to delineate and interpret the suitable groundwater areas (Mahato et al 2018). Keeping in view all these, an attempt was made to delineate the groundwater potential zones in low-hills of Himachal Pradesh.

MATERIAL AND METHODS

Study area: The present study is conducted in industrial areas of districts Sirmaur and Una lying in the low hills of Himachal Pradesh, India. Kala-Amb industrial area in Sirmaur district and Mehatpur industrial areas in Una district has seen a significant increase in the number of industries in the area since 1980 when a large number of industries were. A total of 15 sampling wells were taken in each district to validate the remotely sensed data (Table 1, Fig. 1). The climate of the Sirmaur district is sub-tropical to temperate depending upon the elevation. The average annual rainfall in the district is about 1405 mm, out of which 90% occurs during the monsoon season. The mean maximum and minimum temperatures of 30°C and-0°C respectively experienced in the district. Sirmaur district presents an intricate mosaic of high mountain ranges, hills and valleys with altitudes ranging from 300 to 3000 m above mean sea level (amsl). The soil in the district varies from thin and bare soil of high mountains to rich deep alluvial soil of the valleys. The climate of the Una district is tropical to temperate in nature, as the terrain varies from plains to high hills. Temperature varies from a minimum of 4°C in winter to a maximum of 46°C in summer. The area receives rainfall during the monsoon period, extending from June to September, and also during the non-monsoon period. The annual average rainfall in the area is about 1040 mm, with about 55 average rainy days. The winter season starts in November and continues till the middle of March.

Hydrogeology: Hydro-geologically, the unconsolidated and semi-consolidated/ consolidated rock formations form aquifers in Sirmaur district. Intergranular pore spaces in the sedimentary formations and secondary fissured porosity in hard rocks, topographical set up coupled with precipitation in

Table 1. Sampling wells along with depth to water level

Sampling wells	Source	Latitude	Longitude	Elevation (m amsl)	Depth to water level (mbgl)
District Sirmaur					
1	Borewell	30º30'39"N	77º13'08"E	353	22
2	Borewell	30º30'35"N	77º12'57"E	351	5
3	Borewell	30º30'26"N	77º13'05"E	359	16
4	Borewell	30º31'31"N	77º12'10"E	352	13
5	Borewell	30º31'13"N	77º12'04"E	353	8
6	Borewell	30º31'01"N	77º12'03"E	350	14
7	Handpump	30º31'25"N	77º11'55"E	342	17
8	Handpump	30º30'32"N	77º12'20"E	339	11
9	Borewell	30º30'30"N	77º12'55"E	338	6
10	Borewell	30º30'09"N	77º12"34"E	376	12
11	Handpump	30º31'08"N	77º13"43"E	380	15
12	Handpump	30º29'52"N	77º12'41"E	385	13
13	Borewell	30º31'05"N	77º12'32"E	346	7
14	Borewell	30º30'37"N	77º12'38"E	358	16
15	Handpump	30º30'39"N	77º12'40"E	351	11
District Una					
1	Borewell	31º24'33"N	76º20'52"E	400	16
2	Borewell	31º24'47"N	76º20'47"E	381	13
3	Borewell	31º24'40"N	76º20'49"E	377	15
4	Borewell	31º24'37"N	76º20'53"E	382	14
5	Borewell	31º24'41"N	76º20'56"E	386	13
6	Borewell	31º24'35"N	76º20'49"E	390	9
7	Borewell	31º24'28"N	76º20'33"E	398	8
8	Borewell	31º24'46"N	76º20'25"E	391	10
9	Borewell	31º25'15"N	76º20'12"E	383	16
10	Handpump	31º25'10"N	76º21'05"E	388	15
11	Handpump	31º25'29"N	76º20'09"E	398	12
12	Borewell	31º25'09"N	76º20'43"E	410	13
13	Borewell	31º24'22"N	76º20'08"E	393	11
14	Borewell	31º24'18"N	76º20'09"E	386	7
15	Borewell	31º24'22"N	76º20'17"E	384	9

the form of rain and snow, mainly govern occurrence and movement of ground water. Porous alluvial formation occurring in the valley area forms the most prolific aquifer system where as the sedimentary semi-consolidated formations and hard rocks form aquifer of low yield prospect. Major parts of the district are hilly & mountainous with highly dissected and undulating terrain. These areas are underlain by semi-consolidated and consolidated hard rocks of tertiary and pre- tertiary period. Ground water potential in such areas is very low due to its hydro-geomorphic set up. Springs are the main ground water structures that provide water supply for domestic and irrigation in major rural and urban areas. The springs, locally called C*hasma,* have discharges varying from seepages to 15 liters per second. *Bowries*, a type dug well, are another structure constructed in the hill slopes to tap the seepages. Such *Bowries* are common and observed all southern part of the district. In the last more than a decade, state government have drilled shallow bore wells fitted with hand-pumps to provide domestic water. These hand pumps have depth up to average 50-60m and have low discharges up to 1 lps. Ground water occurs both under phreatic and confined conditions. Wells and tube wells are the main ground water abstraction structures. Ground water is being developed in the area by medium to deep tube wells, dug

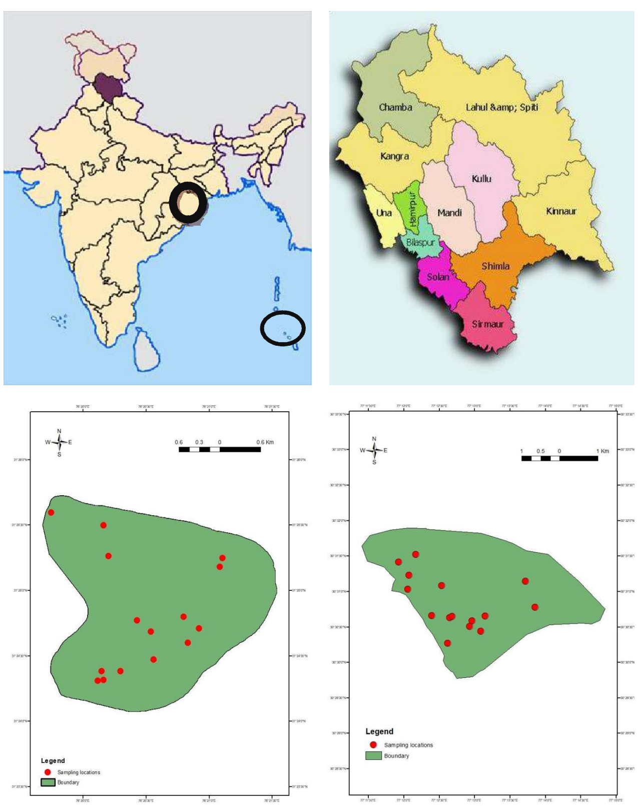

Fig. 1. Location map of study area along with sampling well locations

wells, dug cum bored wells. Depth to water level shows wide variation from near surface to more than 35 m bgl. Yield of shallow aquifer is moderate with well discharges up to 10 lps.

In Una district hydro-geologically, the unconsolidated valley fill or alluvial formations, occurring in the valley area and semi-consolidated sediments belonging to Siwalik Group form aquifer system. Porous alluvial formation, forms the most prolific aquifer system in the valley area, where as the sedimentary semi-consolidated formation form aquifer of low yield prospect. The ground water in the Siwalik group of rocks occur under the unconfined to semi confined conditions, mainly in the arenaceous rocks viz., sandstone, siltstone, gravel boulder beds etc. Siwalik sediments underlie hilly/undulating areas, where springs (mostly gravity/contact type) and *bowries* are the main ground water structures apart from hand pumps. The discharges of the springs, varies from seepages to 0.50 lps. In the low lying areas underlain by Siwalik rocks, dug wells and hand pumps are the main ground water structures that range in depth from 3.00 to 25.00 m bgl, where in depth to water level ranges from 2.50 to 15.00 m bgl. In upland/plateau areas, the water level is generally deep. In B*eet* area water level is more than 60 m below land surface has been observed. In Una valley area, the ground water occurs in porous unconsolidated / alluvial formation (valley fills) comprising sand, silt, gravel, cobbles / pebbles etc., and forms prolific aquifer.

Methodology: Geospatial techniques were applied in this study to delineate the groundwater potential zones of the study area. ArcGIS 10.8 have been used for creating various digital maps, compiling geographic data, analysing mapped information, sharing and managing geographic information database. The base map was created from SOI toposheets 53F and 53E for Sirmaur district and 53A and 53M for Una district at the scale of 1:50,000. For Georeferencing, the GCS WGS 1984 projection coordinate system was used. The objects were then stored as thematic maps for further delineation of groundwater potential zones.

Creation of digital maps: Various digital maps such slope, geology, aspect, soil, land use/land cover (LULC), drainage and lineament were created by vectorizing the geodatabase in ArcGIS 10.8. The geology and soil maps were collected and digitized from Geological Survey of India and National Bureau of Soil Survey, respectively. The IRS LISS-III geo-coded false color composite data was used for the preparation of LULC. Drainage density and lineaments map were digitized from DEM by using ArcGIS 10.8 Hydrology tools and Spatial Analyst Tool-Hill shade respectively. The slope and aspect maps were generated from DEM (Digital elevation model) with the help of ArcGIS 10.8 Spatial Analyst Tool-Slope and Aspect respectively.

Ranking of thematic maps and assigning weight: The groundwater potential zones for the study were obtained by overlaying all the thematic maps viz., slope, geology, aspect, soil, land use land classification, drainage density, and lineament density using weighted overlay method in the spatial analysis tool of ArcGIS 10.8. During this weighted overlay analysis, ranks have been assigned for each individual thematic maps and weight was assigned according to the influence of individual maps. The ranks and weights have been assigned considering previous works executed by researchers (Saraf and Chowdhary 1998, Waikar and Nilawwar 2014). Table 2 indicated the assigned individual ranks and weights for the various factors in consideration.

Groundwater Potential Zone map: After the digitization of various thematic maps such as geology, soil, land use/land cover (LULC), drainage density, lineament, aspect and slope, the groundwater potential zone map was prepared by integrating these thematic maps and classified into various potential zones (Fig. 2).

Validation: In order to validate the results obtained from analysis through GIS and RS, a field survey was conducted in both the districts during the period 2020-2022 and 15 observation wells (handpump/borewells) were taken in each of the districts along with their GPS locations. Generally, the groundwater potential map is validated with well yield data (Kumar and Krishna 2018), but in this case, the well yield data is not available, so the validation is done by using water depth data. Based on the water depth, the sampling wells have been divided into five categories viz. 3-5 m, 6-9 m, 10-12 m, 13-15 m, and >15m which were referred to as very low, low, medium, high, and very high (Table 6). Lower water depth indicates a high chance of it being in a potential zone (Raju et al 2019). An accuracy assessment was also carried out in order to know the relationship between the groundwater potential zones and the observed well data by superimposing the sampling wells with the potential zone map. The overall accuracy was obtained by using the formula given by Jensen (1996).

$$\text{Overall accuracy \%} = \frac{\text{No. of Correct observation wells}}{\text{Total no. of observation wells}} \times 100$$

Table 2. Classification of weighted factors for delineating groundwater potential zones

Parameter	Classes	Groundwater prospect	Weight (%)	Rank
Slope classes	Very gentle	Very good	15	5
	Gentle	Good		5
	Moderate	Moderate		4
	Moderately steep	Poor		3
	Steep	Poor		2
	Very steep	Very poor		1
Geology	Quarternary	Good	10	4
	Lower Shivalik	Moderate		3
	Upper Siwalik	Moderate		3
Aspect	Flat	Moderate	10	3
	North	Poor		2
	Northeast	Poor		2
	East	Moderate		3
	Southeast	Good		4
	South	Very good		5
	Southwest	Good		3
	West	Moderate		2
	Northwest	Poor		
Soil	Sandy loam	Good	10	4
	Sandy clay loam	Good		4
	Loamy clay	Moderate		3
	Clay loam	Moderate		3
Land use/land cover	Forest	Very good	20	5
	Agriculture land	Very good		5
	Water body	Good		4
	Shrubs	Moderate		3
	Building	Poor		2
	Open/waste land	Very poor		1
Drainage density (km/km^2)	0-1.2	Very good	20	5
	1.2-2.4	Good		4
	2.4-3.6	Moderate		3
	3.6-4.8	Poor		2
	4.8-6	Very poor		1
Lineament (km)	Major	Very good	15	5
	Minor	Good		4

Kappa (K) analysis represents a multivariate approach for accuracy assessment and it provides a Khat statistic which means a measure of accuracy (Usman et al 2015). It is calculated as:

$$\text{Kappa coefficient} = \frac{\text{Total accuracy} - \text{random accuracy}}{1 - \text{random accuracy}}$$

Kappa coefficient value lies from 0 to 1 where a value of 1 means perfect agreement whereas a value close to 0 means that the agreement is no better than would be expected by chance.

RESULTS AND DISCUSSION

Slope: Slope is one of the important terrain parameters for identifying groundwater potential zones. Higher degree of slope leads to rapid runoff and erosion rate increases with feeble recharge potential (Magesh et al 2012). Larger slope produces smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall

Table 3. Rating criteria of Kappa statistics

Kappa statistics	Strength of agreement
<0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

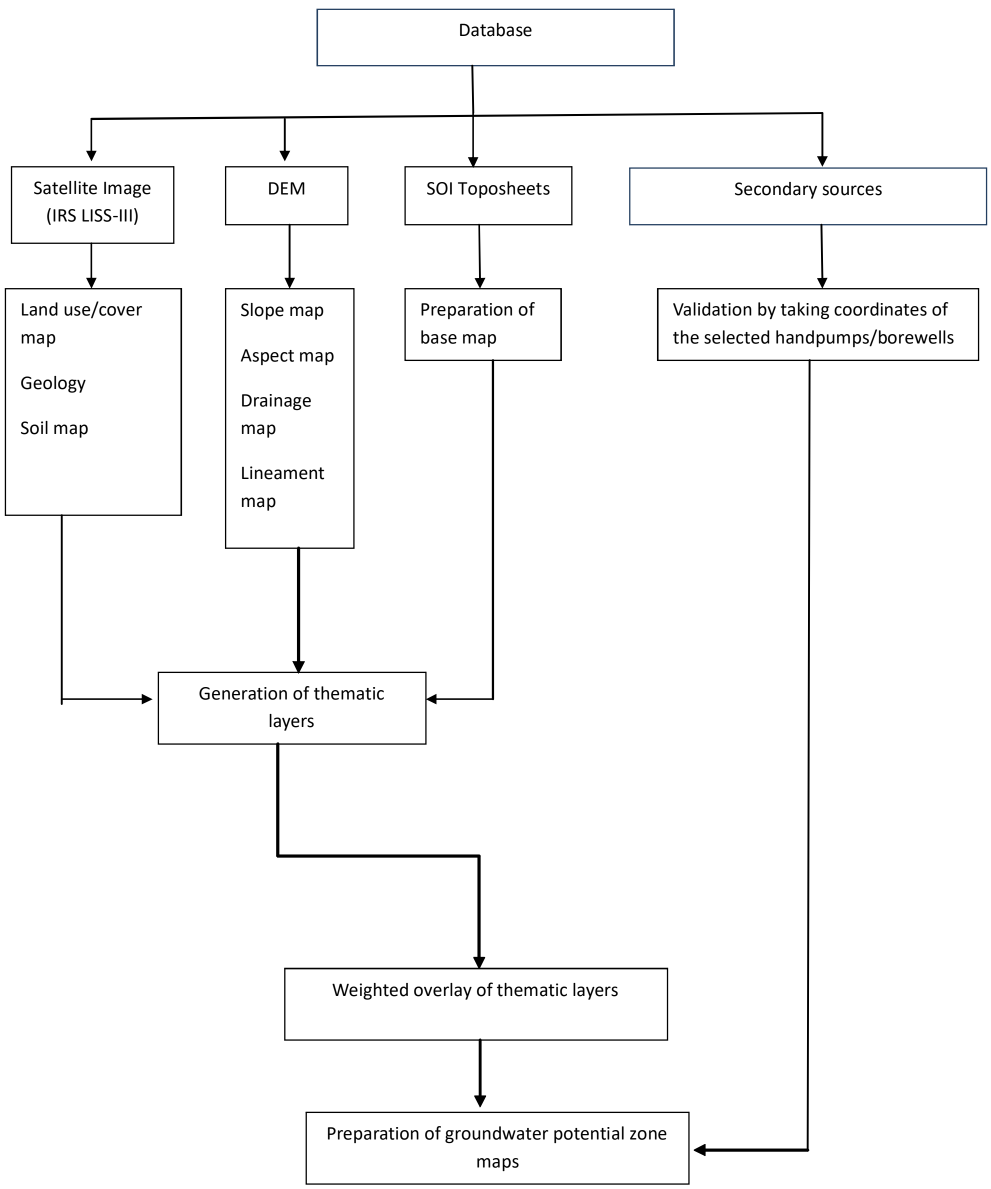

Fig. 2. Flow chart showing methodology of the work

(DeReu et al 2013). Based on the slope, the study area was divided into 6 classes (Table 4). The slope map of both the districts cover 0.30 km^2 (2.55%) (Figs. 3 and 4) These steep slopes may cause relatively high runoff and low infiltration, if there is absence of vegetation. But, in the study area, forest and shrubs were found in these steep slopes which may slow down the runoff rate. Moderately steep slopes cover an area of 0.51 km^2 (4.40%) while moderate slopes cover 0.99 km^2 (8.49%). Majority of the area came under gentle slope with an area of 7.09 km^2 (60.61%). In District Sirmaur out of the 11.7 km^2 study area, very steep slopes cover an area of only 0.18 km^2 (1.51%) while steep slopes cover 0.30 km^2 (2.55%). These steep slopes may cause relatively high runoff and low infiltration, if there is absence of vegetation. But, in the study area, forest. In District Sirmaur out of the 11.7 km^2 study area, very steep slopes cover an area of only 0.18 km^2 (1.51%) while steep slopes shrubs were found in these steep slopes which may slow down the runoff rate. Moderately steep slopes cover an area of 0.51 km^2 (4.40%) while moderate slopes cover 0.99 km^2(8.49%).

Majority of the area came under gentle slope with an area of 7.09 km^2 (60.61%) to very gentle slopes which cover an area of 2.63 km^2(22.44%) These gentle to very gentle slopes can be considered good for groundwater storage with high infiltration rate. In District Una, the slope varies from very gentle to moderate. This indicated that the surface runoff is slow allowing more time for rainwater to percolate. Very gentle slopes cover most of the region (74.05%) with an area of 4.60 km^2 followed by gentle slopes with a cover of 1.55 km^2 (24.97%). Moderate slopes were found in minute patches covering about 0.06 km^2 (0.98%).

Geology: geology map of the study region was digitized from a published geological map obtained from the Geological Survey of India and presented in Figures 5 and 6 for District Sirmaur and Una respectively. Based on processing and interpretation of the remotely sensed data, the study area in

Table 4. Slope category

Slope category	Slope (%)
Very gentle	0-1.5
Gentle	1.5-4
Moderate	4-8
Moderately steep	8-13
Steep	13-19
Very steep	19-34

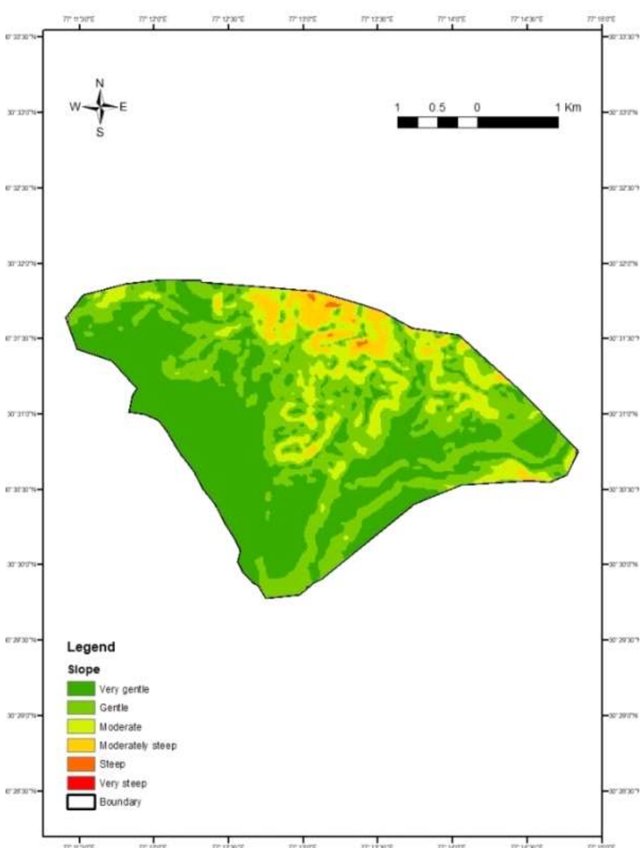

Fig. 3. Slope map of District Sirmaur

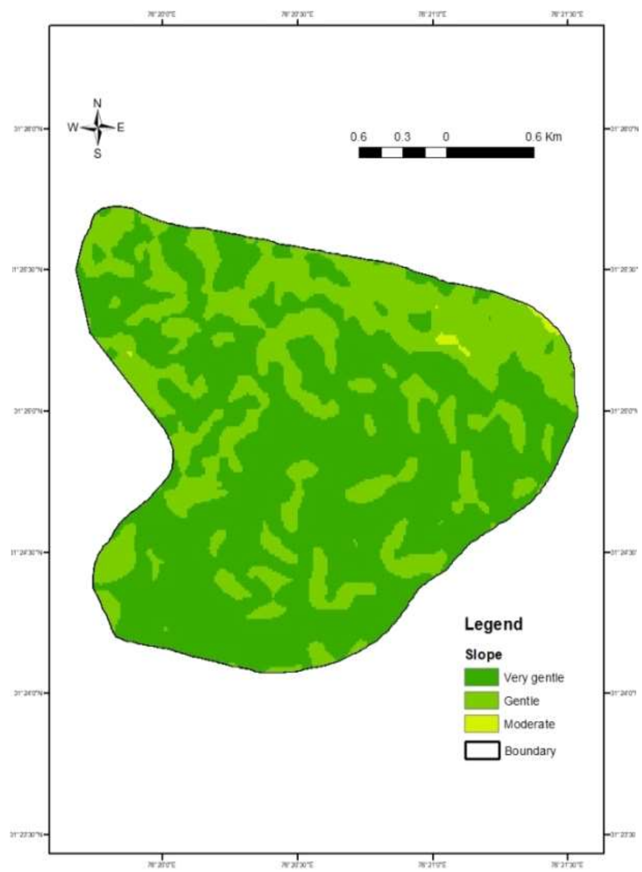

Fig. 4. Slope map of District Una

District Sirmaur consisted of three different rock units. On the north and north-eastern parts, upper Siwalik deposits are found which comprise of boulder deposits and rocks. The lower Siwalik which consisted of fine to medium grained sandstones occupies rest of the study area. The quaternary deposits comprising of porous alluvial formations are considered to have excellent groundwater recharge conditions and were found near the river beds. In District Una, the whole study area comprise of quaternary rocks with alluvium, fluvial and terrace formations containing sand, silt, clay, gravel and pebbles.

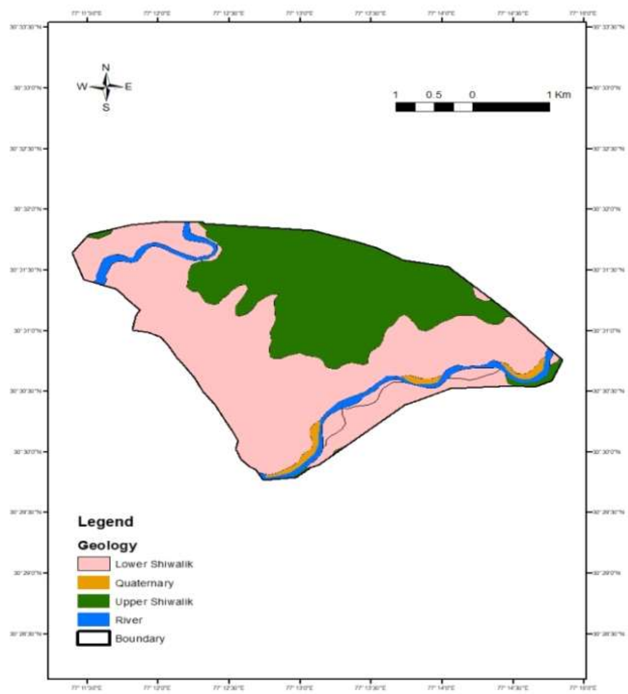

Fig. 5. Geology map of district Sirmaur

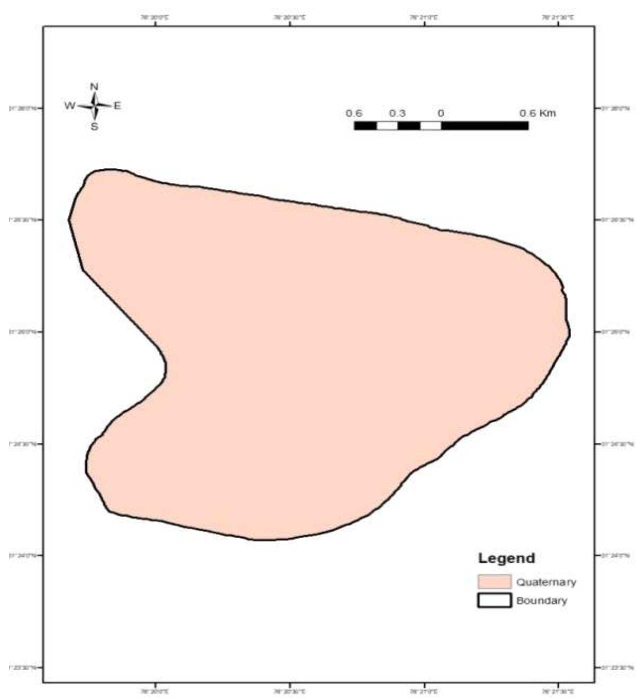

Fig. 6. Geology map of district Una

Aspect: Aspect was used as an important explanatory variable for generating groundwater potential maps because this variable is correlated with evapotranspiration and describes the direction of water flow that influences groundwater recharge and storage (Singh et al 2019). The aspect map is given in Figures 7 and 8 while areas under various aspects in the study area have been presented in Table 5. It is evident that in both the districts, majority of the areas fall under southerly aspects which can be considered good for groundwater recharge.

Soil: Soil properties i.e. soil type, soil texture, etc. show to have a main role in the spatial variation of groundwater recharge (Mehra et al 2016). Soil texture can be described in the ratio of sand, silt, and clay applying texture triangles which determine soil infiltration and water holding capacity. Groundwater recharge depends on runoff, water holding capacity, soil thickness, soil porosity, etc. (Zomlota et al 2015). Figure 9 and 10 depicts the soil map of the study areas. In District Sirmaur, the study area is mainly covered by clay loam soils (6.87 km^2) followed by loamy clay (4.54 km^2) while sandy loam was only found in minute patches (0.29 km^2). The sandy loam soils have excellent percolation capacity because of high sand proportion (Saravanan 2021); hence, it is assigned with a high rank. In District Una, 41.64% of the area was covered by sandy loam soils while sandy clay loam soils cover 39.84 % stretching towards the northern parts of the area. Clay loam soil cover 18.52% of the area and is found in the central to south-eastern parts.

Land use/Land cover (LULC): LULC gives the essential information on infiltration, soil moisture, groundwater,

Table 5. Areas under various aspects

Aspect	District Sirmaur		District Una	
	Area (Km^2)	%	Area (Km^2)	%
Flat	0.02	0.17	0.01	0.16
North	0.56	4.79	0.28	4.51
North-east	0.33	2.82	0.17	2.74
East	0.51	4.36	0.41	6.60
South-east	1.17	10.00	0.52	8.37
South	2.78	23.76	1.75	28.18
South-west	2.71	23.16	1.14	18.36
West	2.56	21.88	0.61	9.82
North-west	1.06	9.06	1.32	21.26

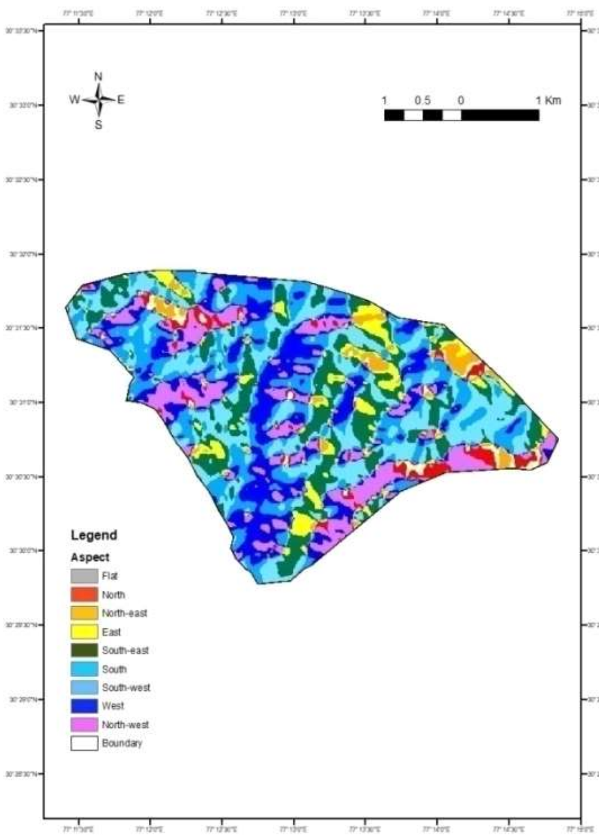

Fig. 7. Aspect map of district Una

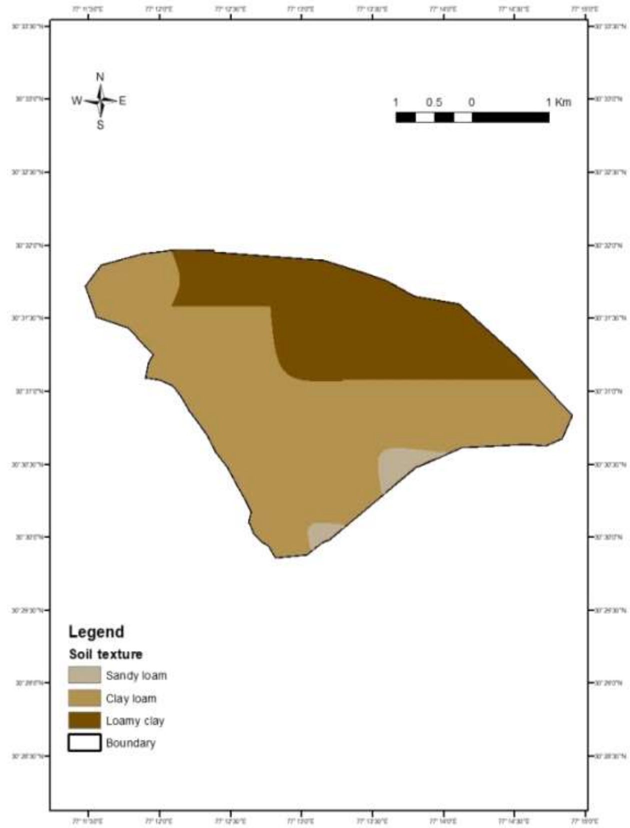

Fig. 9. Soil map of district Sirmaur

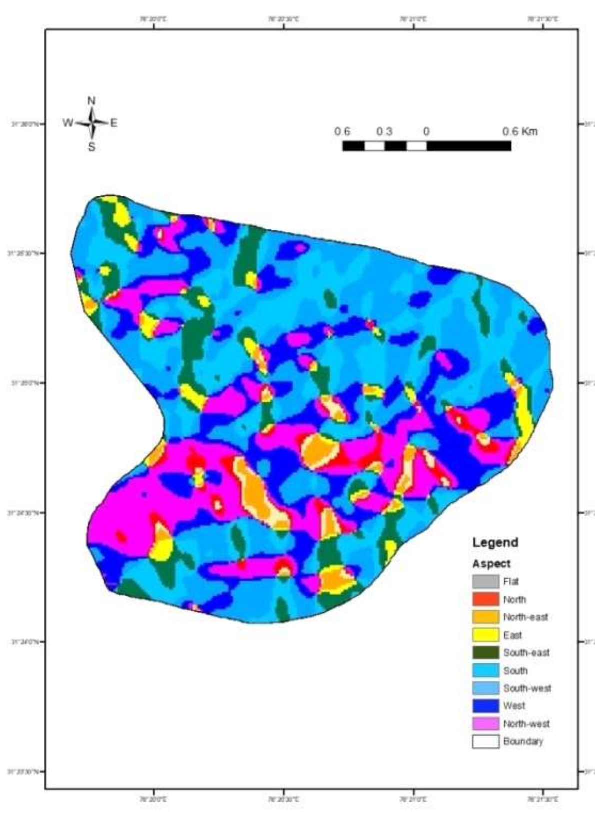

Fig. 8. Aspect map of district Una

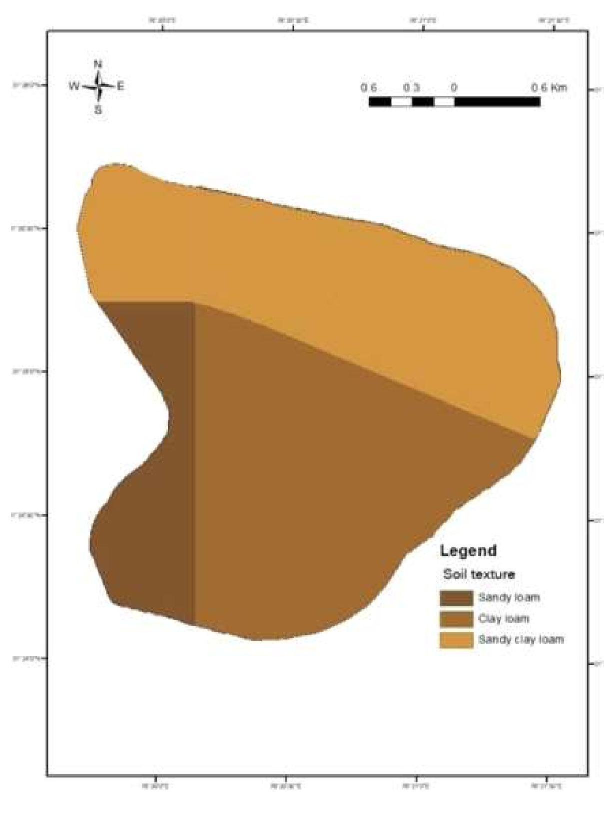

Fig. 10. Soil map of district Una

surface water etc., in addition to providing indication on groundwater requirements (Yeh et al 2016*)*. Reliable and precise information is provided by land-use for sustainable water resource management. Land use pattern controls the infiltration and permeability process. Figures 11 and 12 showed the LULC map of both the districts in study. The study area was classified into six classes namely; building, agriculture land, forest area, open land/ waste land, shrubs and water body. In District Sirmaur, the highest land use was of forest area (27.44%) with an area of 3.21 km^2 followed by open land/waste land (26.41%) with area coverage of 3.09 km^2. Agriculture takes up 16.92% of the area while buildings occupied 14.96% of the area. Shrubs cover 1.54 km^2 (13.16%) while water bodies occupy 0.13 km^2 (1.11%). Built-up/buildings are impervious surfaces, which increase the storm runoff and reduce the infiltration capacity. On the other hand, agriculture, grassland and forest areas have high infiltration and moderate runoff capability, which helps to increase groundwater recharge (Abhijith et al 2020). In District Una, majority (56.13%) of the area was covered by agriculture land (3.48 km^2) which was the highest coverage followed by buildings (18.22%) with an area of 1.13 km^2, open land/wasteland (15.81%) with area coverage of 0.98 km^2 and forest (7.42%) with area cover of 0.46 km^2. The least land use was that of shrubs (2.42%) with an area covering 0.15 km^2. The high area cover of agriculture land coupled with gentle slopes in the district can be considered favorable for groundwater recharge.

Drainage and drainage density: The drainage map consists of water bodies, rivers, tributaries, perennial and ephemeral streams and ponds. Figures 13 and 14 indicated the drainage map of both the districts in study. The majority of the study area in both the districts comes under gentle to very gentle slopes and areas with high drainage density are influenced by high groundwater recharge and low runoff. Therefore, the entire drainage density map is divided into five categories for both the districts (Table 6, Fig, 15, 16). Majority of the drainages in both the district comes under medium to high drainage density while only a few patches comes under very high drainage density.

Lineament: Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. Thus, in the present study lineaments were classified into major lineaments for quantification purpose, lineament with length > 1km is classified as a major lineament and minor lineaments for quantification purpose, lineament with length < 1km is classified as a major lineament. Figure 17 and 18 indicated the lineament maps for District Sirmaur and Una respectively. As evident from the figures, most of the lineaments falls under major lineaments in both the districts and only a few minor lineaments could be found.

Groundwater potential zone map: In District Sirmaur, the area with very high groundwater potential zone comprises 0.44 km^2, covering 3.76% of the area. Similarly, an area of 0.36 km^2 falls under high zone, covering 3.05% of the study area. Another 3.83% of the region comes under moderate zone with area coverage of 0.45 km^2. Low groundwater potential zone covers 1.79 km^2 making up 15.27% of the area. Majority (74.62%) of the area comes under poor zone covering an area of 8.66 km^2(Table 7, Fig. 19).

According to ground truthing results, very high to high groundwater potential zones were found in areas where the slope was relatively gentle, present near river and lineaments, has medium to very high drainage densities with presence of agriculture land to forest areas, therefore having excellent infiltration ability and low runoff. The region under sandy loam soils also comes under the high potential zone thus indicating the high percolation and infiltration capability by these soils. The moderate zones were found in patches spreading in the southern parts and towards south-west as well as south-eastern parts. These were areas mostly covered with open/waste land with very little agriculture or forest cover thus having a comparatively higher runoff than the high or very high zones. Low potential zone was found in areas where there was medium to low drainage density with parts of it covered by buildings. In areas with moderate to steep slopes, this low zone was found in areas covered by forest and shrubs which might have slowed down the runoff process. The area with steep to very steep slopes devoid of vegetation falls under poor potential zone. This poor potential zone was found spreading in the most part of the study area.

Table 6. Drainage density category

Class	Km/Km^2	Category
1	0-1.2	Very low
2	1.2-2.4	Low
3	2.4-3.6	Medium
4	3.6-4.8	High
5	4.8-6	Very high

Table 7. Groundwater potential zones

Potential zones	District Sirmaur		District Una	
	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)
Very high	0.44	3.76	0.08	1.24
High	0.36	3.05	0.11	1.80
Moderate	0.45	3.83	0.97	15.61
Low	1.79	15.27	1.09	63.83
Poor	8.66	74.62	3.96	17..52

There was presence of built-up/buildings even though the slope was gentle which might have increased the runoff thus making the infiltration capacity much lower. Drainage density was also found to be low to very low in these areas thus disabling groundwater recharge.

In District Una, 1.24% of the area falls under very high potential zone with an area of 0.08 km^2 while 1.80% falls under high zone covering an area of 1.80 km^2 (Fig. 20). Moderate zone comprises of 0.97 km^2 which is about 15.61% of the area. Low potential zone covers the largest area

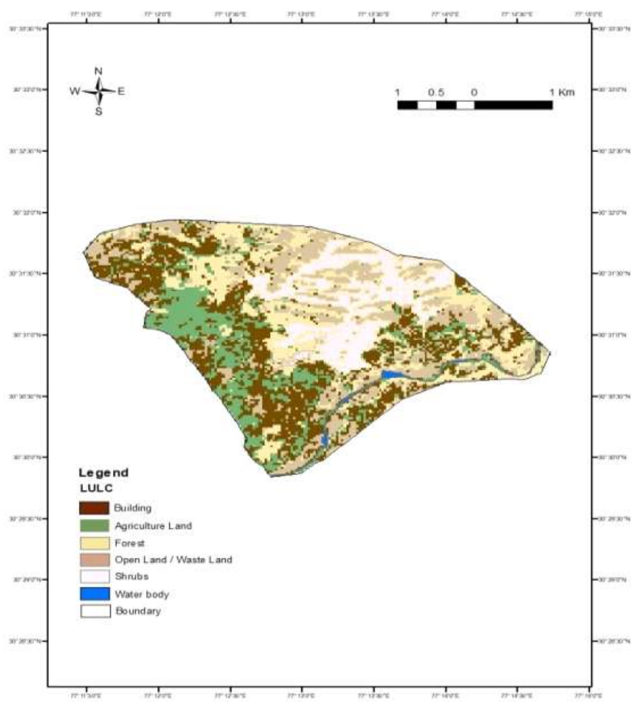

Fig. 11. LULC map of district Sirmaur

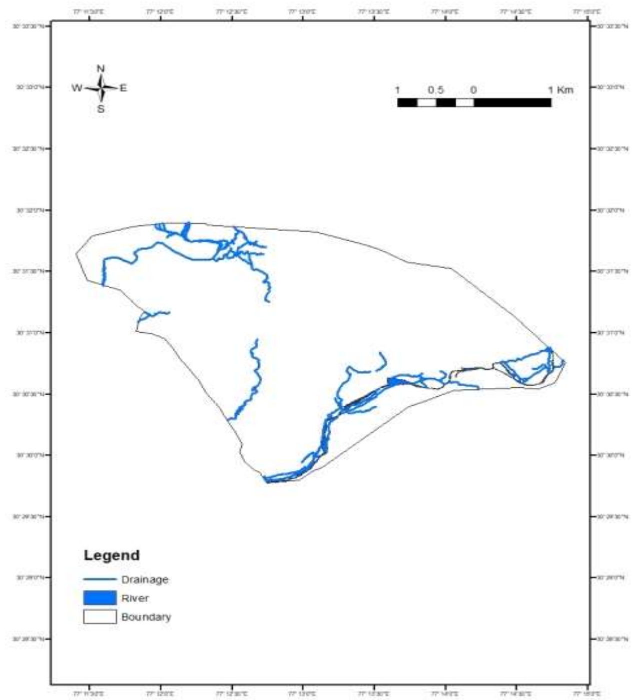

Fig. 13. Drainage map of district Sirmaur

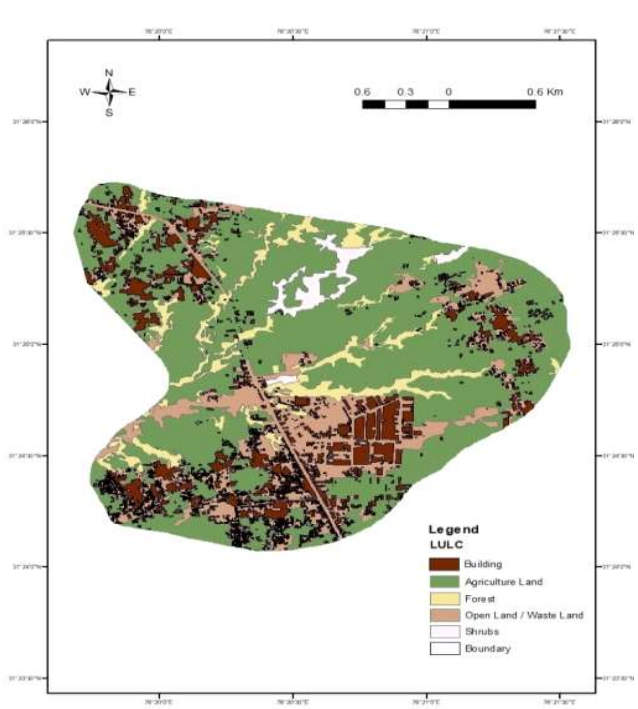

Fig. 12. LULC map of district Una

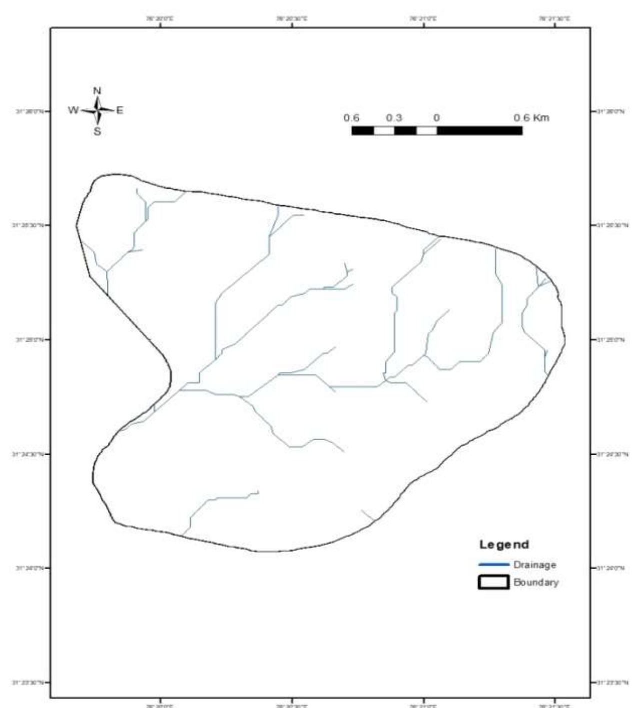

Fig. 14. Drainage map of district Una

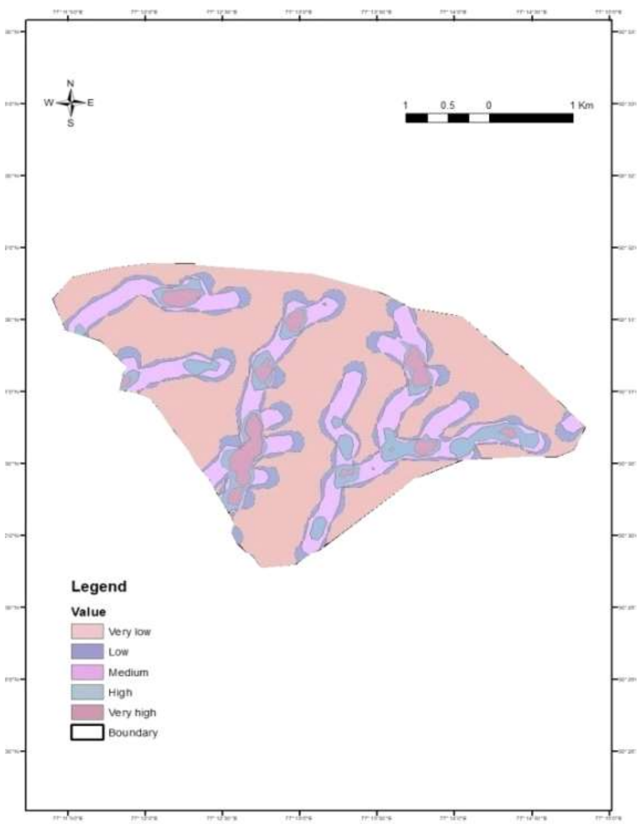

Fig. 15. Drainage density map of district Sirmaur

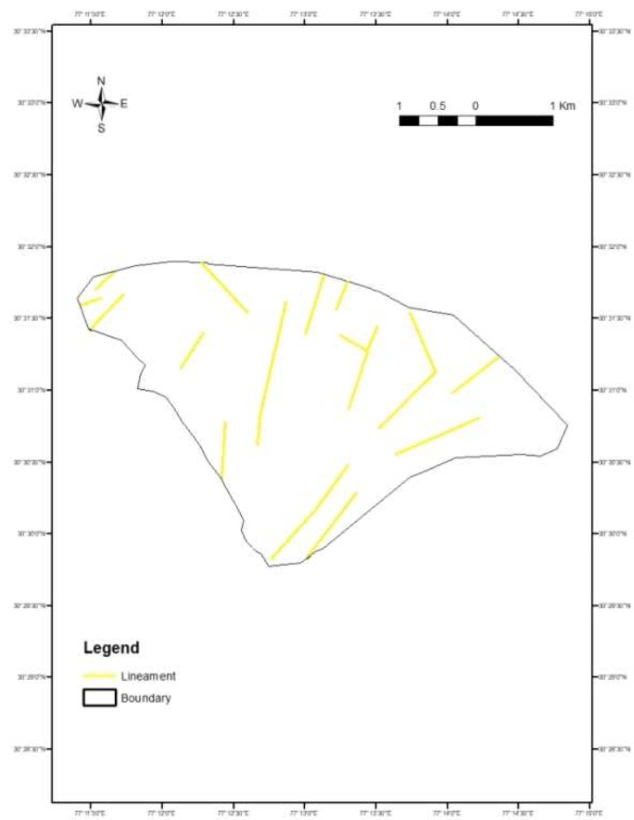

Fig. 17. Lineament map of district Sirmaur

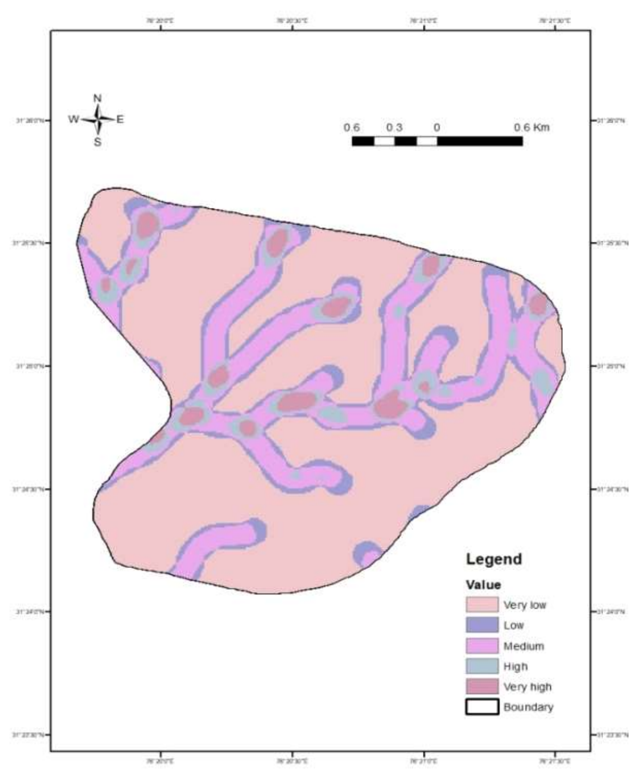

Fig. 16. Drainage density map of district Una

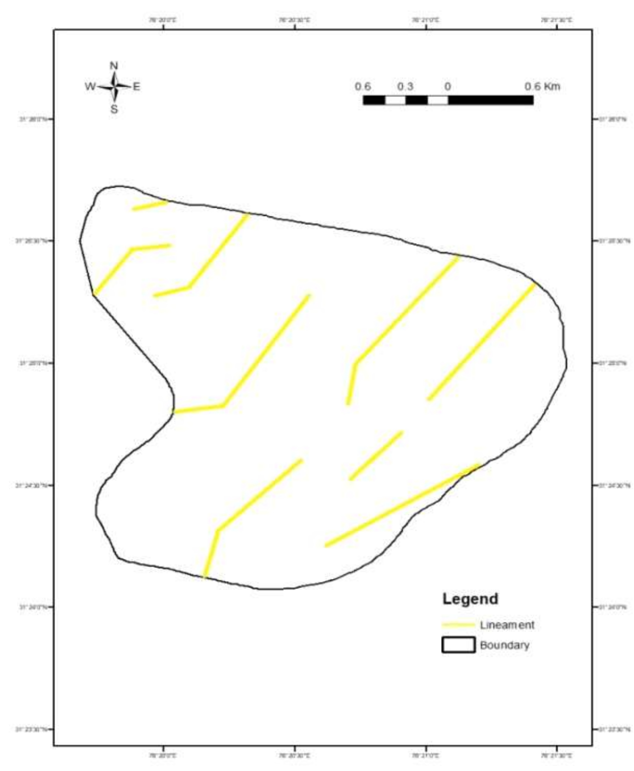

Fig. 18. Lineament map of district Una

(63.83%) with 3.96 km^2 coverage while poor zone comprises of 17.52% covering 1.09 km^2. Very high groundwater potential zone was found in small patches in the north-western and north-eastern parts. This has been verified by ground truthing. These are regions with very high drainage density, have southerly facing aspect with gentle slopes and were found in agriculture land and forest areas with sandy clay loam textures that allow high percolation and slow to runoff. High potential zones were found in the northern to central parts of the study area with most of it under agriculture and shrub coverage with gentle to very gentle slopes and having high to medium drainage densities. Moderate zones were present distributed throughout the whole area with only a few patches in the southern side. The area under these zones have medium to low drainage density, mostly covered by shrubs and forest with parts under agriculture land and present near lineaments. Majority of the area under this zone comes under west to north-western aspects. Low potential zone has the highest coverage in the area with low to very low drainage densities covering most of the built-up areas as well as open/waste lands and has northerly aspects indicating a higher evapotranspiration and lower percolation in these areas. Poor potential zone was found in patches distributed throughout the whole area but mostly concentrated towards central to southern parts. Even though the slope is gentle, these are areas covered by buildings and open land/waste lands and hence there is more runoff and low infiltration capacity leading to low groundwater recharge.

The error matrix table has been presented in Table 8 for Sirmaur and Una respectively. In district Sirmaur, the overall efficiency was 80% with a kappa coefficient of 0.73, which means there is substantial agreement between the potential zone map and the well data. In district Una, the overall efficiency of the groundwater potential zone map was 86.67% with a kappa coefficient of 0.81, which indicated an almost perfect agreement. Mahato et al *(*2021) also delineated groundwater potential zones in Papumpare district of Arunachal Pradesh where their analysis showed an overall accuracy of 81.25% and a Kappa coefficient of 0.72. The low accuracy level obtained in this study may be attributed to the fact that a relatively lesser number of sampling wells were taken for validation. The factors taken into consideration like slope, aspect, geology, etc. only deal with the physical parameters of the area and climatological parameters like rainfall could not be taken into consideration as there was a similar rainfall distribution pattern in the area.

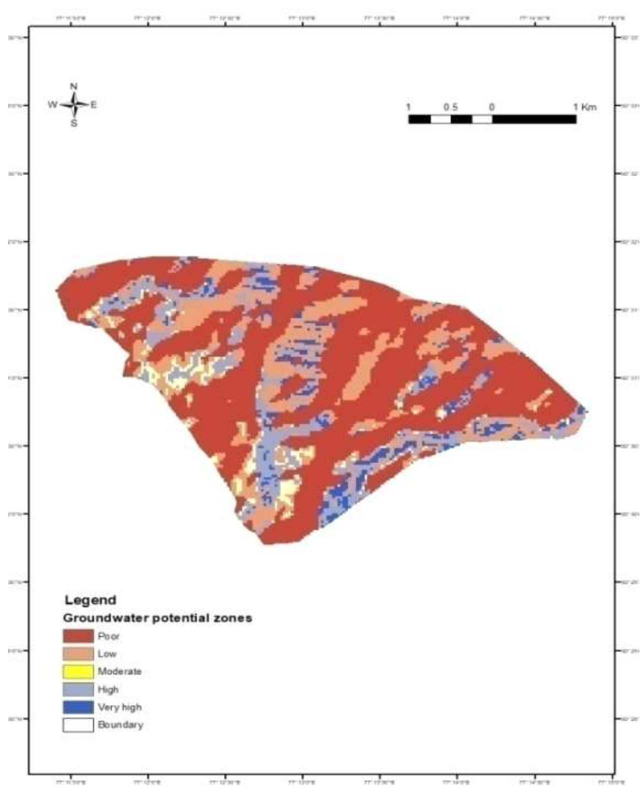

Fig. 19. Groundwater potential zone map of district Sirmaur

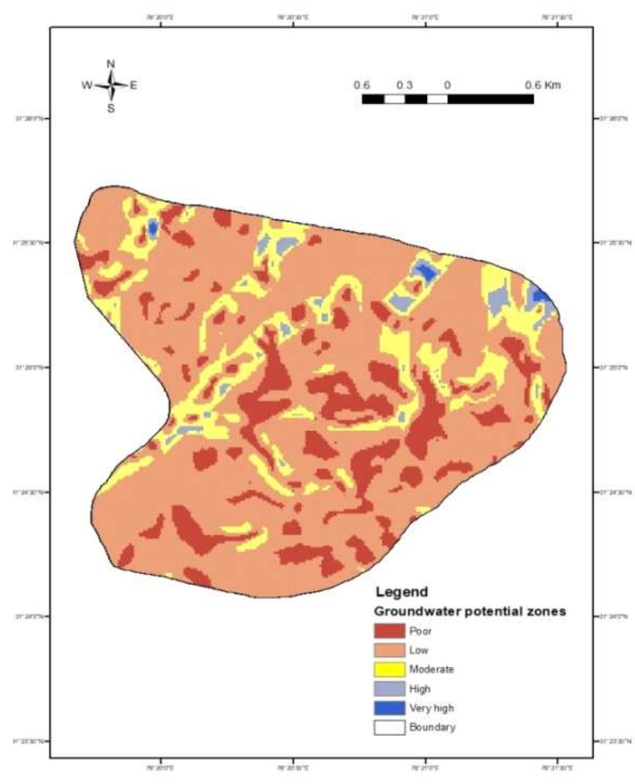

Fig. 20. Groundwater potential zone map of district Una

Table 8. Error matrix of groundwater potential zones in district Sirmaur and Una

GWPZ	Very High	High	Moderate	Low	Poor	Total
District Sirmaur						
Very High	0	0	0	0	0	0
High	1	3	0	0	0	4
Moderate	0	0	2	0	0	2
Low	0	0	1	2	0	3
Poor	0	0	1	0	5	6
Total	1	3	4	2	5	15
Overall accuracy			80.00%			
Kappa coefficient			0.73			
District Una						
Very High	0	0	0	0	0	0
High	0	0	0	0	0	0
Moderate	0	1	4	0	0	5
Low	0	0	1	5	0	6
Poor	0	0	0	0	4	4
Total	0	1	5	5	4	15
Overall accuracy			86.67%			
Kappa coefficient			0.81			

CONCLUSIONS

The present study was conducted to delineate the groundwater potential zones in two districts lying in low-hills of Himachal Pradesh by using RS and GIS techniques. The method involves weighted overlay of various thematic layers (slope, geology, aspect, soil, land use land classification, drainage density, and lineament) after assigning individual ranks and weights to each of the factors. The final groundwater potential zone map was then developed for both the districts and the areas were classified into five distinct groundwater potential zones such as very high, high, moderate, low and poor. In district Sirmaur, majority of the area falls under low to poor groundwater potential zones while only minute patches of high to very high potential zones are found. This indicated that the groundwater resources in the areas have been over-consumed for the industrial and other domestic purposes and appropriate management for groundwater resources is very much needed in the area. In district Una, majority of the area falls under low to moderate potential zones indicating there is some prospects for groundwater utilization but if appropriate steps are not take, the groundwater resources will soon decline in the near future. Assessment of groundwater potential as well as delineation of potential zone map was significant for groundwater resource management and future planning for efficient groundwater uses. Thus, this study can provide an insight about the groundwater status in the study areas and it may be useful for future groundwater management plans.

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Assessment of Spring Water Quality In Upper Himalayan Villages Using Water Quality Index

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Abstract: Springwater is a primary source of water in the Himalayan region of Uttarakhand in India. These spring water sources quickly approach degraded water quality in both quantitively and qualitatively patterns because of its population boom, increased industrialization, and usage of pesticides in agriculture. In the present study, 16 spring water samples were collected from 9 upper Himalayan villages of Chamoli during the pre and post-monsoon period. Physic-chemical assessment and analysis of the collected spring water samples were performed to evaluate the water quality indices for drinking as well as irrigation purposes. The analysis of 14 physicochemical parameters including, pH, TDS, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, F^{-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-} and NO_3^{-} were performed during pre and post-monsoon periods whereas Sodium percentage (Na%), Sodium Absorption Ratio, and Residual Sodium Carbonate, Soluble sodium percentage, Permeability index, Kelley's ratio, and, Magnesium hazard were evaluated to assess irrigation water quality. Out of 16 spring water samples, only 44% were in the 'good' water quality range for drinking during pre-monsoon whereas the significant 75% were in the same category water class during post-monsoon period. Three sampling sites had 'poor' water quality during both pre and post-monsoon periods. There were 6 springwater sampling sites that had 'very poor' water quality during pre-monsoon, but no site was found in this class during the post-monsoon period. The average value of irrigation water quality parameters Na%, SAR, RSC, SSP, Permeability index, Kelley's ratio, and, Magnesium hazard was observed as 27.43, 1.26, 1.96, 18.97, 0.24, 82.41, and 45.92 meq/l during pre-monsoon and 22.03, 0.71, 1.07, 24.56, 0.34, 83.34, and 39.41 meq/l during the post-monsoon period in the study area.

Keywords: Springwater, Water quality, Irrigation Water quality, Chamoli

Groundwater is becoming a contentious and important issue around the world. About one-third of the population relies on groundwater for drinking water (Nickson et al 2005). The primary source of freshwater in India is groundwater resources. Groundwater resources supply 85% of India's rural water supplies (World Bank 2010). High-relief and complicated rock geological structures are crucial for the formation of mountain aquifers in mountainous areas like the Himalayas. These mountain aquifers hold a large amount of water, which eventually naturally releases as spring (Mahamuni and Upasani 2011, Khadka and Rijal 2020). India is quickly approaching a significant groundwater crisis as a result of its population boom, increased industrialization, and usage of pesticides in agriculture (Chandra et al 2015). After groundwater becomes contaminated, regular monitoring of its quality becomes crucial because it cannot be restored by ceasing the pollution at its source (Ramakrishnaiah et al 2009). In addition to having a direct impact on human health, water pollution significantly impacts water quality (Milovanovic 2007).

There are around 3 million springs are in the Indian Himalayan Region (IHR). On a broader scale, the Himalayan region considered to be the "spring scopes of India," where a gross estimate of approximately 200 million (about 15%) Indians depend on spring water (NITI Ayog 2019). Around 60% of the population of the Himalayas, both in the towns and the rural areas, depends on spring water, and over 80% of them are directly employed in agriculture. Although just 11% of the total cultivable land area is irrigated and only 12.5% of the total land area is cultivated, 64% of that land is fed by natural springs (Gupta et al 2003). Since water is so important, numerous studies have been conducted using various methodologies to evaluate the groundwater quality for drinking, irrigation, and another usage (Molekoa et al 2019, Srivastava 2019, Bahir et al 2020, Madhav et al 2020, Jawadi 2020, Taloor et al 2020, Amiri et al 2021, Deoli and Nauni 2021, Thakur et al 2023, Saw et al 2023). Abdulwahid (2013) used the water quality indexing approach to evaluate the Delizhiyan springs and Shawrawa River's suitability for human consumption and other uses in the Soran area of Erbil, Kurdistan Region of Iraq. Ameen (2019) conducted a study to assess the spring water quality in the Barawari Bala area of Duhok, Iraq, using a WQI based on several physicochemical characteristics. It was found that, out of 118 samples, except 2 samples rest were of good quality. By collecting water from five distinct locations, Chauhan et al (2020) evaluated WQ of Sumari Village in Uttarakhand. Based on the WQI, the authors discovered that, of the 5 samples, 2 are of excellent quality, 2 are of good quality, and 1 is of moderate quality. In accordance with World Health Organization and BIS criteria, Shinde et al (2020) assessed the quality of the groundwater in Thane, India. QGIS software has been used to map the spatial assessment of groundwater quality using a remote sensing technique. To analyze the groundwater quality for the Wanaparthy watershed in Telangana, India, Vaiphei et al (2020) employed WQI and GIS techniques. Thakur et al (2023) used WQI and irrigation WQI to assess drinking and irrigation water quality for Pithoragarh Uttarakhand.The study was carried out to assess the quality of spring water for drinking and irrigation purposes at Himalayan villages of Chamoli block in Uttarakhand.

MATERIAL AND METHODS

Study area: The studied villages are situated at the Chamoli block of Chamoli district in the Uttarakhand state of India. The block lies between 30.2937°N latitude and 79.5603°E longitude and falls under the Chamoli district having a geographical area of 7520 km^2. As the elevation of the block ranges from 800 m to 8,000 m above mean sea level the climate of the district largely depends upon elevation difference. The block receives an average annual rainfall of 1230.8 mm. Most of the rainfall occurs during the month of June to September in the study area. Temperature also varies with the elevation the highest temperature was recorded at 34°C and the lowest was 0°C during the month of January.

Data collection: The 16 spring water samples were collected from 9 villages of Chamoli block during the pre and post-monsoon periods. Physic-chemical assessment and analysis of the collected spring water samples were performed to evaluate the water quality indices (WQI) of the sampling sites during pre and post-monsoon periods in the study area for drinking as well as irrigation purposes (Table 1).

Approach and methodology: Water samples were collected from springs *(Naula and Dhara)* of Chamoli block of Chamoli district of Uttarakhand in 1000 ml sampling bottles. The data was collected on color, odor, taste, temperature, pH, TDS, EC and turbidity, total hardness (TH), calcium content, sodium content, chloride content, magnesium content, free CO_2, acidity, alkalinity, sulphate content, Ca hardness, Mg hardness, sodium adsorption ratio (SAR). Electric conductivity, pH, temperature and TDS were determined in the site using a Pocket EC tester, pH tester, thermometer and Pocket TDS, respectively. All the other tests were performed in the laboratory. Different methods used in the analysis are shown in Table 2. The weighted arithmetic mean method is used to evaluate the Drinking WQI for both pre and post-monsoon periods in the study area.

Table 1. Sample collection points

Village	Spring name	Latitude	Longitude
Karaki	Gada Dhara	30.437	79.305
Karaki	Karaki Dhara	30.436	79.306
Malagaon	Phakuna Dhara	30.436	79.3
Malagaon	Dathi Dhara	30.44	79.298
Malagaon	Lagdi Dhara	30.438	79.293
Romadi	Tapar Dhara	30.432	79.301
Romadi	Talla Dhara	30.432	79.299
PoulDhar	Poul Dhara	30.433	79.304
PoulDhar	Siya Dhjara	30.428	79.305
Baragaina	Road Dhara	30.443	79.285
Kunkuni	Kunkuni Spring	30.454	79.290
Siroli	Kularkudi Dhara	30.467	79.281
Siroli	Bhagial Dhara	30.465	79.280
Khalla	Khalla Magara	30.475	79.274
Khalla	Simar Magara	30.449	79.272
Bandwara	Bandwara Magara	30.436	79.284

Table 2. Different methods used for physic-chemical analysis

Parameter (s)	Method
Colour	Visual Interpretation
Odour	Smelling
Taste	Drinking (with precautions)
Total dissolved solids (TDS)	Electrometric
Electrical conductivity (EC)	Electrometric
Temperature	Electrometric
pH	Electrometric
Acidity	Titration by 0.05N NaOH solution
Alkalinity	Titration by 0.01N HCL
Turbidity	Absorbance method
Free CO_2	Titration by 0.05N NaOH
Dissolved O_2	Titration by Sodium thiosulphate
TH	Titration by EDTA
Ca and Mg	Titration by EDTA
Chloride	Titration by 0.02N $AgNO_3$
Na and K	Flame photometry
Sulphate	Absorbance method

Water quality indexing for drinking water: Water Quality Index (WQI) is a single-valued term used to represent the overall quality of water depending upon a huge variety of parameters. The weights are assigned to each parameter based on their evident significance in overall water quality and the final index was evaluated by taking the weighted average of all the parameters. The water quality index has been broken down into five essential categories: excellent, good, poor, very poor, and unsafe for consumption.

The weightage to each of the parameter was assigned using the methodology given by Aabbasi and Arya (2000) as:

$$W_i \propto \frac{1}{S_i} \quad \dots (1)$$

Where, W_i = Unit weight for i^{th} parameter; and S_i = Standard permissible value for i^{th} parameter.

$$W_i = \frac{K}{S_i} \quad \dots (2)$$

Where, K is proportionality constant, which can be defined as:

$$K = \frac{1}{[\frac{1}{S_1}+\frac{1}{S_2}+\cdots\dots\dots+\frac{1}{S_n}]} \quad \dots (3)$$

The summation of all the values of W_i must be equal to 1.

Water quality rating: The following equation was used to determine the rating of water quality (Qi) for each selected parameter for potable water (Brown et al 1970).

$$Q_i = \frac{V_a - v_i}{S_i - v_i} \times 100 \quad \dots (4)$$

Where, V_i and V_a are the ideal and actual values of water quality parameters of water samples. For all the parameters, except pH (7) and DO (14.6 mg/l) the ideal value (V_i) is 0.

Indexing: The overall water quality indices (WQI) for drinking water were (Brown et al 1970) .

$$WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{j=1} W_i} \quad \dots (5)$$

Q_i and W_i are the quality rating and relative weight for i^{th} parameter.

Evaluation of water quality for irrigation: The water derived from natural springs may contain chemicals in some proportion which affects crop yield and fertility of soil. To evaluate suitability of spring water for irrigation in this study area, sodium adsorption ratio (SAR), Magnesium hazard and Permeability Index (PI) have been calculated.

Sodium adsorption ratio: SAR was calculating using following eq.:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad \dots (6)$$

Magnesium hazard: The Mg hazard of irrigation water was calculated using the relationship given by Szabolcs and Darab (1964) as:

$$Mg_{hazard} = \frac{Mg}{Ca+Mg} \times 100 \quad \dots (7)$$

Permeability index: Based on the Permeability Index (PI), the following equation proposed by Kacmaz and Nakoman (2010) was used to assess the suitability of irrigation water:

$$PI = \frac{Na+\sqrt{HCO_3}}{Ca+Mg+Na} \times 100 \dots (8)$$

Irrigation water quality indexing: For irrigation water quality indexing, several parameters are to be determined .Parameters used for water quality indexing for irrigation purpose electrical conductivity sodium adsorption ratio, sodium chloride and bicarbonates were estimated . Rating for irrigation water quality was estimated using the following equation for each of the selected parameter, a method suggested by Meireles et al (2010) and criteria and permissible limit recommended by Ayers and Westcot (1985) (Table 3).

$$Q_i = Q_{imax} - \left[\frac{X_{ij} - X_{inf}}{X_{amp}}\right] \times Q_{iamp} \dots (9)$$

Q_{imax} is the class's highest value of Q_i, x_{ij} is the parameter's actual value; x_{inf} is the corresponding value for the class's lower limit; q_{iamp} is the class amplitude; x_{amp} is the class amplitude to which the parameter belongs. To evaluate $x_{amp,}$ for the last class of each parameter the highest value of parameter obtained from the physico-chemical analysis of water samples was used to the upper limit.

Table 3. Parametric permissible values for irrigation water quality

Q_i	EC (dS/cm)	SAR $(meq/l)^{1/2}$	Na (meq/l)	Cl (meq/l)	HCO_3 (meq/l)
85-100	0.20≤EC<0.75	2≤SAR<3	2≤Na<3	1≤Cl<4	1≤HCO_3<1.5
60-85	0.75≤EC<1.50	3≤SAR<6	3≤Na<6	4≤Cl<7	1.5≤HCO_3<4.5
35-60	1.50≤EC<3.00	6≤SAR<12	6≤Na<9	7≤Cl<10	4.5≤HCO_3<8.5
0-35	0.20>EC≥3.00	2>SAR≥12	2>Na≥9	1>Cl≥10	1>HCO_3≥8.5

Source: Meireles et al (2010)

Table 4. Drinking water quality indices of study area during pre-monsoon period

Station	pH	TDS	TH	EC	Chloride	HCO_3^-	Ca	Mg	Na	K	Phosphate	Sulphate	Nitrate	Fluoride	WQI
Gada Dhara	7.53	431.00	488.00	713.50	46.15	400.00	51.40	48.40	48.40	7.30	0.64	117.07	51.30	1.14	80.42
Karaki Dhara	7.55	611.50	558.00	955.50	31.95	455.00	48.20	27.56	27.56	4.00	0.08	53.53	76.40	1.11	78.57
Phakuna Dhara	8.08	294.00	353.00	478.50	53.56	260.10	27.10	18.40	18.40	4.50	0.57	85.14	41.20	0.64	50.26
Dathi Dhara	7.85	212.80	261.00	518.50	22.72	249.00	27.90	32.40	32.40	5.50	0.17	50.84	76.00	1.14	81.88
Lagdi Dhara	8.01	577.70	457.00	946.28	103.56	382.50	25.60	22.60	22.60	3.60	0.15	18.80	21.60	0.82	46.78
Tapar Dhara	7.05	282.50	360.00	406.50	22.72	247.50	38.60	13.20	13.20	6.50	0.59	57.07	36.90	0.45	45.84
Talla Dhara	7.79	309.50	388.00	524.60	58.93	295.00	36.40	15.40	15.40	1.60	0.35	51.16	88.70	0.78	84.54
Poul Dhara	7.55	656.48	294.00	1182.00	28.40	157.50	41.20	29.90	29.90	1.70	0.32	60.12	34.50	0.34	45.01
Siya Dhara	7.70	345.50	576.00	746.00	41.89	430.00	39.60	22.70	22.70	1.60	0.19	101.52	12.80	0.05	40.44
Road Dhara	8.35	614.50	237.00	975.00	18.46	180.00	23.30	0.90	0.90	3.50	0.17	103.47	7.50	0.42	28.31
Kunkuni Spring	8.05	376.20	266.00	406.50	28.40	287.50	23.60	7.80	7.80	4.50	1.08	76.73	79.00	1.11	77.97
Kularkudi Dhara	7.64	401.50	498.00	721.50	48.99	387.50	38.20	12.80	12.80	1.50	0.55	39.02	22.60	0.55	42.63
Bhagial Dhara	7.44	640.50	569.00	1022.40	43.31	535.80	21.20	28.30	28.30	1.40	0.13	116.15	41.80	1.03	57.94
Khalla Magara	7.82	434.70	398.00	648.10	22.72	382.50	24.50	8.77	8.77	6.50	0.17	77.60	77.80	1.25	71.00
Simar Magara	8.15	268.00	190.00	623.50	28.40	380.00	38.90	10.39	10.39	3.50	1.30	7.39	85.90	1.10	78.60
Bandwara Magara	7.89	306.40	236.00	498.80	105.64	166.10	35.20	21.50	21.50	1.60	0.44	34.97	47.10	0.64	44.75

Table 5. Drinking water quality indices of study area during pos-monsoon period

Station	Longitude	Latitude	pH	TDS	TH	EC	Chloride	HCO3-	Ca	Mg	Na	K	Phosphate	Sulphate	Nitrate	Fluoride	WQI
Gada Dhara	79.5314	29.0397	7.28	426	342	682.6	22.65	301	47.6	28.2	22.5	6.8	0.63	92.5	47.56	1.04	73.77
Karaki Dhara	79.4738	29.0195	7.41	574.5	381	922.1	19.87	281.6	41.5	21.5	11.3	3.9	0.04	51.25	51.23	1.07	62.50
Phakuna Dhara	79.4143	29.0242	7.8	305	315	418.6	7.8	195.2	26.9	14.8	14.3	3.2	0.42	74.25	39.25	0.52	49.22
Dathi Dhara	79.52	28.9947	6.9	114.2	154	208.9	18.64	238.4	19.8	23.5	21.4	5.1	0.13	42.65	45.1	1.09	47.77
Lagdi Dhara	79.4123	28.9733	7.28	534.8	304	864	79.46	301.5	25.9	18.7	21.2	3.5	0.12	9.74	20.55	0.43	47.95
Tapar Dhara	79.389	28.953	7.01	215.5	205	332.4	13.5	136.5	33.8	5.4	18.4	6.3	0.46	53.24	21.2	0.35	37.77
Talla Dhara	79.3445	28.9864	7.5	304.7	288	474.7	29.85	158.4	31.2	10.2	17.6	0.9	0.31	45	46.87	0.66	44.54
Poul Dhara	79.4605	28.9403	7.6	625.4	119	1025.6	16.62	87	29.5	17.5	15.1	1.5	0.27	59.87	28.7	0.22	38.55
Siya Dhjara	79.5192	28.9125	7.25	210	330	341.4	36.5	358.5	38.4	21.6	18.7	1.3	0.12	93.2	7.54	0.06	41.96
Road Dhara	79.5208	28.9625	7.48	542	134	874.8	8.92	87.1	23.1	0.8	11.2	2.8	0.16	102.46	3.12	0.35	28.77
Kunkuni Spring	79.437	28.901	7.62	376.2	142	452.7	25.4	197.4	18.7	1.7	15.3	3.4	0.94	41.65	48.68	1.05	21.34
Kularkudi Dhara	79.3231	29.0506	7.1	205.5	445	361	36.52	306.9	35.4	11.4	18	1.5	0.42	36.02	22.14	0.56	48.92
Bhagial Dhara	79.302	29.1131	7.41	542.7	432	899	21.36	430.7	16.5	17.3	16.3	1.2	0.11	74.8	23.65	0.94	28.40
Khalla Magara	79.2879	29.0827	6.9	390.3	195	649.3	9.78	171.3	22.2	4.6	24.2	5.2	0.14	65.49	53.46	1.13	46.78
Simar Magara	79.2466	29.0448	7.54	222.5	75	378.9	15.4	246.3	22	8.9	19.6	3.3	1.23	5.4	55.67	1.05	52.40
Bandwara Magara	79.9722	28.9221	7.8	301.8	215	484.9	73.2	52.3	32.6	7.7	15.9	0.9	0.38	36.52	46.9	0.61	40.73

The overall water quality indices (WQI) for irrigation water were calculated by

Eq. 10 given by Meireles et al (2010) as follows:

$$IWQI = \sum_{i=1}^{n} Q_i W_i \qquad \dots (10)$$

Where,

Q_i and W_i are the quality rating and relative weight for i^{th} parameter, respectively.

RESULTS AND DISCUSSION

The results are shown in Table 4 and 5 for drinking WQI during the pre and post-monsoon period, respectively. The descriptive statistics of spring water quality in the study area has been shown in Table 6. The comparative study showed significant improvement in spring water quality during the post-monsoon period and out of 16 spring water samples, only 44% (7 samples) were in the 'good' water quality range for drinking during pre-monsoon whereas significantly 75% (were in the same category water class during the post-monsoon period. Three sampling sites had 'poor' water quality during both pre and post-monsoon periods. There were 6 spring water sampling sites that had 'very poor' water quality during pre-monsoon, but no site was in this class during the post-monsoon period. The one sampling site was found with excellent water quality for drinking.

Table 6. WQI of Springwater during pre and post monsoon period

WQI range	Rating of groundwater quality	No. of samples	
		Pre-monsoon	Post-monsoon
≤25	Excellent	0	1
>25-50	Good	7	12
>50-75	Poor	3	3
>75-100	Very poor	6	0
≥100	Unsuitable	0	0

Talla Dhara has the poorest and *Siya Dhara* has the purest water quality during the pre-monsoon period whereas *Gada Dhara* and *Kunkuni Spring* were most impure and pure spring water sites during pre and post-monsoon period, respectively in the study area. No sampling site was with excellent drinking water quality during pre-monsoon whereas 1 sampling site (*Kunkuni Dhara)* was in this category during the post-monsoon period, Though, no sampling site was found unsuitable for drinking during both pre and post-monsoon periods in the study area but 6 sampling sites were found with very poor water quality during pre-monsoon in the study area. According to the sodium absorption ratio of spring water to assess its suitability for irrigation purposes all the samples were found excellent except only one location during the pre-monsoon period. All the sampling sites were found excellent for irrigation during post-monsoon in the study area.

Irrigation WQI: The descriptive statistics of the irrigation water quality during the pre and post-monsoon period in the study area are shown the Table 7 and 8, respectively. During

Table 7. Descriptive statistics of irrigation water quality during pre-monsoon period

Parameters (meq/l)	Sample range				Range	Classification	No. of samples
	Minimum	Maximum	Average	S.D.			
Na% (Wilcox 1955)	16.66	47.45	27.43	8.48	≤20	Excellent	2
					>20 - ≤40	Good	12
					>40 - ≤60	Permissible	2
					>60 - ≤80	Doubtful	0
					>80	Unsuitable	0
SAR (Rechards 1954)	0.05	11.16	1.26	2.65	≤10	Excellent	15
					>10 - ≤18	Good	1
					>18 - ≤26	Doubtful	0
					>26	Unsuitable	0
RSC (Raghunath 1987)	-1.97	5.37	1.96	1.97	≤1.25	Good	5
					>1.25 - ≤2.5	Doubtful	3
					>2.5	Unsuitable	8
SSP	3.06	26.47	18.97	5.73			
KI	0.03	0.36	0.24	0.08			
PI	49.68	137.35	82.41	24.99			
MR	6.05	68.99	45.92	15.77			

post-monsoon irrigation water was more suitable for irrigation. The detailed characteristic values of the spring water samples in the study area during pre and post-monsoon (Tables 9 and 10). The average value of irrigation water quality parameters Na%, SAR, RSC, SSP, Permeability index, Kelley's ratio, and Magnesium hazard were 27.43, 1.26, 1.96, 18.97, 0.24, 82.41, and 45.92 meq/l during pre-monsoon and 22.03, 0.71, 1.07, 24.56, 0.34, 83.34, and 39.41 meq/l during the post-monsoon period in the study area.

Table 8. Descriptive statistics of irrigation water quality during post-monsoon period

Parameters (meq/l)	Sample range				Range	Classification	No. of samples
	Minimum	Maximum	Average	S.D.			
Na% (Wilcox 1955)	13.26	33.72	22.03	6.24	≤20	Excellent	7
					>20 - ≤40	Good	9
					>40 - ≤60	Permissible	0
					>60 - ≤80	Doubtful	0
					>80	Unsuitable	0
SAR (Rechards 1954)	0.35	1.22	0.71	0.19	≤10	Excellent	16
					>10 - ≤18	Good	0
					>18 - ≤26	Doubtful	0
					>26	Unsuitable	0
RSC (Raghunath 1987)	-1.51	4.79	1.07	1.56	≤1.25	Good	9
					>1.25 - ≤2.5	Doubtful	9
					>2.5	Unsuitable	0
SSP	11.27	41.33	24.56	7.70			
KI	0.13	0.70	0.34	0.15			
PI	51.56	141.46	83.34	24.59			
MR	5.46	66.42	39.41	17.30			

Table 9. Details of the spring water quality during pre-monsoon period

Station	SSP	SAR	RSC	%Na	KI	MR	PI
Gada Dhara	24.17	11.16	-0.05	25.76	0.32	61.08	53.57
Karaki Dhara	20.29	0.78	2.75	21.65	0.25	48.80	66.54
Phakuna Dhara	21.69	0.67	1.38	24.07	0.28	53.09	77.68
Dathi Dhara	25.60	0.98	-0.01	47.45	0.34	65.93	62.31
Lagdi Dhara	23.70	0.78	3.11	25.36	0.31	59.54	84.10
Tapar Dhara	15.92	0.47	1.03	39.64	0.19	36.30	71.82
Talla Dhara	17.75	0.54	1.73	18.63	0.22	41.35	76.03
Poul Dhara	22.22	0.86	-1.97	22.79	0.29	54.74	49.68
Siya Dhjara	20.31	0.71	3.18	40.98	0.25	48.86	74.96
Road Dhara	3.06	0.05	1.71	29.41	0.03	6.05	137.35
Kunkuni Spring	15.63	0.35	2.88	29.90	0.19	35.52	115.72
Kularkudi Dhara	15.75	0.46	3.38	16.66	0.19	35.83	87.09
Bhagial Dhara	26.47	0.94	5.37	27.03	0.36	68.99	90.22
Khalla Magara	16.32	0.39	4.31	21.89	0.19	37.37	123.46
Simar Magara	13.85	0.38	3.42	26.15	0.16	30.80	90.35
Bandwara Magara	20.84	0.70	-0.83	21.55	0.26	50.45	57.62

Table 10. Details of the spring water quality during post-monsoon period

Station	SSP	SAR	RSC	%Na	KI	MR	PI
Gada Dhara	17.14	0.64	0.20	19.59	0.21	49.68	56.05
Karaki Dhara	11.27	0.35	0.75	13.26	0.13	46.34	60.58
Phakuna Dhara	19.43	0.55	0.62	21.44	0.24	47.83	75.33
Dathi Dhara	23.99	0.77	0.96	16.47	0.32	66.42	74.96
Lagdi Dhara	24.42	0.77	2.09	26.17	0.32	54.61	83.31
Tapar Dhara	27.21	0.77	0.10	31.00	0.37	21.03	78.09
Talla Dhara	24.10	0.70	0.19	14.65	0.32	35.27	74.85
Poul Dhara	18.29	0.54	-1.51	19.15	0.22	49.72	51.56
Siya Dhjara	17.94	0.60	2.16	18.53	0.22	48.39	71.42
Road Dhara	28.50	0.62	0.21	31.38	0.40	5.46	98.44
Kunkuni Spring	38.19	0.91	2.16	21.14	0.62	13.16	141.46
Kularkudi Dhara	22.34	0.67	2.31	23.19	0.29	34.93	86.38
Bhagial Dhara	23.82	0.67	4.79	24.60	0.31	63.60	113.13
Khalla Magara	41.33	1.22	1.31	14.25	0.70	25.67	107.17
Simar Magara	31.63	0.89	2.20	33.72	0.46	40.27	106.23
Bandwara Magara	23.33	0.65	-1.41	23.92	0.30	28.25	54.58

CONCLUSIONS

The physicochemical analysis was performed for 16 sampling sites of the Chamoli block of the Chamoli district of Uttarakhand during the pre and post-monsoon period. From the study, it has been concluded that 7 samples are good for drinking whereas 9 samples are in the poor and very poor categories. In post-monsoon season, 1 sample is of excellent water quality whereas 12 samples are of good water quality. From the result, it might be calculated that the major water pollution problem is in the pre-monsoon season for the studied area. Similarly, in irrigation water quality the post-monsoon season water is better to use in than pre-monsoon water for irrigation purposes.

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Isotherm Modelling of Pb Sorption by Lime and SSP from Contaminated Waste Waters

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***Abstract*:** Lead (Pb) pollution from various industrial activities results in many health issues in plants, animals and human beings. Removal of Pb using inorganic chemicals like lime and phosphates makes it unavailable and prevents its entry into the food chain. This study deals with the removal of lead by chemical sorbents *viz*., lime and single super phosphate (SSP) from aqueous solutions through a batch incubation experiment. The effect of sorbent dosage, initial $Pb2^+$ concentrations, and incubation time intervals on Pb adsorption was described using isotherm models. It was inferred that, SSP had higher Pb adsorption capacity (6.08 mg g^{-1}) than lime (4.96 mg g^{-1}) which increased with increasing time intervals from 0 to 6.6 mg g^{-1} for SSP and 5.59 mg g^{-1} for lime. The adsorption capacity of SSP increased from 1.14 to 12.7 mg g^{-1} in SSP and 0.99 to 10.1 mg g^{-1} in lime when the initial Pb concentration increased from 100 to 2000 mg kg^{-1}. Langmuir adsorption isotherm explained the sorption process better than Freundlich model for both the sorbents. Hence, it could be concluded that, SSP is the effective sorbent which can be utilized for the removal of Pb from wastewater and adsorption mechanism was well described by Langmuir adsorption isotherm.

***Keywords*:** Lead, Lime, SSP, Adsorption isotherm, Contaminated water

Pollution refers to the presence of undesirable materials, in the ecosystems beyond the permitted levels that can adversely disturb life. Increased industrialization activities involving the use of chemical substances like hydrocarbons, pesticides, chlorinated hydrocarbons and heavy metals serve as the prime anthropogenic source which is the key contributor for pollution (Rodríguez et al 2020). Lead is one of the ubiquitous and hazardous environmental pollutants. Lead poisoning in humans causes severe damage to the kidneys, nervous system, reproductive system, liver, and brain (Ara and Usmani 2015). Despite its toxicity, lead is widely used for different applications, in particular as electrodes in the lead-acid batteries, photovoltaic cells, glasses, paint, etc. (Kumar et al 2022). As a result, the levels of Pb in the environment continue to grow, making the development methodologies inevitable for the remediation of Pb-contaminated waters and soil (Alsafran et al 2023).

Remediation of metal-contaminated media is a time-consuming and expensive process. Existing methods for heavy metal removal from waste water include chemical precipitation, ion exchange, membrane filtration, and adsorption (Wang et al 2014, Tavakoli et al 2017 and Rajendran et al 2022). Adsorption is relatively suitable technique to reduce the Pb load in wastewater, since adsorbing materials have higher metal binding capacity. The major advantages of adsorption over other methods are: better efficiency, low cost, and minimization of chemical and biological sludge (Uddin, 2017 and Chakraborty et al 2022). Application of adsorption isotherm models and their adsorption parameters aids in delineating the mechanism of adsorption pathways, adsorbent capacities and the extent of dependence on adsorbent's surface properties for Pb sorption, and ultimately in designing competent adsorption systems.

The geochemical behaviour of Pb indicates that phosphate and carbonate, when present in sufficient amounts, forms lead phosphates and carbonates which are highly insoluble thus reducing Pb leachability and bioavailability. Using soluble phosphates and carbonates to adsorb and immobilize Pb is a cost-effective, efficient and viable remedial approach. Several insoluble Pb orthophosphate and carbonate minerals have formed after reaction with phosphate (Mouflih et al 2005). Many studies have been conducted using natural apatite and rock phosphate as a phosphate source (Mouflih et al 2005 and Minh et al 2012). Single super phosphate is a commercial P fertilizer containing 16% water soluble P_2O_5 which is widely used in agricultural sector. Zhao et al (2018) suggested that, calcium phosphate addition promote the precipitation of lead phosphate particles which are less soluble than lead carbonate and provide equilibrium dissolved lead concentrations lesser than the toxic limits. Among the carbonates, calcium carbonate ($CaCO_3$) is one of the most abundant low-cost materials on earth which is biocompatible and biodegradable, meeting all the desirable criteria for an adsorbent to be used on large-scale. Previous studies on the use of various polymorphs of $CaCO_3$ like calcite, aragonite, and amorphous $CaCO_3$ for adsorbing heavy metals, unfortunately demonstrated that, natural $CaCO_3$ has lesser efficiency in removing heavy metal ions (Zhang et al 2018).

However, limited study has been conducted to compare the efficiencies of lime (pure calcium carbonate) and soluble calcium phosphate (SSP). Thus, this study aims to investigate and compare the parameters that affect amount of Pb adsorbed at varying contact time, initial Pb concentrations, and adsorption capacity of lime and SSP. Furthermore, to ascertain the best fitting isotherm model for describing Pb adsorption by SSP and lime and to know the mechanisms involved in Pb removal to choose the best model to justify the Pb removal from waste water.

MATERIAL AND METHODS

Lead (Pb) standards and sorbents: The Pb standards were prepared using analytical grade lead nitrate ($Pb(NO_3)_2$) salt and about 2000 mg L^{-1} stock solution was prepared. Using the stock, different concentrations *viz.*, 100, 250, 500, 1000 and 1500 mg L^{-1} of Pb^{2+} was prepared. The fertilizer grade single super phosphate (SSP) was procured from Tamil Nadu Co-operative Marketing Federation (TANFED), Ramnathapuram, Coimbatore and commercial grade lime was used as sorbents in the study.

Batch sorption experiment: Batch sorption experiment was conducted at room temperature (25ºC) with the chemical sorbents for assessing their adsorption potential at different dosage, contact time and Pb concentration. The sorption studies were conducted in 50 ml centrifuge tubes with different doses of sorbents (1, 2.5 or 5 g) added to 25 ml of known Pb concentration solution. The centrifuge tubes with sorbents and Pb solution at different concentration was agitated on a mechanical shaker at 160 rpm for an appropriate contact time of 24, 48, 72, 96 and 120 hours, and centrifuged for 3 min at 5000 rpm. The supernatant was filtered using Whatman No.42 filter paper and analysed for residual Pb concentration using atomic absorption spectrophotometer (Model: GBC AvantaPM) with air-acetylene flame. Sufficient care was taken to prevent the loss of sorbents while separating the supernatant. The experiment was conducted in duplicates with a blank simultaneously to quantify the Pb adsorbed by the sorbents from solution. The quantity of Pb^{2+} adsorbed (q_e, mg g^{-1}) was estimated (Ray et al 2020) using the following equation (1)

$$q_t = V * \frac{C_0 - C_f}{m} \text{ --------- (1)}$$

where 'C_0' and 'C_f' are the concentrations of Pb^{2+} (mg L^{-1}) in initial and final solutions, respectively, 'V' is the volume of Pb^{2+} solutions added (25 ml) and 'm' is mass of the sorbent (g). **Adsorption isotherms:** The data obtained from batch experiments were fitted to isotherms models like Langmuir and Freundlich to identify the best fitted model so as to explain the retention and release characteristics of Pb in waste water by SSP and lime.

Langmuir isotherm: The adsorption isotherm model outlined by Langmuir is furnished in the equation given below:

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \text{--------- (2)}$$

Where, 'q_m' is the maximum monolayer coverage capacity (mg g^{-1}), 'q_e' is the amount of Pb adsorbed per gram of adsorbent at equilibrium (mg g^{-1}), 'C_e' is the concentration of Pb at equilibrium (mg L^{-1}) and 'K_L' is the constant representing the affinity of active binding sites (L mg^{-1}). The values of 'q_m' and 'K_L' were obtained from slope and intercept of plot between 'C_e/q_e' vs. 'C_e' (Langmuir 1918).

Freundlich isotherm: The adsorption isotherm proposed by Freundlich is commonly used for describing adsorption on heterogeneous surface (Dada et al 2012) which is represented in the equation (3) below:

$$q_e = K_F C_e^{1/\eta} \text{--------- (3)}$$

Where 'K_F' is the constant related to adsorption capacity (mg g^{-1}) and 'n' is the intensity of adsorbent. The values of 'n' and 'K_F' were obtained from slope and intercept of Freundlich plot of log q_e vs. log C_e. The favourability of adsorption is indicated by the magnitude of exponent 'η'.

Statistical analysis: The linear forms of six kinetic equations were fitted to the kinetic experimental data. The R^2 values and isotherm parameters were subsequently obtained from the fitted equations. The constants and parameters of all the isotherms were calculated using OriginPro 2022. The data is subjected to statistical analysis using SPSS software and simple variance analysis was done using factorial completely randomized block design with three factorial arrangement (Pb^{2+} concentration, sorbent dose and incubation time interval) and two replications. The least significance test was used to detect the variations between means at $p < 0.005$.

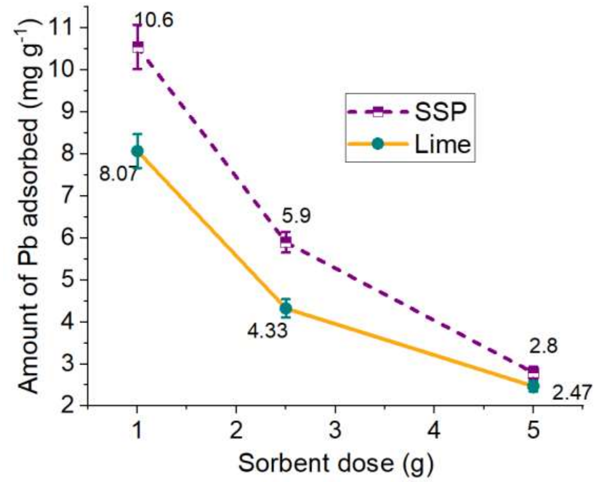
RESULTS AND DISCUSSION

Lead (Pb^{2+}) adsorption as influenced by various factors: *Sorbent dose:* The amount of Pb^{2+} adsorbed increased with increasing sorbent dosage (1.0 to 5.0 g/25 ml) irrespective of the sorbent studied (Fig. 1a). The amount of Pb^{2+} adsorbed decreased from 10.6 to 2.8 mg g^{-1} in SSP and 8.07 to 2.47 mg g^{-1} in lime when the sorbent dose increased from 1 to 5 g. The adsorption capacity decreased with the increase in adsorbent dosage for both adsorbent. As the sorbent dosage increased, the ratio of number of adsorption sites to the number of heavy metal ions would increase and there would be plenty of unabsorbed adsorption sites (Yarkandi 2014). It might also be the result from the aggregation of sorbents particles at higher dosages, thereby resulting in a decline in the surface area of adsorbent and also an increase in the diffusion path length (Rezaei et al 2022 and Ayodele et al 2016).

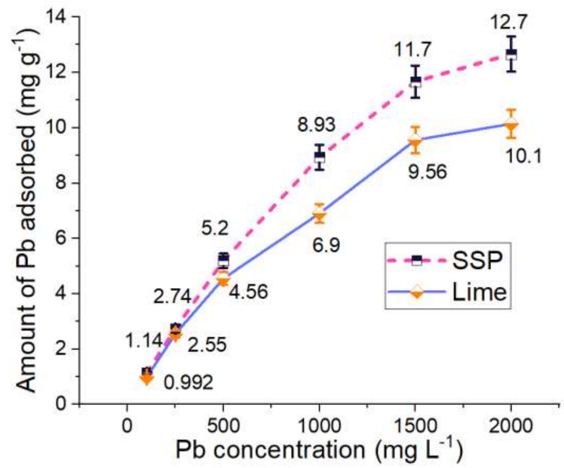
Initial Pb concentration: The amount of Pb^{2+} adsorbed increased with increasing initial Pb concentrations and the amount of Pb^{2+} adsorbed was significantly higher in SSP than lime for varying Pb concentrations (Fig. 1b). The amount of adsorbed Pb^{2+} varied from 1.14 to 12.7 mg g^{-1} in SSP and 0.99 to 10.1 mg g^{-1} in lime. The increase in Pb concentration resulted in increased number of available Pb ions per binding site in the adsorbent thus bringing a higher probability of Pb ion binding to the adsorbent. The probability of chemical interaction between the adsorbent and the adsorbate was enhanced by higher availability of Pb molecules in solution (Ahmad et al 2012). Increasing initial Pb concentration, increases the interaction between the metal ions and the sorbents, thus enhancing the availability of binding sites on the surface of sorbents (Mandal et al 2016 and Bulut et al 2018). These results corroborate with the findings reported by Yarkandi (2014) and Rezaei et al (2022).

Time: The Pb^{2+} adsorption capacity was studied at different incubation time intervals for both the sorbents (Fig. 1c) and observed an increase in adsorption capacity with the advancement of time for both sorbents. The adsorption capacity was found to increase from 0 to 5.33 mg g^{-1} for SSP and 4.1 mg g^{-1} for lime within 24 hours of incubation. The initial faster adsorption was due to a rapid diffusion of ions from solution to external adsorbent surface, and the slower adsorption capacity in the second stage was possibly the result of diffusion of Pb ions into the adsorbent material (Harja et al 2017). Upon saturation of adsorption sites, equilibrium is attained and adsorption capacity tends to increase at lesser rates (Shah et al 2018). Similar observations were noted in this study where there is a slow and steady increase in the adsorption rates (5.33 to 6.6 and 4.1 to 5.59 mg g^{-1} for SSP and lime respectively) from 24 to 120 hrs. These results are in line with the findings of Harja et al (2017) and Shah et al (2018).

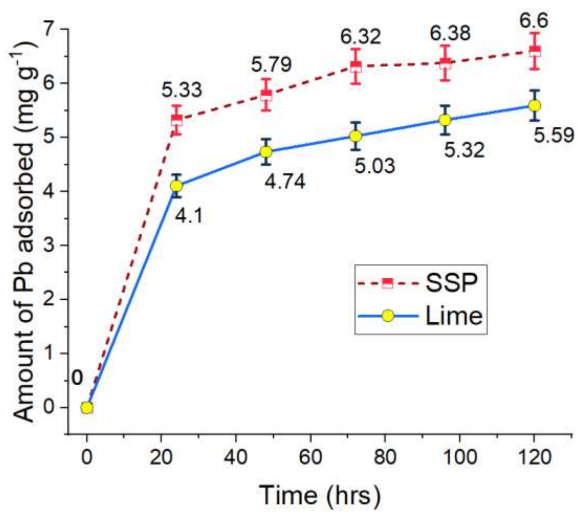
Adsorption isotherms: The data obtained from the



(a) Sorbent doses



(b) Initial Pb concentrations



© Time

Fig. 1. Adsorption rate (%) by SSP and Lime as influenced by (a) Sorbent doses (b) Initial Pb concentrations (c) Time. Bars represent standard error; data are average of two replications; comparison of mean was done at 5% level

experiment was fitted to Langmuir and Freundlich isotherm models to identify the best model to explain the Pb adsorption characteristics of the sorbents (Table 1).

The coefficient of determination varied from 0.96** to 0.99** for SSP and 0.96** to 0.99** for lime indicating that, the Langmuir isotherm explains the adsorption process well and indicated that the adsorption takes place in a homogeneous monolayer (Kamal et al 2021) (Fig. 2, 3). Testing with the

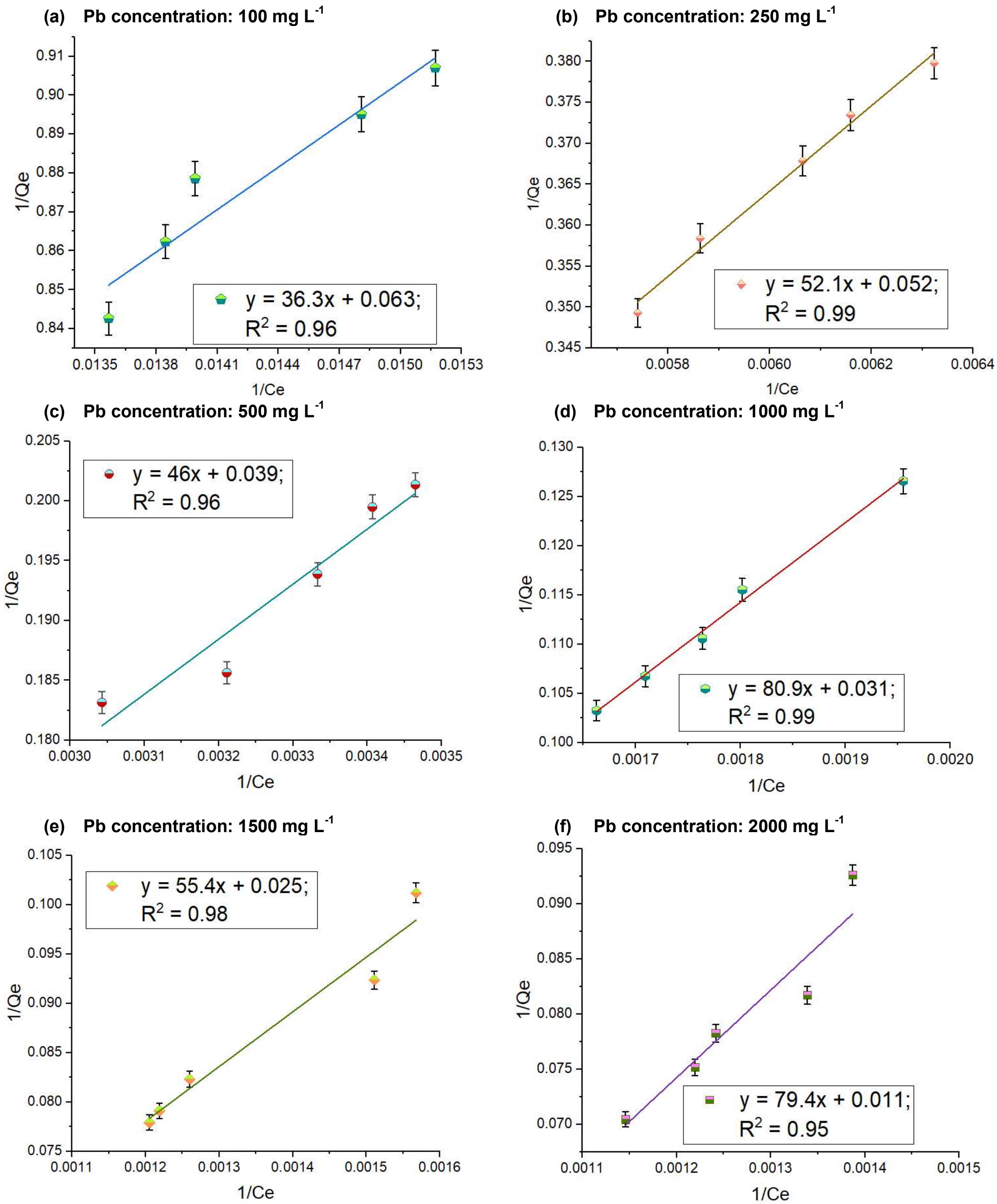


Fig. 2. Langmuir Adsorption Isotherm for describing the effect of SSP in removing Pb as influenced by varying initial Pb concentrations. Bars represent standard error; data are average of two replications; comparison of mean was done at 5% level

Langmuir isotherm where 'q_m' is the maximum monolayer coverage capacity and 'K_L' is the constant representing the affinity of active binding sites revealed a maximum monolayer coverage capacity ('q_m') of 15.3 to 95.2 and 12.7 to 27.2 mg g^{-1} in SSP and lime respectively. The monolayer coverage capacity was observed to increase with increasing initial Pb concentrations. However, the 'K_L' constant varied from 1.76 to 0.19 x 10^{-3} L mg^{-1} for SSP and 1.29 to 0.50 x 10^{-3}

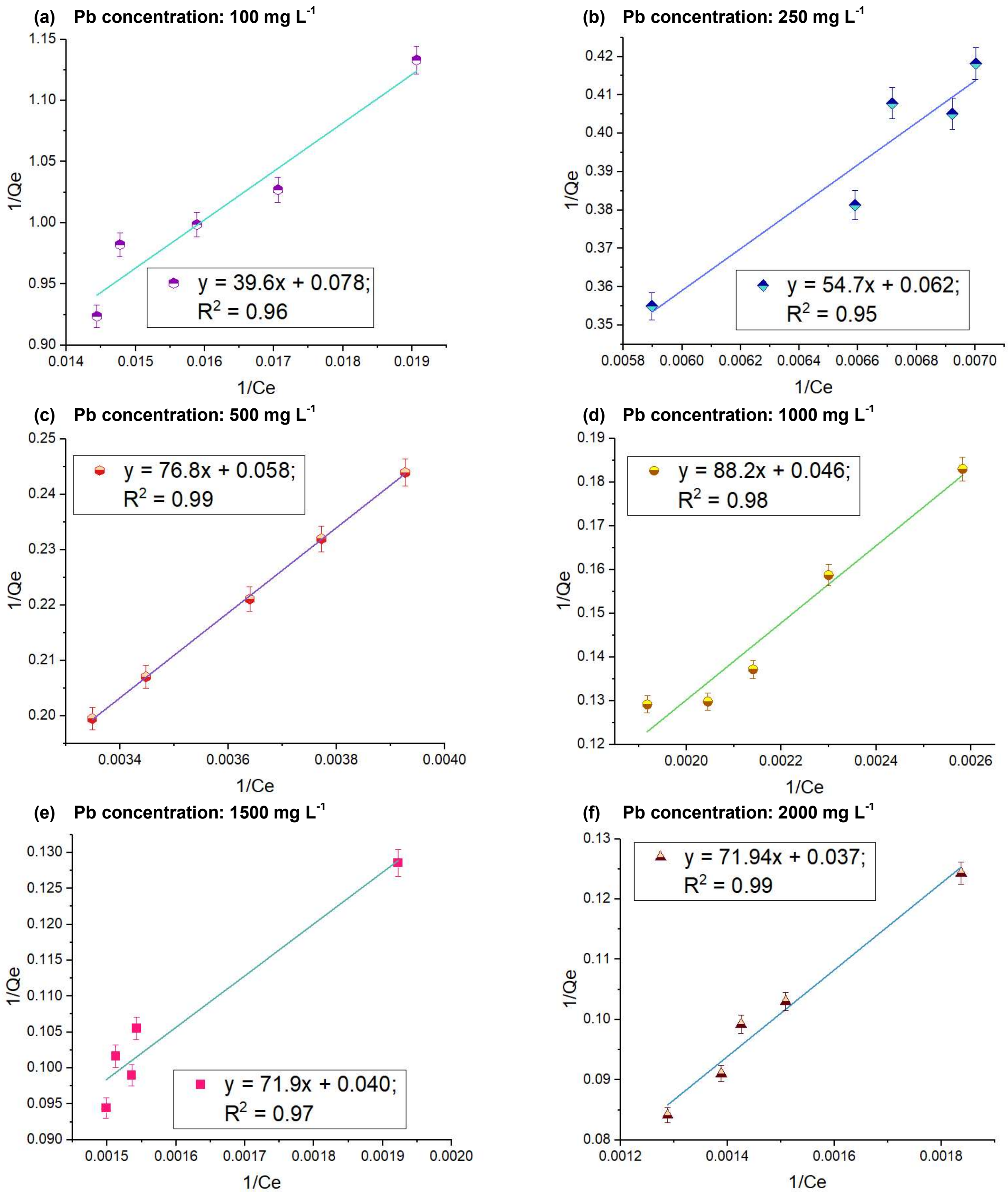


Fig. 3. Langmuir Adsorption Isotherm for describing the effect of lime in removing Pb as influenced by varying initial Pb concentrations. Bars represent standard error; data are average of two replications; comparison of mean was done at 5% level

for lime and higher binding affinity was observed at lesser initial Pb concentrations and declined with increasing initial Pb concentrations. This confirms that the affinity of Pb towards both the sorbents decreased with increasing initial Pb concentrations (Mouflih et al 2005, Mouflih et al 2006).

As regards to Freundlich isotherm, the coefficient of determination, (R^2) varied from 0.92** to 0.99** for SSP and 0.91** to 0.99** for lime showing that this model could be used to explain the adsorption process and the adsorption takes place on a heterogeneous surface (Fig. 4, 5). The

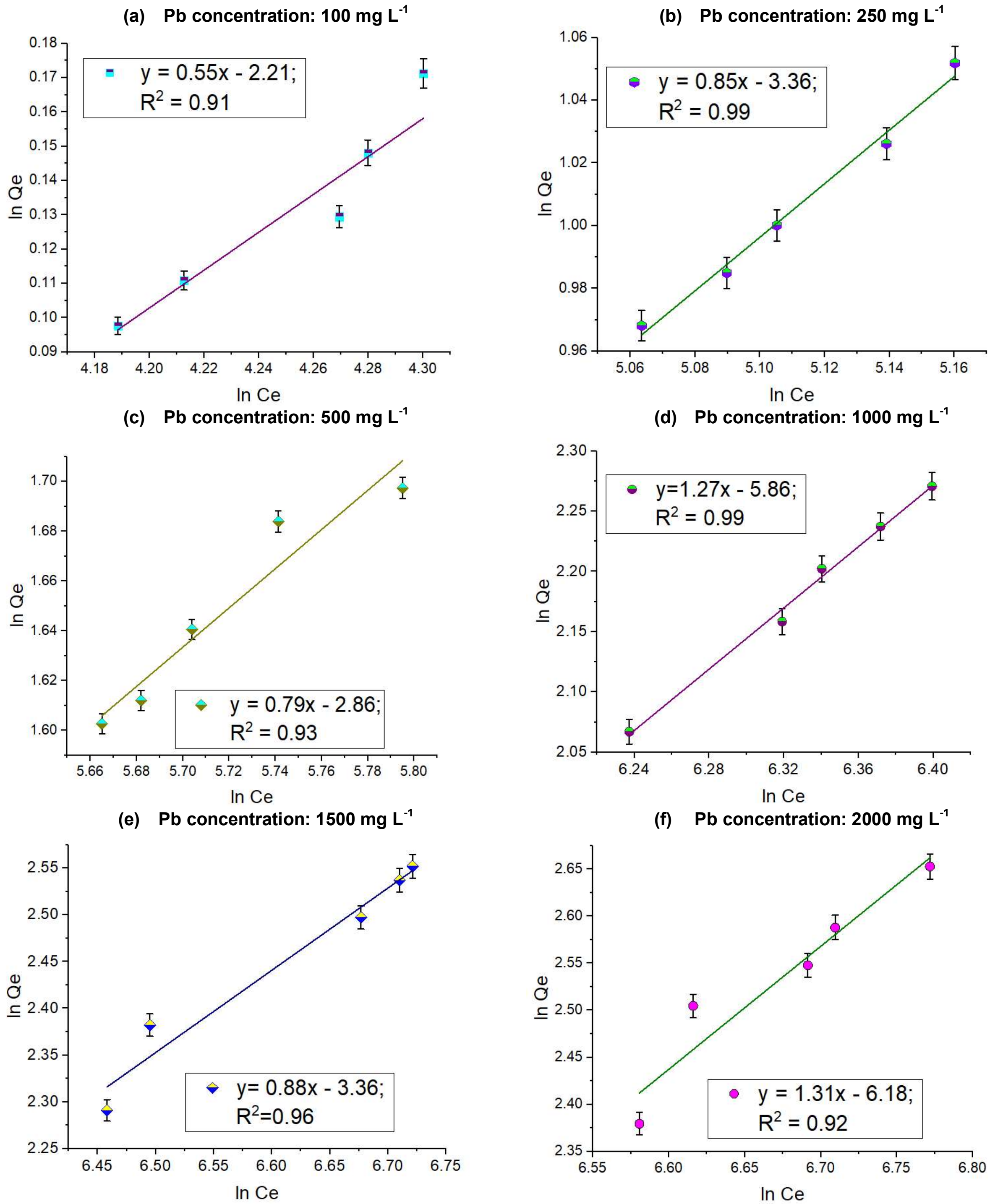


Fig. 4. Freundlich Adsorption Isotherm for describing the effect of SSP in removing Pb as influenced by varying initial Pb concentrations. Bars represent standard error; data are average of two replications; comparison of mean was done at 5% level

Freundlich isotherm assumes that the amount of adsorbed material increases with the increasing concentration of adsorbed material in solution. 'K_F' is the adsorption capacity constant (mg g^{-1}) and 'η' is the intensity of adsorbent. From the estimated results, the intensity of adsorbent ('η') varied from 0.78 to 1.69 for SSP and 0.78 to 1.57 for lime. Adsorption capacity constant 'K_F' varied between 0.002 to 0.092 mg g^{-1} and 0.003 to 0.071 mg g^{-1} in SSP and lime

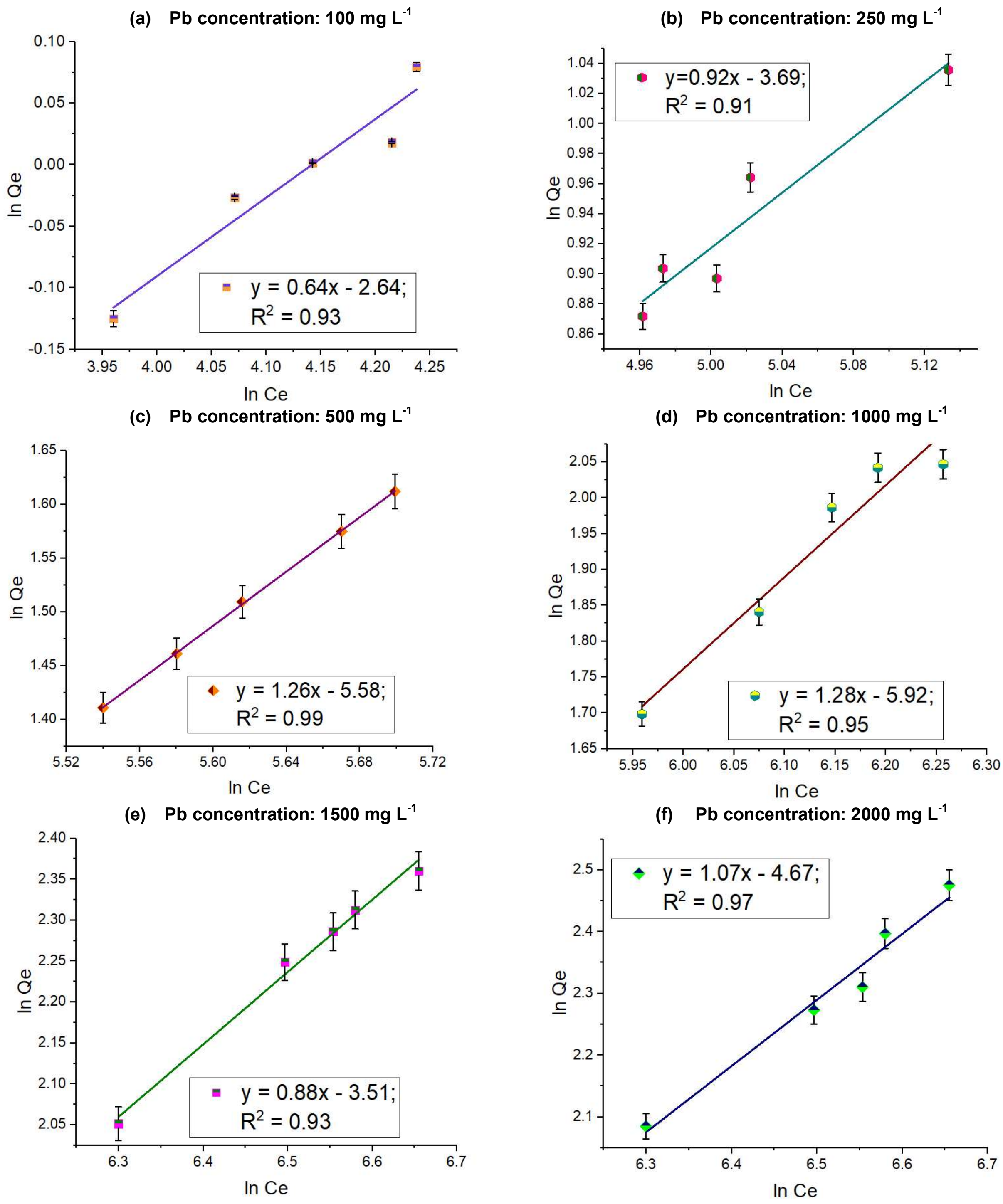


Fig. 5. Freundlich Adsorption Isotherm for describing the effect of lime in removing Pb as influenced by varying initial Pb concentrations. Bars represent standard error; data are average of two replications; comparison of mean was done at 5% level

Table 1. Description of Pb sorption by SSP and Lime using Freundlich and Langmuir isotherms

Sorbents	Pb concentration (mg L^{-1})	K_F	η	R^2	Q_m	K_lx10^{-3}	R^2
SSP	100	0.092	1.69	0.91**	15.8	1.76	0.96**
	250	0.034	1.17	0.99**	18.9	1.02	0.99**
	500	0.059	1.28	0.93**	25.2	0.86	0.99**
	1000	0.003	0.79	0.99**	32.2	0.38	0.99**
	1500	0.036	1.14	0.96**	40.4	0.30	0.98**
	2000	0.002	0.78	0.92**	95.2	0.19	0.95**
Lime	100	0.071	1.57	0.93**	1.98	1.29	0.96**
	250	0.025	1.09	0.91**	1.12	0.50	0.95**
	500	0.004	0.79	0.99**	0.75	0.75	0.99**
	1000	0.003	0.78	0.95**	0.52	0.52	0.98**
	1500	0.008	0.92	0.93**	0.55	0.55	0.97**
	2000	0.009	0.92	0.97**	0.51	0.51	0.99**

respectively. High K_F and η values indicate higher affinity of sorbent to sorption and desired levels of sorption process. These results are in line with the findings of Cekim et al (2015), Okoli et al (2017), Ozsin et al (2019) and Thabede et al (2020).

CONCLUSION

This study demonstrates that both SSP and lime showed higher Pb^{2+} sorption and removal potentials from aqueous solutions, however, SSP had higher Pb removal capacity than lime. The adsorption capacity increased with increasing Pb^{2+} concentrations and successive time intervals for both the sorbents. The models tested for sorbent-metal ion interactions showed that, Langmuir model explained the Pb^{2+} adsorption mechanism precisely explaining that adsorption takes place in a monolayer on a homogeneous sorbent surface. Hence it could be concluded that, SSP is the effective sorbent used for removing Pb^{2+} from the aqueous systems.

AUTHOR CONTRIBUTION

The research work was carried out and the first draft was written by Ms. G. Mohanapriya, Ph D. Scholar. Dr. T. Chitdeshwari, Professor (SS&AC) designed the methodology and edited the manuscript as Chairperson of the advisory committee. Dr. R. Shanmugasundaram, Dr. M. Maheswari and Dr. A. Senthil as advisory committee members edited the manuscript draft.

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Evaluating Predictive Efficiency of Analytical Hierarchy Process (AHP) for Landslide Susceptibility Mapping in Relation to Unparalleled Rainfall in 2018: A Case Study of Kuttiyadi River Basin, Kerala, India

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Abstract: Kuttiyadi River Basin (KRB) which falls in the Western Ghat ranges of South India, is prone to frequent landslides which are mostly triggered by continuous heavy rainfall for a short period. The landslides which happened in 2018, were the worst in the state's history. As Kerala Western Ghats is thickly populated and has unique geological and ecological characteristics, the need for Landslide Susceptibility Mapping (LSM) is an essential requisite. In this study, an attempt is made to identify landslide-prone areas using Analytical Hierarchy Process (AHP). Seven key causative factors such as slope, relative relief, drainage density, distance from drainages, land use/land cover (LULC), distance to roads, and road density were used to generate Landslide Susceptibility Index (LSI) and hence, an LSM of the basin. Thirty-two paleo landslide scars of the 2018 deluge were identified through inventory mapping which was used as test data to determine the accuracy of the AHP model using the Receiver Operating Characteristics (ROC) curve approach. The total basin area is 666 km^{2}and out of which 503 km^2(76%) falls in the stable region validated two landslides, 83 km^2 (13%) in moderate 13 landslides validated in this class, 57 km^2 (9%) in high 12 landslides have validated, and 23 km^2 (3%) in very high susceptible zones validated 5 landslides. The ROC curve model demonstrated 84% accuracy for the susceptible map. The AHP method-based landslide susceptible map accurately identified possible landslide-susceptible zones in the KRB, demonstrating the efficacy of the AHP tool in LSM.

Keywords: Kuttiyadi River Basin, Landslide susceptibility map, AHP, ROC, Geospatial

Landslides have become more common and intense in the latest decades due to a combination of factors such as geological, geomorphological, morphometric, climatic, and anthropogenic interventions (Paliaga et al 2019). Rainfall-induced landslides account for the vast majority of landslides in India (Ering and Babu 2016). Natural disaster events are unavoidable, however by raising public awareness, the number of fatalities can be reduced. Kerala faces a greater threat to natural disasters because of the exposure of a high density of population and its geographical characteristics. The state experienced unparalleled heavy rainfall during the monsoon seasons in 2018 and 2019 and causing severe floods and related disasters throughout the state (Vijayakumar et al 2021). Landslides are frequent in the Western Ghats where the slope is steep and the soil is oversaturated as a result of prolonged rainfall combined with unscientific land use, irrigation, and construction activities (Sajinkumar et al 2011, Yuvaraj and Dolui 2021). Achu et al (2020) produced the landslide susceptibility maps of the southern Western Ghats region in Kerala using Dempster-Shafer, Bayesian probability, and logistic regression methods.

In particular geoscience, mapping, remote sensing, and geographic information systems play an important role in landslide studies (Suresh 2018). For the hazard zonation mapping, a variety of techniques and models are utilized, including models such as Logistic Regression (LR), Frequency Ratio (FR), Weights of Evidence, AHP, Fuzzy logic, Fuzzy-AHP, machine learning techniques, and others (Kumar and Anbalagan 2016, Mokarram and Zarei 2018, Pham et al 2018, Noorollahi et al 2018, Devaraj S and Yarrakula 2018, Chandrasekaran R et al 2019, Bragagnolo et al 2020, Sreedevi and Karthikeyan 2021).AHP is widely used to generate potential landslide zones among them since it has been extensively used in decision-making for complex mathematical problem-solving scenarios and it is a powerful yet sophisticated method for making the decision as well (Mandal and Mandal 2018). As a result, attempts were made in the current study to measure the reliability of the AHP in identifying landslide-susceptible zones in the KRB based on actual landslide events due to intense rainfall that occurred in August 2018. The main objectives of this work were identifying landslide susceptible areas using an integrated approach of Remote sensing and checking the effectiveness and accuracy of AHP to weigh the factors causing landslides and hence, generating susceptibility zonation maps

MATERIAL AND METHODS

Study area: KRB in Kerala, India lies within $75^{\circ}35'$ to $75^{\circ}59'$ East Longitude and $11^{\circ}30'$ to $11^{\circ}44'$ North Latitude and has an area of 666 km^2 (Fig. 1). The study area consists of topographically three regions, the rocky highlands on the eastern side, the sandy low lands with deltas close to the Arabian Sea on the western side, and midlands with lateritic hillocks. Kuttiyadi River is the major drainage for the Kozhikode district. The watershed shows a dendritic drainage pattern. The river dammed at Kakkayam for the hydroelectric project and the tailrace waters of the project are stored at Peruvannamuzhi, for irrigation.

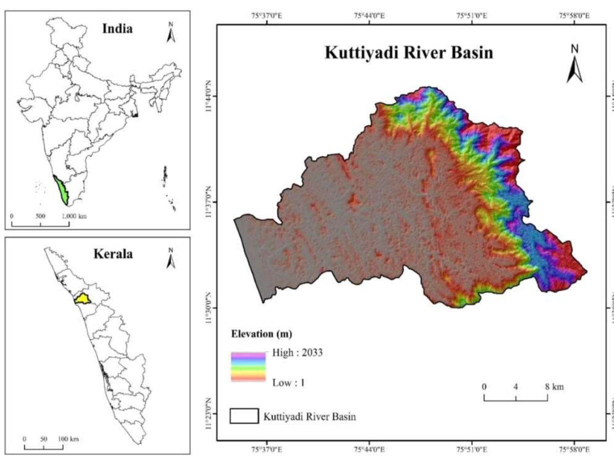

Fig. 1. Map of the KRB region

Methodology: Seven causative factors such as slope, relative relief, drainage density, distance from drainages, land-use/land cover, distance to roads, and road density were discovered to be primarily responsible for the Landslide Susceptibility Mapping. Thematic maps were created for each of the seven aspects, and were georeferenced, projected Universal Transverse Mercator (UTM Zone 43N) using the World Geodetic System (WGS 1984). Weights for all classes of each of the seven factors were calculated using AHP (Myronidis et al 2015). Then, the landslide susceptibility index was applied and the layers were integrated to create the landslide susceptibility map of the study area. Finally, validation of the map was done by examining the landslide inventory locations in 2018 within the study area obtained by field-validated data delineated using Open Street Map (OSM) and accuracy tested using Receiver Operating Characteristics (ROC) curve method (Vakhshoori and Zare 2018). The datasets used in the study are given in Table 1 and the methodology followed is shown in Figure 2.

Data acquisition: Sentinel 2A – Band 8, Band 4 and Band 3 data (04/11/2019) procured from USGS for the preparation of LULC and lithological map from Bhukosh, Geological Survey of India on the scale 1:50000. Drainage map delineated from Survey of India toposheets – 49 M/10, 11, 14, and 15 on the scale 1:50000. Road network data has been derived from

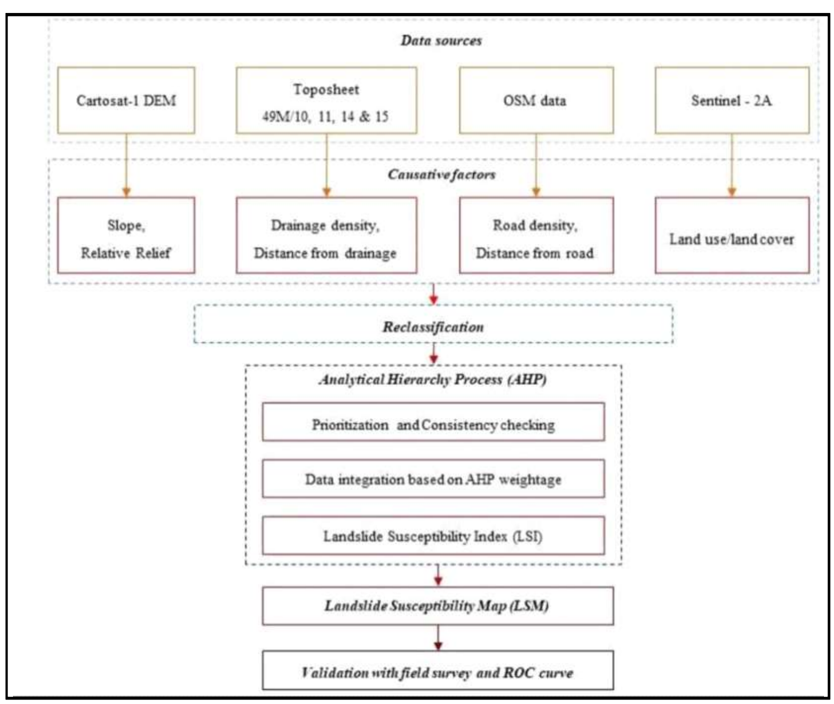

Fig. 2. Methodology flow chart

Open Street Map (OSM) and Slope map created using ASTER DEM (30 m × 30).

Analytical hierarchy process-based landslide hazard zonation: The AHP method was utilized to characterize the factors that trigger landslide events more qualitatively and to determine their weights. The AHP method is based on a matrix-based pair-wise comparison of the classes of each causative factor. To establish the importance of factors between one another, each factor is rated against every other factor. This is done by assigning a value between 1 and 9 and this value and its importance (Table 2).

To establish a pair-wise comparison matrix (A) for causative factors, factors of each level and their weights are given as $A_1, A_2 \ldots A_n$. The relative importance between factors A_1 and A_2 is expressed as A_2/A_1.

$$A=\begin{bmatrix} 1 & \frac{A1}{A2}\cdots & \frac{A1}{An} \\ \frac{A2}{A1} & 1\ldots & \frac{A2}{An} \\ \frac{An}{A1} & \frac{An}{A2}\cdots & 1 \end{bmatrix}$$

Matrix calculation gives factor and class weights results as eigenvector. Calculation of maximum eigenvalue is a part of the AHP model as well. The pairwise comparison matrix for this study is given in Table 3.

Where λmax is depicted as the maximum eigenvalue and n is the number of elements present in the row/column of a pair-wise matrix. Consistency ratio (CR) is formulated as:

Consistency Ratio (C.R) = Consistency Index (C.I)/ Random Consistency Index (R.I) (3)

Table 1. Datasets used in the study

Conditioning factors	Resolution	Data source
LULC	10m	Sentinel 2A (https://earthexplorer.usgs.gov/)
Drainage	1:50000	Survey of India toposheets – 49 M/10, 11, 14 and 15
Road network	-	Open Street Map (OSM) (https://www.openstreetmap.org/)
Slope, relative relief	30m	ASTER DEM (https://search.earthdata.nasa.gov/)
Rainfall	-	India Meteorological Department (https://mausam.imd.gov.in/)

Table 2. Ordinal scale for pair-wise comparisons (Saaty 1977)

Importance	Definitions	Explanation
1	Equal importance	Both elements have equal contribution in the objective
3	Moderate importance	Moderate advantage of the one element compared to the other
5	Strong importance	Strong favoring of one element compared to the other
7	Very strong importance	One element is strongly favored and has domination in practice, compared to the other element
9	Extreme importance	One element is favored in comparison with the other, based on the strongly proved evidences and facts
2,4,6,8	Intermediate importance	
1/3, 1/5, 1/7, 1/9	Value for inverse comparison	

Table 3. Pairwise comparison matrix, consistency ratio, and criteria weights of each class

	Slope	RR	D.Dist	DR	DD	RD	LULC	Class weights	λ_{max}	CI	RI	CR
Slope	1.00	1.80	3.00	4.50	1.29	4.50	1.13	0.25	7	(7-7)/(7-1) = 0	1.32	0/1.32 = 0 < 0.10
RR	0.56	1.00	1.67	2.50	0.71	2.50	0.63	0.14				
D.Dist	0.33	0.60	1.00	1.50	0.43	1.50	0.38	0.08				
DR	0.22	0.40	0.67	1.00	0.29	1.00	0.25	0.06				
DD	0.78	1.40	2.33	3.50	1.00	3.50	0.88	0.19				
RD	0.22	0.40	0.67	1.00	0.29	1.00	0.25	0.06				
LULC	0.89	1.60	4.00	4.00	1.14	4.00	1.00	0.22				
Sum	4.00	7.2	13.34	18	5.15	18	4.52	-				

where RI depicts a random index. Random indexes are compiled based on a number of random samples given in Table 4 (Saaty 1980). The correlation between the causative factors with their CR values is given in Table 5.

Accuracy assessment: Accuracy of the prepared landslide susceptibility map is typically determined using Receiver Operating Characteristics (ROC) curves. It is considered a tool for assessing the model's accuracy and effectiveness (Vakhshoori and Zare 2018). The ROC curve is a graphical representation of the model's results. The True Positive Rate (TPR) and the False Positive Rate (FPR) are used to calculate it. FPR refers to the number of incorrect positive results that occur in all negative cases, while TPR refers to the number of accurate positive results that occur in all positive cases. The most perfect model depicts a curve with the maximum area under the curve (AUC). The AUC value of an ideal model is close to 1.0, while a value of close to 0.5 suggests the inaccuracy of the model (Pradhan and Lee 2010, Zare et al 2013).

RESULTS AND DISCUSSION

Landslide inventory: Thirty-two large and small-scale slope failures occurred during the southwest monsoon period of 2018 (Fig. 3). The rainfall distribution during the southwest monsoon period is graphically represented in Figure 4. Rainfall was the triggering factor for most of the landslides. Analyzing the rainfall data during the southwest monsoon period of 2018, indicated that the rainfall distribution was 783.3mm, 807.2mm, and 734.9 mm, in June, July, and August. However, the rainfall received during the short period (August 13-16) is 472mm. This contributes to 20% of the total rainfall for the three months and the details of those locations are delineated from OSM (Table 6).

Influence of causative factors on landslide: KRB has a slope ranging from 0° to 59° and was divided into five slope categories. From the slope analysis, it is estimated that 466 km^2 area falls under very gentle (0°-15°), 107 km^2 area falls under gentle (16°-25°), 65 km^2 area under moderate (26°-35°), 21 km^2 area under steep (36°-45°), and 3 km^2 area under very steep slope (>45°). The eastern section of the basin is dominated by steep slopes and very steep slopes. Relative relief data has been classified into seven classes with different ranges in relative relief, < 150m, 151-250 m, 251-350 m, 351-450 m, 451-550 m, and > 650 m. In the study area drainage density is classified into five classes and it is varied as 0-1000, 1001-2000, 2001-3000, 3001-4000, and >4000 m/km^2. Distance from drainage has been divided into eleven classes, each with a 200-meter interval for the first two classes and a 400-meter interval for the remaining classes. Road density was divided into five categories: 0-6000, 6001-12000, 12001-18000, 18001-24000, and > 24000m/km^2. Distance from road layers has eleven classes with 200m intervals for the first two classes and an interval of 400m for the rest of the classes. Out of the total LULC, 451 km^2 is covered with Agricultural/populated flat land, 108km^2

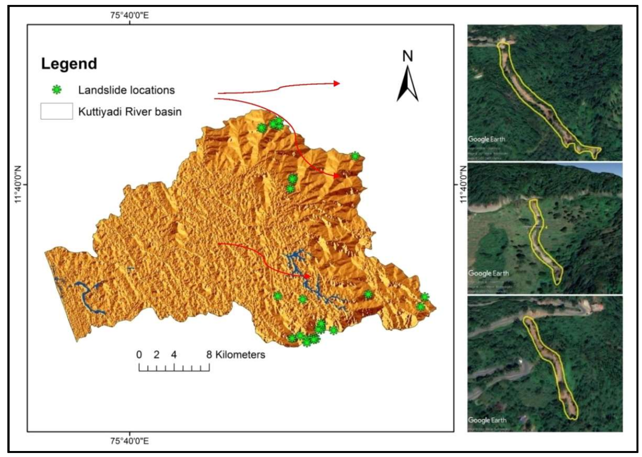

Fig. 3. Landslide locations (2018)

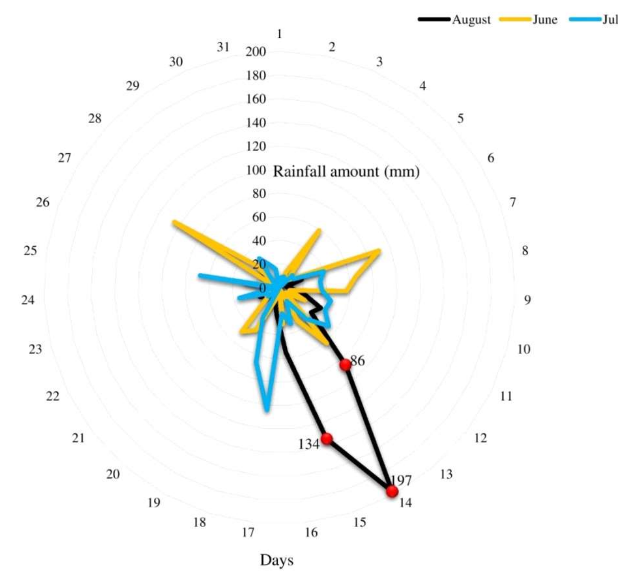

Fig. 4. Rainfall Kuttiyadi River Basin June to August 2018 (in mm)

Table 4. Average random consistency index (RI)

N (number of factors)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Table 5. Range of landslide susceptibility index for each criterion

Parameter	Features	Area (km^2)	Factor weight	Rank	CW	LSI	λ_{max}	CI	RI	CR
Slope (°)	0 - 15	466	0.25	1	0.04	0.010	5	(5-5)/(5-1) = 0	1.12	0/1.12 = 0 <0.10
	16 - 25	109		3	0.12	0.030				
	26 - 35	66		5	0.20	0.050				
	36 - 45	22		7	0.28	0.070				
	>45	3		9	0.36	0.090				
Relative relief (m)	<150	443	0.14	1	0.03	0.004	7	(7-7)/(7-1) = 0	1.32	0/1.32 = 0 < 0.10
	151 - 250	80		1	0.03	0.004				
	251 - 350	83		3	0.09	0.013				
	351 - 450	42		5	0.16	0.022				
	451 - 550	15		6	0.19	0.026				
	551 - 650	2		7	0.22	0.039				
	>650	1		9	0.28	0.039				
Distance from drainage (m)	0 - 200	355	0.08	9	0.20	0.016	11	(11-11)/(11-1) = 0	1.51	0/1.51 = 0 < 0.10
	201 - 400	104		8	0.17	0.014				
	401 - 800	79		7	0.15	0.012				
	801 - 1200	45		6	0.13	0.010				
	1201 - 1600	25		5	0.11	0.009				
	1601 - 2000	13		4	0.09	0.070				
	2001 - 2400	11		3	0.07	0.005				
	2401 - 2800	9		1	0.02	0.002				
	2801 - 3200	7		1	0.02	0.002				
	3201 - 3600	6		1	0.02	0.002				
	>3600	12		1	0.02	0.002				
Distance from road (m)	0 - 200	331	0.06	9	0.24	0.014	11	(11-11)/(11-1) = 0	1.51	0/1.51 = 0 < 0.10
	201 - 400	138		8	0.21	0.013				
	401 - 800	99		7	0.18	0.011				
	801 - 1200	30		4	0.11	0.006				
	1201 - 1600	16		3	0.08	0.005				
	1601 - 2000	12		2	0.05	0.003				
	2001 - 2400	10		1	0.03	0.002				
	2401 - 2800	7		1	0.03	0.002				
	2801 - 3200	6		1	0.03	0.002				
	3201 - 3600	5		1	0.03	0.002				
	>3600	12		1	0.03	0.002				
Road density (m/km^2)	0 -6000	508	0.06	1	0.04	0.001	5	(5-5)/(5-1) = 0	1.12	0/1.12 = 0 <0.10
	6001 - 12000	140		2	0.08	0.002				
	12001 - 18000	12		6	0.23	0.004				
	18001 - 24000	4		8	0.31	0.004				
	>24000	2		9	0.35	0.007				
LULC	Agricultural/ populated flat land	451	0.22	1	0.04	0.002	5	(5-5)/(5-1) = 0	1.12	0/1.12 = 0 <0.10
	Thickly vegetated forest area	108		3	0.12	0.005				
	moderately vegetated forest area	77		5	0.20	0.014				
	Sparsely vegetated area	17		7	0.28	0.019				
	Barren land	2		9	0.36	0.021				
	Waterbody	11		0	0.00	0.000				
Drainage density (m/km^2)	0 - 1000	245	0.02	1	0.04	0.001	5	(5-5)/(5-1) = 0	1.12	0/1.12 = 0 <0.10
	1001 - 2000	134		3	0.12	0.002				
	2001 - 3000	140		5	0.20	0.004				
	3001 - 4000	112		7	0.23	0.004				
	>4000	35		9	0.36	0.007				

CW – Criteria Weight, LSI – Landslide Susceptibility Index, CI – Consistency Index, RI – Random Index, CR – Consistency Ratio
CR value of 0.1 is the maximum permissible consistency of any matrix. CR value >0.1 is considered as inconsistent. Meanwhile, value 0 demonstrates a perfectly consistent comparison result (Saaty 1980)

covered with thickly vegetated forest area, 778km^2 with moderately vegetated forest area, 17 km^2 with sparsely vegetated area, 2 km^2 with barren land and 11 km^2 with waterbody Landslides are less likely in vegetation-covered areas, yet landslides are reported even in such zones of the study area. Although sparsely vegetated areas account for only 3% of the total land area, they account for 28% of all landslides, making this class the most vulnerable to landslides. The maps of landslide causative factors are given in Figure 5.

Landslide susceptibility zonation (LSZ): The LSZ of the study area grouped as stable, moderately susceptible, highly susceptible, and very highly susceptible, depending on their ability to trigger landslides (Fig. 6). A total of 23 km^2 (3%) of land has been identified as being in the very high susceptible category five landslides are validated in this zone. A total of 57 km^2 (9%) is at high susceptibility 12 landslides are identified in this class, while 83 km^2 (12%) is in a moderately susceptible area 13 landslides are validated in this zone. The large area, which covers 503 km^2 (76%) out of a total area of

Table 6. Landslide locations from OSM

Name	Latitude	Longitude	Distance from crown to toe (m)	LULC	Year
Location 1	11.726948	75.82009	129.12	Thickly vegetated forest area	2018
Location 2	11.728744	75.8148	223.15	Moderately vegetated area	2018
Location 3	11.508158	75.85521	34.46	Thickly vegetated forest area	2018
Location 4	11.728777	75.81358	150.54	Moderately vegetated area	2018
Location 5	11.732344	75.8199	166.88	Moderately vegetated area	2018
Location 6	11.508784	75.85754	47.76	Thickly vegetated forest area	2018
Location 7	11.673406	75.83444	24.2	Barren land	2018
Location 8	11.67195	75.83399	20.2	Barren land	2018
Location 9	11.551536	75.96919	38	Thickly vegetated forest area	2018
Location 10	11.554262	75.91114	38.17	Moderately vegetated area	2018
Location 11	11.696172	75.89767	145.42	Moderately vegetated area	2018
Location 12	11.549148	75.84406	18.41	Moderately vegetated area	2018
Location 13	11.552435	75.81837	26.48	Agriculture/Populated flat land	2018
Location 14	11.509442	75.83326	47.95	Agriculture/Populated flat land	2018
Location 15	11.50537	75.84831	101.18	Thickly vegetated forest area	2018
Location 16	11.510031	75.85503	81.35	Thickly vegetated forest area	2018
Location 17	11.508241	75.85526	43.28	Thickly vegetated forest area	2018
Location 18	11.508915	75.85756	124.56	Thickly vegetated forest area	2018
Location 19	11.512169	75.84142	51.57	Moderately vegetated area	2018
Location 20	11.508436	75.84811	40.52	Agriculture/Populated flat land	2018
Location 21	11.519749	75.86272	180.44	Thickly vegetated forest area	2018
Location 22	11.520759	75.86299	142.29	Moderately vegetated area	2018
Location 23	11.51842	75.86292	107.13	Thickly vegetated forest area	2018
Location 24	11.518842	75.86004	12.54	Moderately vegetated area	2018
Location 25	11.524412	75.86295	110.72	Agriculture/Populated flat land	2018
Location 26	11.517659	75.87559	60.91	Moderately vegetated area	2018
Location 27	11.541397	75.96494	94.49	Barren land	2018
Location 28	11.672332	75.83318	14.1	Moderately vegetated area	2018
Location 29	11.662535	75.83136	18.66	Moderately vegetated area	2018
Location 30	11.724154	75.80292	43.84	Moderately vegetated area	2018
Location 31	11.725018	75.8016	17.36	Moderately vegetated area	2018
Location 32	11.504785	75.84834	134.92	Thickly vegetated forest area	2018

Table 7. Area distribution of landslide susceptible classes and percentage of validation of landslides on respective classes

Landslide susceptibility class	Area (km^2)	Area (%)	Validation slides	Percentage of slides
Stable	503	76	2	6
Moderate	83	12	13	41
High	57	9	12	37
Very High	23	3	5	16
Total	666	100	32	100

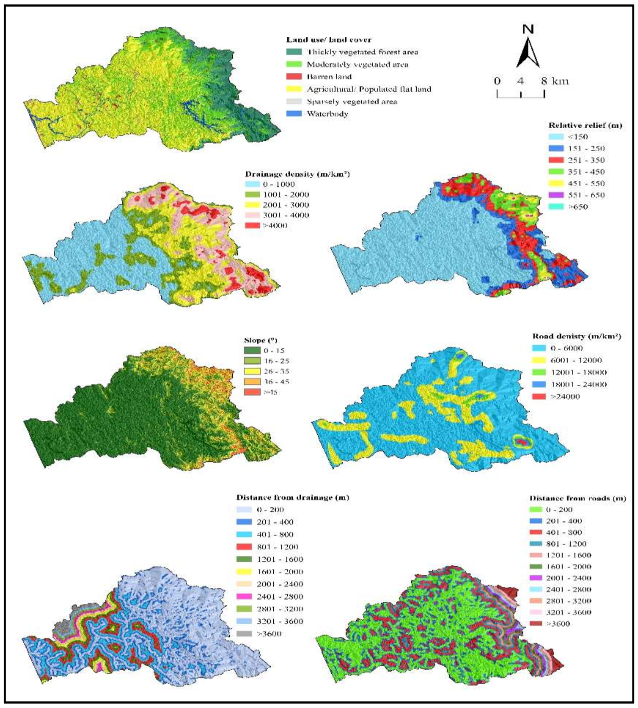

Fig. 5. Spatial distribution of the selected causative factors

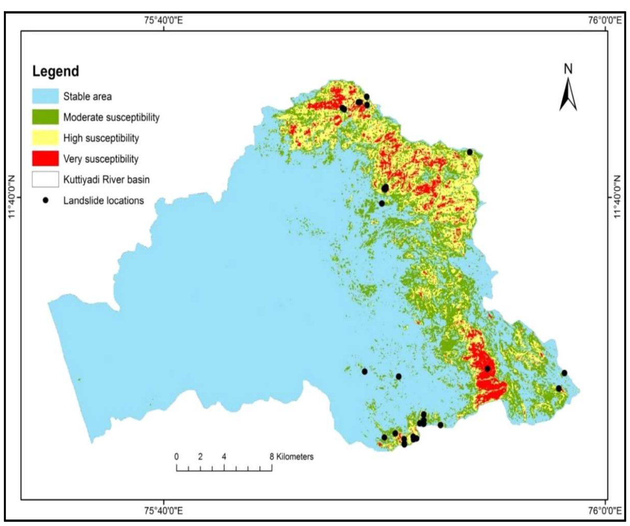

Fig. 6. Landslide susceptibility classes with landslide inventory

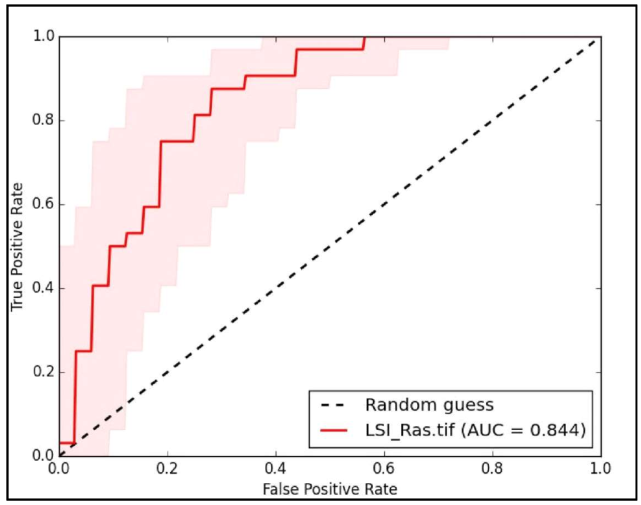

Fig. 7. Assessment of landslide susceptibility map performance based on ROC

666 km^2, is stable and two landslides are identified during the southwest monsoon period of 2018 (Table 7). 75% of landslides in the study area in 2018 occurred in the moderate, high, and very high susceptibility zones. Landslide Inventory 2018 and validation establish the accuracy of the Landslide Susceptibility Map (LSM). The AHP method predicted possible landslide areas in the KRB, and the area under the AUC was 0.84, indicating 84% accuracy (Fig. 7). Steeper slopes are the home to landslide activities. Most of the slope failure activities in the KRB have taken place on cut slopes or an embankment alongside roads. 32% of the landslides that occurred in 2018 were within the vicinity of 100m from the roads. The eastern part of the KRB which has highly susceptible areas possesses a high drainage density. Distance from drainage was very low in the eastern part which causes high seepage and triggered landslides. Land use/land cover also has a great influence on the occurrence of landslides. In the study area, 65% of the total landslides occurred either in the moderately vegetated area or in thickly vegetated areas. It may be due to the high-intensity rainfall for a couple of days and over saturation of overburdened materials by the infiltration of water due to thick vegetative cover.

CONCLUSION

The study area contains 503 km^2 of stable with two landslides validated, 83 km^2 of moderately susceptible zones validated with 13 landslides, 57 km^2 of high susceptible zone with 12 landslides, and 23 km^2 of very high susceptible zones validated with 5 landslides. AUC of the ROC curve showed 84% accuracy in the result. This study proves the accuracy and efficiency of the AHP method on weighted parameters. Hence, AHP can be taken as a reliable tool and used for landslide susceptible zonation studies. The conclusions of this study show that when field circumstances are adequately determined by good proficiency, the AHP approach can generate more accurate results. The results obtained on the stability of the area can be utilized for administrative planning and to chalk out mitigation strategies in the study area.

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Landfill Site Suitability Analysis in Puduserry region, Palakkad, Kerala: An Integrated Approach Using Geospatial Techniques and Analytical Hierarchy Process

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Abstract: The primary goal of the current study was to identify and discover a suitable site at Pudussery Panchayat in Kerala's Palakkad district for a landfill site in a way that was financially viable, environmentally beneficial, and acceptable to society. The landfill location was chosen based on nine critical criteria transportation network, water bodies, drainage, slope, public assets, settlements, geomorphology, land use/land cover, and depth to groundwater. Analytical Hierarchy Process (AHP) concept and geospatial technology were applied to the analysis. According to the study, of the total 65.14 km^2, 0.14 km^2 (0.21%) was highly suitable, 0.18 km^2 (0.28%) was moderately acceptable, 25.85 km2 (39.68%) was less suitable, and 38.97 km2 (59.83%) were unsuitable for garbage disposal. The study demonstrated the effectiveness of using GIS technologies in conjunction with AHP to make decisions and locate appropriate disposal sites.

Keywords: Solid waste management, Geographical information system, Remote sensing, Landfill, Analytical hierarchy process

The solid waste management (SWM) system is a serious environmental issue that will soon get considerably worse due to the current rising industrialization and urbanization (Ajay 2019, Kamdar et al 2019). To achieve a better sustainable development society, SWM has emerged as a significant challenge for both developing and developed countries (Khan et al 2018). Sustainable approaches to dealing with this waste are thus urgently needed (Abdel-Shafy and Mansour 2018). It is essential to develop a management system that is efficient and enables the resolution of solid waste disposal-related complexity, uncertainty, multi-objectivity, and subjectivity with the least amount of detrimental environmental effects. A symbolic SWM system in both developed and developing countries brought to the forefront several issues including low and inconsistent waste collection, unlawful dumping and burning, the emergence of fly and vermin breeding grounds informal garbing activities that cause major constraints.

In emerging countries like India, SWM has emerged to be one of the major development challenges (Kumar et al 2017). Over the last six years, from 2015 to 2020, India's per capita waste generation increased from 118.68 gm/day to 119.07 gm/day (CPCB 2020). An estimated 80% to 90% of solid waste in India is burned in open areas or dumped in landfills without proper management practices, which pollutes the air, water, and soil. There are different methods of disposal of solid wastes practiced in and around the globe such as thermal treatment or incineration, burial, biological treatment or composting, landfills, etc. (Makarichi et al 2018). Among those, landfills are the most widely used method in low and medium-income countries because of their simple and cost-effective (Kamdar et al 2019). In this context, reliable waste management systems must plan for the selection of new landfills and manage huge volumes of solid waste (Sukholthaman and Shirahada 2015).

Emerging technologies like geographic information systems (GIS) and Remote Sensing (RS) can be integrated to ensure the best potential results in effective and efficient strategies for SWM (Hazarika and Saikia 2020). GIS is a tool that allows users to store, retrieve and analyze spatial data and visualize the results of any spatial and non-spatial-based analysis (Mohammedshum et al 2014), and RS technology can provide up-to-date spatial information on land-cover patterns useful as input data in the task. Decision-making is a kind of data mining process that helps to solve day-to-day problems using standard optimization techniques. GIS and multi-criteria decision analysis (MCDA) offers tools to assist in resolving this problem and suggest suitable sites for landfilling, waste segregation, and recycling process (Chamchali et al 2019, Aderoju et al 2020, Eghtesadifard et al

2020). The analytic hierarchy process (AHP) (Saaty 1980) is one of the most widely accepted MCDA approaches and has been widely used in identifying potential landfill sites (Chabuk et al 2017, Rana et al 2017, Sharma et al 2018). The integration of GIS with the AHP is used to assist in the selection process as a decision-making tool (Ramya and Devadas 2019). The studies are lacking, despite the reality that the use of MCDM for thoroughly determining the suitability of potential landfill sites is recognized. Moreover, no studies have used the GIS and AHP techniques to identify potential landfill sites using locally available variables related to socioeconomic conditions, natural resources, land use, etc. In the end, it might be a reliable approach to selecting a landfill site, according to various technological, ecological, financial, sociocultural, and other factors with rigorous national and international rules (Chabok et al 2020). . This study is attempt to identify a suitable site for landfills by comprehending the factors that should be taken into account when determining whether a site is suitable, and how the AHP functions as a strong decision-making tool when ranking the factors and identifying suitable sites in Pudussery Panchayat of Palakkad district, Kerala.

MATERIAL AND METHODS

Study area: The study area which is located in the Palakkad district is known as the land of palmyras and agriculture and is often known as the Gateway of Kerala which is composed of 23 wards stretches between 10º 45' 50.14" N to 10º 50' 55.17" N latitudes and 76º 42' 55.13" E to 76º 50' 56.14" E longitudes of an elevation of 105 meters above mean sea level with an area of 65.14 sq. km (Fig. 1). The gap in the Western Ghats itself makes the area different from other places in the district. The study area has a tropical wet and dry climate and the temperatures remain moderate throughout the year except during the summer months which are extremely hot. The study area is bounded by Pudussery East, Pudussery West, and Pudussery Central, and the majority of the industries are concentrated in Kanjikode, known as the second-largest industrial region in Kerala state. Kanjikode is the industrial belt in Palakkad linking Kochi with Bengaluru through Palakkad and Coimbatore. The Walayar river, one of the tributaries of Bharathapuzha flows through the study area The major part of the study area is practicing agriculture and allied activities and the rest consists of open forests, natural vegetation, and plantations. The high-altitude wind direction is mainly from the west, east, and southwest direction in all seasons which is also a reason for the concentration of industries within the study area.

Selection criteria: Site selection for waste disposal in this study was an important step based on ten major parameters: groundwater level, drainage, slope, geomorphology, public assets, waterbodies, settlements, land use/land cover (LULC), and transportation system. The continuous granulite terrain disqualified geology. The significance of the study, regional traits, and long-term goals were taken into consideration when choosing the criteria. Proposed landfill sites were assessed using secondary data, including literature studies. Priority was given to factors like groundwater depth, distance from drainage, and proximity to water bodies to prevent water contamination. Settlements and public property were considered to protect public health, and distance from transportation networks helped avoid traffic congestion. Terrain slopes and bare land in the geomorphology were crucial for efficient and safe waste disposal sites, minimizing the risk of contamination and public disturbance.

Data acquisition and preparation of thematic layers: The details of data acquired from different sources for thematic layer preparation using GIS and RS are summarized in Table 1. Criteria layers for the evaluation of nine parameters were prepared for landfill site suitability analysis in the QGIS

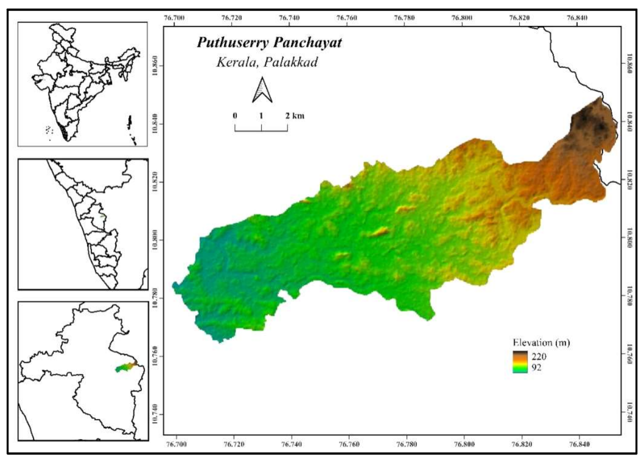

Fig. 1. Location map of the study area

Table 1. Data sets used in the study

	Data type	Data sources
Transport network	Vector	Open street map
Waterbodies	Vector	Open street map
Settlements	Vector	Open street map
Public assets	Vector	Open street map
Drainage	Vector	Bhuvan, Indian geo-platform of ISRO
Geomorphology	Vector	Bhukosh, Geological Survey of India
Land use/land cover	Raster	Sentinel 2A, 10m resolution (February 28, 2020)
Slope	Raster	ASTER DEM, 30m resolution
Depth to groundwater	Vector	Well inventory data

Platform. Separate buffer maps were created for each criterion using the proximity buffer ring tool in the GIS environment. Buffer maps were created under the guidelines specified in the Municipal Solid Waste Management Manual (May 2000) of the Central Public Health and Environmental Engineering Organization (CPHEEO), Government of India (Table 2) and the final suitability map obtained from hierarchical analysis of the input layers.

The input data layers for the study were generated from related maps by scanning, registering, and digitizing the relevant information in open-source QGIS software. Layers were projected in Universal Transverse Mercator (UTM) projection system, WGS 84/UTM Zone 43N. The transport network layer included both railway and road networks, Waterbodies included dams and rivers, which were extracted from Open Street Map (OSM). Settlements were mainly considered as the human-populated areas which were extracted as a point feature from OSM. Geomorphologic and Drainage datasets were acquired from the Bhukosh portal (https://bhukosh.gsi.gov.in/) of the Geological Survey of India and the Bhuvan Geo-portal (https://bhuvan.nrsc.gov.in/) of the National Remote Sensing Centre (NRSC) respectively. The slope was generated from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) with a resolution of 30m. The LU/LC map of the study area was generated from Landsat 8 OLI (Operational Land Imager) satellite data acquired from USGS Earth Explorer (https://earthexplorer.usgs.gov/) by using the maximum likelihood classification technique of supervised learning algorithms. The depth of the well, well parapet height, and groundwater level were measured from 15 wells in the study area and locations were marked with the help of the handheld Global Positioning System (GPS) to prepare the well inventory dataset. Subsequently, the same dataset was interpolated by using Inverse Distance Weighted (IDW) technique and developed raster surface data.

Assign the weights and normalization with AHP: In the present study, a pairwise comparison matrix was created and each parameter was compared with one another by using Saaty's 9-scale table (Table 3). It has a value between 1 and 9. Priority reduces with a decrease in rank i.e., 1 for less preferable and 9 for highly preferable. To establish a pair-wise comparison matrix (A) for parameters, factors of each level and their weights are given as A1, A2… An. The relative importance between parameters A1 and A2 is expressed as A2/A1.

$$A = \begin{bmatrix} 1 & \frac{A1}{A2} & \cdots & \frac{A1}{An} \\ \frac{A2}{A1} & 1 & \cdots & \frac{A2}{An} \\ \frac{An}{A1} & \frac{An}{A2} & \cdots & 1 \end{bmatrix} \quad (1)$$

Table 2. Evaluating criteria specified in municipal solid waste management manual, Government of India (May 2000)

Criteria	Distances
Distance to the transport network	No landfill should be constructed within 200 m
Distance to waterbodies	No landfill should be constructed within 100 m of a navigable river or stream
Distance to drainage	No landfill should construct within 200 m
Distance to settlements	A landfill should be at least 500 m from a notified settlement area
Distance to assets	No landfill should be constructed within 300 m for both restricted and sensitive places
Groundwater	A landfill should not be constructed in areas where water is less than 2m below the ground surface

Table 3. Pairwise comparison scale for AHP

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	Activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

In the study, nine individual parameters have been selected that influence the landfill site suitability. Since each parameter has a different level of influence on the landfill site selection process, it is mandatory to determine the influence quantitatively. To achieve that, the AHP method was used in this study. The significance of each criterion on landfill site suitability was analysed to determine the weight. The results of the pairwise comparison matrix and the parameter weights are given in Table 5. The same procedure was followed to get the weight of each sub-category of the main parameters and the weights are given in Table 6. It is important to get the consistency of the answer because otherwise, inconsistency of results regarding the judgment may occur (Saaty 2001). The Consistency Ratio (CR) is a comparison between the Consistency Index (CI) of the matrix and the Random Index (RI), which are already provided by Saaty who developed the AHP (Eq. 2). RI has been compiled based on several random samples (Saaty 1980) that are given in Table 4. CR is formulated as:

$$CR = CI/RI \quad (2)$$

CI can be calculated using the following equation:

$$CI = (\lambda max - n) / (n - 1) \quad (3)$$

where λ_{max} is the largest matrix eigenvalue and n is the number of elements present in the pairwise comparison matrix.

If CR is < 0.1, the consistency value can be considered

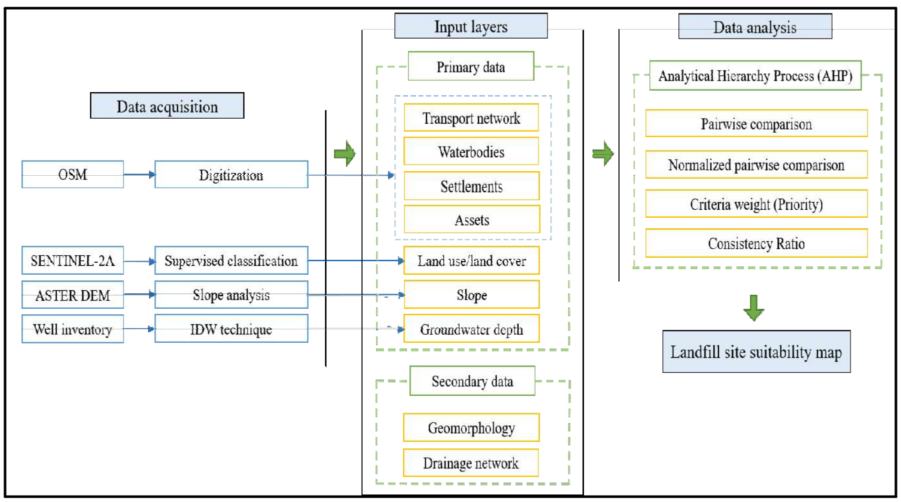

Fig. 2. Methodology followed in the study

Table 4. Random consistency values

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty (1980)

Table 5. Pairwise comparison matrix of nine thematic layers

Layers	LULC	SL	DT	AS	GM	SE	DW	DD	GW	Priority	Weighted sum	λ	λ_{max}	CI	CR
LULC	1	3	4	4	5	7	9	9	9	0.33	3.36	10.17	9.66	(9.66-9) / (9-1) = 0.08	0.08/1.45 = 0.06 < 0.10
SL	1/3	1	3	5	3	8	7	7	7	0.23	2.38	10.54			
DT	1/4	1/3	1	3	3	6	5	6	6	0.15	1.52	10.15			
AS	1/4	1/5	1/3	1	2	5	4	5	4	0.10	0.97	9.69			
GM	1/5	1/3	1/3	1/2	1	3	4	4	4	0.08	0.74	9.39			
SE	1/7	1/8	1/6	1/5	1/3	1	2	3	3	0.04	0.38	8.88			
DW	1/9	1/7	1/5	1/4	1/4	1/2	1	1	1	0.03	0.24	9.47			
DD	1/9	1/7	1/6	1/5	1/4	1/3	1	1	1	0.02	0.22	9.30			
GW	1/9	1/7	1/6	1/4	1/4	1/3	1	1	1	0.02	0.23	9.36			

LULC – Land use/land cover, SL - slope, DT – Distance from transport network, AS - Asset, GM – geomorphology, SE - settlement, DW – Distance from waterbodies, DD – Drainage density, GW - Groundwater, CI - Consistency Index, CR - Consistency Ratio realistic, whereas CR > 0.1 recommends a revised judgment. The CR values of each parameter are also given in Table 6.

RESULTS AND DISCUSSION

Assignment of weights: According to the impact of each variable on the choice of landfill location, weights were allocated, with the LULC receiving the largest weight (0.33) and the groundwater having the lowest weight (0.02). Table 6 shows the area covered in each class, and Figure 3 shows the criteria map.

Distance from public assets: Based on Distance from public assets, 23.55 km2 falls under the "unacceptable" zone (within 300 meters of public assets). 300-600 meters covers 21.43 km^2, 600-900 meters comprises 10.36 km^2, 900-1200 meters extend over 5.17 km^2, 1200-1800 meters encompass 2.80 km^2, 1800-2100 meters includes 1.22 km^2, 2100-2400 meters covers 0.46 km^2, and beyond 2400 meters spans 0.14 km^2.

Distance from drainage: The drainage buffer zones were categorized into seven classes. Within a distance of less than 200 meters, there is an extensive area of approximately 46.29 km^2, rendering it highly unsuitable for a landfill site. In the 200–300-meter range, there's an area of 11.80 km^2. 300-400 meters cover 5.02 km^2, 400-500 meters encompass 1.55 km^2, 500-600 meters comprise 0.31 km^2, 600-700 meters occupy 0.13 km^2, and finally, 700-800 meters cover 0.04 km^2.

Geomorphology: The geomorphology layer reveals several distinct landforms in the studied area, including pediplains, floodplains, active quarries, water bodies, and moderately to highly dissected hills and valleys. Predominantly, pediplains, resulting from denudation processes, cover the largest area at 58.75 km^2. A working quarry takes up 0.07 km^2, while floodplains take up 1.89 km^2, water bodies 1.76 km^2, moderately and badly dissected hills and valleys, and dams and reservoirs together take up 0.61 km^2.

Depth to groundwater: The landfill site is legally forbidden from having depth of groundwater within two meters. Within the surveyed area, 4.58 km^2 falls under the category of a less suitable intermediate zone (2-4 m), with an additional 0.01 km^2 falling within the narrower buffer zone (2 m). The land can be categorized into three depth ranges: 4 to 6 meters, which covers 27.60 km^2, 6 to 8 meters, encompass 28.90 km^2 and 8 to 10 meters, which constitutes 4.05 km2 of the area.

Distance from settlements: Regarding proximity to settlements, a significant portion of approximately 61.97 km2 lies within the buffer zone (500 m), making it strongly unsuitable for the landfill site. The rest of the categorized intervals 500-600 m spans around 1.81 km^2, 600-700 m encompasses about 0.82 km^2, 700-800 m includes 0.38 km^2, 800-900 m comprises 0.13 km^2, and 900-1000 m makes up 0.03 km^2.

Land use Land Cover: In the study area, the dominant land use and land cover categories include water bodies, paddy fields, plantations, natural vegetation, human settlements, and barren terrain. Specifically, water bodies occupy 1.73 km^2, while paddy fields cover 8.65 km^2. Natural vegetation spans an area of 16.33 km^2, followed by plantations at 10.25 km^2 and human settlements at 3.68 km^2. There is a substantial 24.50 km^2 of open, undeveloped land in the research region, which is being considered as a more suitable option for the establishment of a waste disposal site.

Slope: This study region has a slope (inclination) that ranges from 6° to 32°. About 49.61 km^2 of the region had a slope of 7°, making it ideal for dump sites. The area that fell under the intermediate zone was 14.71 km^2. The 0.82 km^2 of the site to be unfit.

Distance from transportation network: One of the evaluating factors for landfill suitability was the distance from the transportation network. With buffer distances, seven courses were dispersed around the research area. The vast majority of the region (55.12 km^2) is in the buffer zone, which is not suitable for landfills. The remaining classes, 200 - 300m, span an area of approximately 6.36 km^2, 2.30 km^2 by 300 to 400 meters, 0.74 km^2 by 500 to 600 meters, 0.41 km^2 by 600 to 700 meters, and 0.03 km^2 by 700 to 800 meters.

Distance from waterbodies: Eight classes were constructed with a set distance from water bodies as a buffer. 7.91 km^2 of the total area, which is not appropriate for a dump site, falls inside the buffer zone (less than 100 m). The remaining classes have a 21.40 km^2 area, which is less suited, The total of 13.50 km^2 is covered by the 600 to 1100 m range, 9.40 km^2 by the 1100 to 1600 m range, 6.89 km^2 by the 1600 to 2100 m range, 1.78 km^2 by the 2600 to 3100 m range, and 0.19 km^2 by the 3100 to 3600 m range. Regarding proximity to waterbodies, 55% of the research area was found to be suitable for the landfill.

Landfill site suitability: Based on the site characteristics, the final landfill suitability map was divided into four categories: highly appropriate sites, moderately suitable sites, less suitable sites, and unsuitable sites. An area of 0.14 km^2 (0.21%) is covered by a highly suitable site, 0.18 km^2 by moderately suitable site, 25.85 km^2 by a less suitable site, and 38.97 km^2 (59.83%) by an unsuitable site (Fig. 4 and Table 7) Sites 1 and 2 in represent the chosen suitable locations (Fig. 4). Due to their location on arid territory, 300–500 meters from the transportation network, 1600-2100 meters from water bodies, and far from drainage, these appropriate sites have very little potential for environmental difficulties. The location's groundwater depth ranges from 6 to 8 meters. The location is 500 to 800 meters away from any populated areas, and there are no resources nearby (900-

Table 6. Thematic layers with their area, weight, consistency index, and consistency ratio

Parameter	T	Features	Area (km^2)	Area (%)	S	T*S	CI	RI	CR
Land use/land cover	0.33	Paddy	8.65	13.28	0.05	0.015	0.08	1.24	0.07
		Plantation	10.25	15.73	0.06	0.019			
		Natural vegetation	16.33	25.07	0.21	0.070			
		Settlements	3.68	5.65	0.13	0.044			
		Waterbodies	1.73	2.66	0.03	0.011			
		Barren land	24.50	37.61	0.52	0.171			
Groundwater	0.02	≤ 2	0.01	0.02	0.05	0.001	0.05	1.12	0.04
		2-4	4.58	7.03	0.08	0.002			
		4-6	27.60	42.37	0.12	0.003			
		6-8	28.90	44.37	0.28	0.007			
		8-10	4.05	6.21	0.48	0.012			
Distance from Settlements	0.04	< 500	61.97	95.13	0.03	0.001	0.08	1.24	0.07
		500-600	1.81	2.78	0.05	0.002			
		600-700	0.82	1.26	0.08	0.003			
		700-800	0.38	0.58	0.14	0.006			
		800-900	0.13	0.20	0.25	0.011			
		900-1000	0.03	0.05	0.45	0.020			
Distance from waterbodies	0.03	< 100	7.91	12.14	0.37	0.009	0.11	1.41	0.08
		100-600	21.40	32.85	0.24	0.006			
		600-1100	13.50	20.73	0.15	0.004			
		1100-1600	9.40	14.43	0.09	0.002			
		1600-2100	6.89	10.58	0.06	0.002			
		2100-2600	4.07	6.25	0.04	0.001			
		2600-3100	1.78	2.73	0.03	0.001			
		3100-3600	0.19	0.29	0.02	0.001			
Distance from transport network	0.15	< 200	55.12	84.62	0.02	0.004	0.10	1.32	0.07
		200-300	6.36	9.76	0.03	0.005			
		300-400	2.30	3.53	0.05	0.008			
		400-500	0.74	1.14	0.09	0.013			
		500-600	0.41	0.63	0.15	0.022			
		600-700	0.18	0.28	0.25	0.037			
		700-800	0.03	0.04	0.41	0.061			
Distance from drainage	0.02	< 200	46.29	71.06	0.03	0.001	0.08	1.32	0.06
		200-300	11.80	18.12	0.03	0.001			
		300-400	5.02	7.70	0.06	0.001			
		400-500	1.55	2.38	0.08	0.002			
		500-600	0.31	0.48	0.14	0.003			
		600-700	0.13	0.20	0.23	0.006			
		700-800	0.04	0.06	0.42	0.010			
Slope	0.23	< 7	49.61	76.16	0.51	0.115	0.04	1.12	0.04
		7-14	14.71	22.58	0.26	0.058			
		14-21	0.77	1.18	0.13	0.029			
		21-28	0.04	0.06	0.06	0.014			
		> 28	0.01	0.02	0.04	0.009			
Geomorphology	0.08	Dam & reservoir	0.61	0.94	0.03	0.002	0.07	1.32	0.05
		Flood plains	1.89	2.90	0.10	0.008			
		Highly dissected hills & valleys	0.69	1.06	0.15	0.012			
		Moderately dissected hills & valleys	1.37	2.10	0.24	0.019			
		Pediplain complex	58.75	90.19	0.08	0.006			
		Quarry & Mine	0.07	0.11	0.37	0.030			
		Waterbodies	1.76	2.70	0.04	0.003			
Distance from assets	0.10	< 300	23.56	36.17	0.02	0.002	0.11	1.41	0.08
		300-600	21.43	32.90	0.03	0.003			
		600-900	10.36	15.90	0.04	0.004			
		900-1200	5.17	7.94	0.06	0.006			
		1200-1800	2.80	4.30	0.10	0.009			
		1800-2100	1.22	1.87	0.15	0.015			
		2100-2400	0.46	0.71	0.23	0.023			
		> 2400	0.14	0.21	0.37	0.037			

T - Theme weights, S - Feature weight, T*S - Final weight, CI - Consistency Index, RI - Random Index, CR - Consistency Ratio

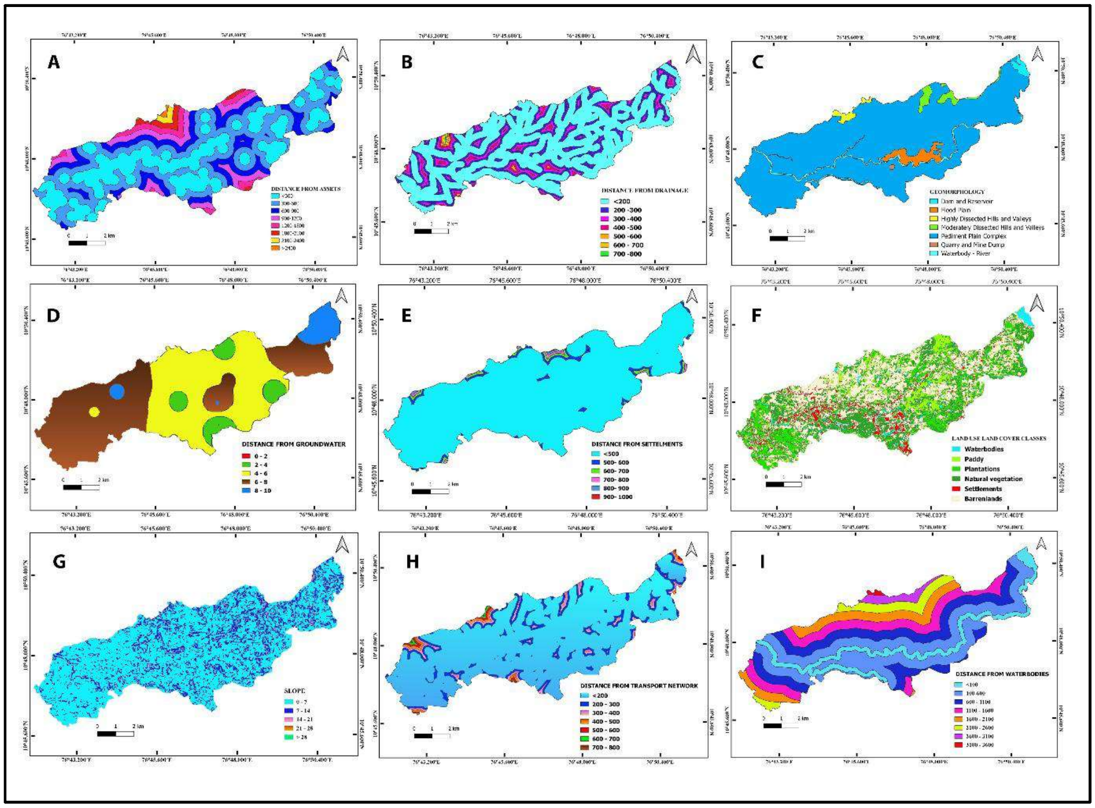

Fig. 3. Contributing criteria in landfill site suitability analysis: (A) Distance from assets, (B) Distance from drainage, (C) Geomorphology, (D) Distance from groundwater, (E) Distance from settlements, (F)Land use Land Cover, (G) Slope, (H) Distance from transport network, (I) Distance from water bodies

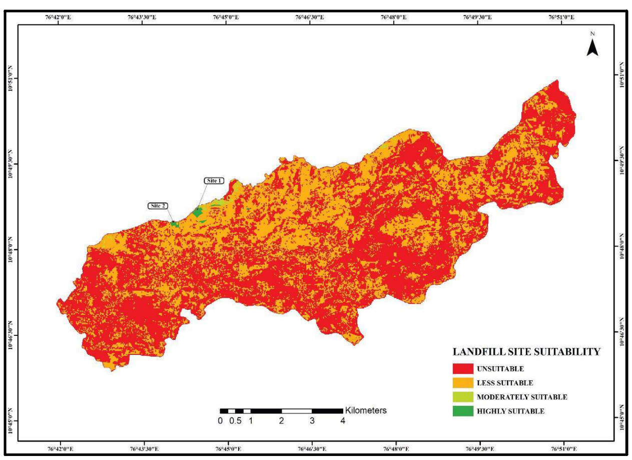

Fig. 4. Final landfill suitability sites derived from analytical hierarchy process

Table 7. Area distribution of final suitability classes

Landfill suitability classes	Area covered (km^2)	Area in %
Unsuitable site	38.97	59.83
Less suitable site	25.85	39.68
Moderately suitable site	0.18	0.28
Highly suitable site	0.14	0.21
Total area	65.14 km^2	100%

1800 m). The location has a flattened slope (< 7°), which is a significant feature that lowers construction costs in the area.

CONCLUSION

In this study, an effort was made to use GIS and Remote Sensing combined with AHP to locate a suitable waste disposal site over the Pudussery Panchayat in the Palakkad region of Kerala. According to the findings in relation to the CPHEEO requirements, there aren't many eligible sites for landfill sites inside the Panchayat. The fastest, cheapest, and most time-effective ways to determine if a landfill site is suitable for disposing of solid waste are through the use of spatial technologies like GIS and Remote Sensing. AHP provides the ideal outcome for this investigation when spatial technologies are combined with powerful decision-making techniques. The study demonstrated how geospatial technologies are more practical for suitability evaluation in a variety of disciplines in the modern, technologically advanced world.

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Ecological Assessment of Natural Populations of *Fritillaria cirrhosa* D. Don: A Critically Endangered Species from Indian North Western Himalaya of Global Significance

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Abstract: *Fritillaria cirrhosa* D. Don, locally known as Kakoli is a critically endangered and perennial plant belonging to the family Liliaceae with immense medicinal importance. It is a major constituent of *Ashtavarga* group. Thus, massive unsustainable extraction from the wild leads to its rapid habitat depletion. Therefore, the present study was carried out to understand the ecological status of this magnificent native species of the Himalaya. Extensive surveys were done following standard ecological methods in Himachal Pradesh. Seventeen natural populations were sampled and recorded 192 herbs from 44 families. Dominant families were Asteraceae, Polygonaceae, Ranunculaceae, etc. The richness of herbs ranged from, 29-51. The total herb density ranged from 11-23 Ind ha^{-1}. The density of *F. cirrhosa* ranged from 0.62-2.30 Ind m^{-2}. The highest density of *F. cirrhosa* was observed in Ritirard (2.30 Ind m^{-2}) and minimum in Kagaldhar (0.33 Ind m^{-2}). The species diversity of herbs ranged from 1.72-3.02. The concentration of dominance ranged from 0.0109-0.0835. Continued unsustainable overuse for its high demand in the market causes challenges to protect the species. Thus, proper management and regular monitoring is required. These findings can be used to guide government policies to safeguard this noteworthy species.

Keywords: Ecological assessment, Diversity, Density, North western Himalaya, Critically endangered, Concentration of dominance

Environmental damage and depleting biodiversity by increasing human populations, demands and anthropogenic pressure on natural forests have also alarmed conservationists, particularly in the fragile Himalayas (Saraswat and Thakur 1998). The broadleaved, evergreen, and coniferous forests of the Himalayas are recognized as representative, natural, and distinctive ecosystems. The western Himalaya is a complex mountain ecosystem ranging from 300 to 6000 m amsl and has diverse biodiversity, amazing landscape and a challenging climate (Rana et al 2022). Himalayan ecosystem is a storehouse of great number of ecologically and socio-economically essential species (Barman et al 2021a). The young and vulnerable Indian Himalayan Region (IHR) is threatened by unsustainable extraction of natural resources, habitat degradation, overexploitation, and climate variability (Ved et al 2003, Rana and Samant 2010, Rana et al 2012). Therefore, the effort has been given to assess the natural populations of *Fritillaria cirrhosa* in the north-western Himalaya because there are no such datasets on the population ecology of the plant or poorly understood, which is a matter of concern. Continuous unsustainable harvesting of bulbs of *F. cirrhosa* due to its high demand in the pharmaceutical industry has resulted in rapid loss of the species' presence throughout the IHR (Chauhan et al 2011). Phytosociological studies will help to identify the species richness, diversity, density and dominance, which will further help to understand the dynamics of its forest vegetation. Thus, managing and conserving the species through an integrated approach is needed, which will further help to formulate specific strategies for the plant's *ex-situ* conservation.

F. cirrhosa comes under the family Liliaceae and it is the medicinal plant of the *Ashtavarga* group, which is perennial and critically endangered medicinal herb in the Himalayan region (Barman et al 2021b) and vulnerable globally according to the IUCN (www.iucnredlist.org), and locally known as Kakoli or Jungli Lahsun. The species is a glabrous, bulbous, 15-60 cm tall plant with a spotted stem. Bulbs are small in size with membranous scales on them. Within a brief period of time, typically from April to September, the plant undergoes both its vegetative and reproductive phases (Bisht et al 2016).

The fully matured bulbs (collected after 3 years) of *F. cirrhosa* are used traditionally in the cure of burns, stomachache, asthma, as a stimulant, and bronchitis (Singh and Rawat 2011). As an aphrodisiac, it is used in Indian Medicine System. In the *Ayurvedic* and *Unani* systems of medicine, the roots are used for healing wounds (Samant et al 1998). The bulbs boiled with the orange peel of this herb and given to cure tuberculosis and asthma (Shaheen et al 2012). Conventionally *F. cirrhosa* is used for tuberculosis, and rheumatism and as a tonic in Jammu and Kashmir UT (Srivastava et al 1986). The powder of bulbs of *F. cirrhosa* is given with milk for body weakness in Uttarakhand, India (Bisht et al 2013). The dried bulb's powder is utilized in Pakistan to alleviate urinary tract infections and to soothe and soften the skin by blending it with butter (Khan et al 2013). Bulbs are also used for the treatment of milk deficiency, fever and hemorrhage (Kaul 2010). For bronchial disorder and pneumonia, it is also recommended in the Chinese medicine system (Zhang et al 2008). The bulbs of the species are also used to cure bronchial and ophthalmic disorder in Himachal Pradesh (Barman et al 2021b) and also used in making anticancerous drugs (Ping et al 1995).

Textural diversity in plant communities is closely linked to species richness, which is considered a crucial factor in both the structural and dynamic aspects of these communities (Van der Marrel 1996). Diversity is commonly alarmed with the sign of variability of natural communities and that's why the study of this species is helps to understand its structure, development, and composition (Li et al 2002). There is a shred of strong evidence that biodiversity and forest resilience are linked together in ecosystems (Folke et al 2004, Thompson et al 2009). Particularly, some species and groups of species carry out crucial activities in forests, making them necessary for the maintenance of all of the forest's functional processes and the long-term development of resilience (Diaz and Cabido 2001). There are no such studies regarding the population structure of *F. cirrhosa* have been done in the Indian northwestern Himalaya. Very less studies on population structure and dynamics have been done on other species (Devi et al 2019, Paul et al 2019, Barman et al 2021a, Rana et al 2022) in the north-western Himalaya. In view of the importance of *F. cirrhosa* as essential species of the temperate forest ecosystem of the Himalaya, the current study has been conducted to assess the population status of *F. cirrhosa* in the north-western Himalaya; and to formulate strategies for the policy makers for the conservation of the species.

MATERIAL AND METHODS

Study area: The State Himachal Pradesh (30°37'50'' N to 33°21'11” N latitudes and 75°59'86” E to 79°07'22” E longitudes) is a part of Trans and North-Western Himalaya (Fig. 1). The study was conducted during 2017-2022 in Lahaul & Spiti (3345-3405 m), Kinnaur (3903 m), Chamba (3592-3712 m), Shimla (3253-3756 m), Sirmaur (3608 m) and Kullu (3150-3538 m) districts of Himachal Pradesh. Topographically, the territory of the state can be divided in three prominent zones, namely the Shiwaliks (Outer Himalaya), mid mountain (Inner Himalaya) and the alpine zones (Greater Himalaya). It is bordered by the autonomous territory of Tibet on the east, Panjab on the west and south-west, Haryana and Uttarakhand on the south-east and by Jammu and Kashmir Union Territory on the north. The whole territory of Himachal Pradesh is hilly region with the altitude ranging from 200 to 7000 m amsl, thus creates great variation in the climatic conditions. The state is blessed with by five major rivers like, Chenab, Yamuna, Ravi, Beas, and Sutlej, as well as numerous tributaries of these rivers. The state is well-regarded for having a healthy and varied climate. Due to different aspects and heights, it also sees significant differences in rainfall distribution and temperature distribution. Precipitation decreases from West to East and South to North. Light to dark brown and yellowish brown with sandy loam to silt and light to dark yellowish brown. The vegetation mainly comprises of tropical, sub-tropical, temperate, sub-alpine and alpine types. Tropical forests are dominated by broad leaved deciduous and evergreen species. Sub-tropical forests are dominated by deciduous broad leaved and ever green and coniferous forests. Temperate and sub-alpine forests are mainly dominated by broad leaved and coniferous species, and alpine meadows are dominated by alpine scrubs and herbaceous species.

Population assessment and data analysis: The physical characteristics of each habitat were used to identify them, and a hand-held Global Positioning System was used to obtain the geographic coordinates of each population. To sample a specific site or habitat where the target species were observed, a 30m x 30m plot was established. For the ecological assessment, a total of 20 quadrats, each measuring 1m x 1m, were randomly placed within the plot

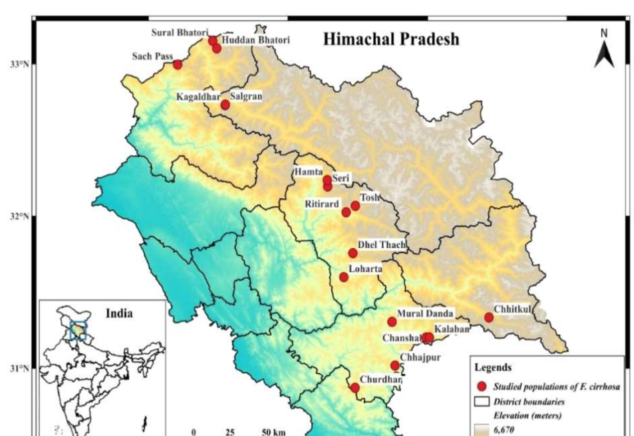

Fig. 1. Studied populations of *F. cirrhosa* in Himachal Pradesh

following standard ecological methods (Curtis and Mc Intosh 1950, Dhar et al 1997, Greig-Smith 1957, Misra 1968, Mueller-Dombois and Ellenberge 1974, Samant et al 2002, Samant and Joshi 2004) were followed. From each site, samples of each species were collected and identified with the help of flora and earlier publications (Aswal and Mehrotra 1994, Dhaliwal and Sharma 1999, Singh and Sharma 2006, Samant et al 2007, Samant 2015). Data analysis was performed on the data using MS Excel 2016. Species diversity (H') was calculated by using the Shannon-Wiener information index (Shannon and Wiener 1963) as follows.

$$H' = \sum_{i=1}^{S} pi \ln pi$$

Where, pi = the proportion of individuals of species i

The Concentration of dominance (Cd) was calculated using Simpson's index (Simpson 1949) as follows.

$$D = \Sigma\,(n/N)^2 \qquad D = \frac{\Sigma\, n(n-1)}{N(N-1)}$$

Where, n = the total number of organisms of a particular species

N = the total number of organisms of all species

(The value of D ranges between 0 and 1)

The total count of species was considered as species richness. Species richness was calculated as follow:

Richness = $S/\sqrt{n}$

Where, S = number of species; n = Total number of individuals of all the species

Density, abundance, frequency, relative frequency and relative density of the species were calculated as:

$$\text{Density} = \frac{\text{Number of individuals of a species}}{\text{Total number of quadrats studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats of occurrence}}$$

$$\text{Frequency} = \frac{\text{Number of quadrats in which species occurred}}{\text{Total number of quadrats}} \times 100$$

Soil sampling and analysis: Soil samples were collected from each studied plot. Soil was cored up to 20 cm depth. Five soil samples, four from the corners and one from the centre of each plot were collected, pooled and mixed properly to make a composite sample. The air-dried soil samples were assessed for further tests and analysis. Soil pH was measured using pH meter in 1:5 mixture of soil and distilled water. Organic carbon was analysed as described by Walkley and Black method (Walkley and Black 1934), available nitrogen by Kjeldahl method (Subbiah and Asiijah 1956), available phosphorus by Olsen's extraction method (Olsen et al 1954) and available potassium by flame photometer (Allen et al 1974, Jackson 1958).

RESULTS AND DISCUSSION

Spatial pattern and distribution: Seventeen populations of *F. cirrhosa* were studied in Lahaul & Spiti, Shimla, Sirmaur, Chamba, Kinnaur, and Kullu districts of Himachal Pradesh. The open meadow habitat represented 11 sites, followed by Partial shade 6 sites between 3150-3903 meters. The slope of sampled sites ranged from 18^0 to 37^0. The highest slope was recorded from Mural Danda and Ritirard (37^0, each), followed by Kalaban and Chhitkul (35^0, each), Tosh (34^0) and minimum in Chanshal (18^0). Studied populations varied from aspect to aspect and highest populations were found in North-east aspect (9 sites) followed by North (6 sites) and South-east (2 sites) (Table 1).

Species composition: Total 192 herbs from 44 families were recorded from studied sites. Maximum species richness was observed in Sach Pass (69 species) followed by Kalaban, Kagaldhar, and Mural Danda. Dominant family was Asteraceae with 32 speices, followed by Polygonaceae, Ranunculaceae, Lamiaceae, Apiaceae, Boraginaceae and Rosaceae.

Species richness and density: The richness of herbs ranged from 29-51. The maximum value of richness was from Sach pass (69 species), followed by Kalaban, Mural Danda and the minimum was recorded from Sural Bhatori (33 species). The maximum total herb density was recorded from Kalaban (90.29 Ind ha^{-1}) followed by Sach Pass (83.51 Ind ha^{-1}), Kagaldhar and the minimum in Sural Bhatori (22.39 Ind ha^{-1}). The highest density of *F. cirrhosa* was in Ritirard (2.3 Ind m^{-2}), followed by Salgran, Kalaban and minimum in Kagaldhar (0.33 Ind m^{-2}) (Table 2).

Species diversity (H') and concentration of dominance (Cd): The H' of herbs was maximum recorded from Tosh (3.02) followed by Loharta, Kalaba), Ritirard and minimum in Chhajpur (1.72). The maximum Cd of herbs was from Dhel Thach (0.0835), followed by Ritirard, Chhajpur, Sural Bhatori and minimum in Huddan Bhatori (0.0109) (Table 2).

Physicochemical properties of soil: The the maximum value of pH was recorded from Salgran (6.45), followed by Mural Danda, Kagaldhar. The highest EC was observed at Mural Danda (162.2 S/m), followed by Kagaldhar (Salgran S/m. Organic Carbon ranged between 1.35-2.91%, with the maximum value of OC recorded at Kagaldhar followed by Mural Danda, Hamta. Total Nitrogen ranged from 165.2-288.5 Kg/ha, the maximum from Mural Danda (288.5 Kg/ha) followed by Kagaldhar and Salgran . Available phosphorous ranged from 3.82-11.68 Kg/ha and maximum was at Hamtay

Tosh. Available potassium ranged from 87.1-197.5 Kg/ha maximum at Mural Danda, followed by Kagaldhar, Tosh (141.8 Kg/ha) (Table 3).

Corelation study: The statistical analysis revealed a significant negative correlation between species richness and altitude (R^2 = 0.417,) (Fig. 2a) which signifies severe climatic conditions at the higher elevations or more anthropogenic pressure making unfavourable condition for natural regeneration. Positive correlation was found between density of *F. cirrhosa* with total density (R^2 = 0.082,) (Fig. 2b). Similar findings were observed by several researches in the Himachal Pradesh (Devi et al 2019, Barman et al 2021a, and Rana et al 2022). Significant positive correlation was found between species richness and total density (R^2 = 0.751) and positive correlation found between organic carbon with species richness (R^2 = 0.165) which states that organic carbon is essential for the growth and germination of the species. These findings are comparable with earlier reported studies in the Himalayan region (Paul et al 2019, Barman et al 2021, Singh et al 2021).

The north western Himalaya has been graced with a broad floristic variety of ecologically and economically significant species, which is essential for human life. The increasing demand and unsustainable extraction of the plant from the wild for its huge medicinal purposes causes population depletion from its natural ecosystem. It even has a significant effect on endemic and native flora found in the forests, raising the possibility of their extinction from their

Table 1. Site characteristics and associated herbs of *Fritillaria cirrhosa* D. Don populations in the studied sites

Populations	Habitat type	Altitude (m)	Aspect	Slope (°)	Latitude (N°)	Longitude (E°)	Major associated species
Mural Danda	Open meadow	3432	East	37	31° 18'15"	77°44'44"	*Trillium govanianum, Angelica glauca*
Chhajpur	Open meadow	3253	North-east	27	31° 01'00"	77°46'04"	*Viola serpens, Meconopsis aculeata, Jurinea macrocephala*
Chanshal	Open meadow	3756	North-east	18	31° 12'03"	77°59'21"	*Aconitum violaceum, Morina longifolia*
Kalaban	Partial shade	3355	East	35	31° 12'06"	78° 00'47"	*Bergenia stracheyi, Arnebia benthamii*
Chhitkul	Partial shade	3903	North-east	35	31° 19'59"	78° 26'25"	*Dactylorhiza hatagirea, Aconitum heterophyllum, Picrorhiza kurrooa*
Churdhar	Open meadow	3608	South-east	31	30° 52'14"	77°28'51"	*Rheum australe, Sinopodophyllum hexandrum, Trillium govanianum,*
Kagaldhar	Partial shade	3405	North-east	30	32° 43'47"	76°33'01"	*Sinopodophyllum hexandrum, Dactylorhiza hatagirea*
Salgran	Partial shade	3345	North-east	28	32° 43'59"	76° 33'05"	*Sinopodophyllum hexandrum, Prunella vulgaris*
Sach Pass	Open meadow	3592	East	33	32° 59'46"	76°12'35"	*Aconitum heterophyllum, Rheum australe, Lilium polyphyllum.*
Sural Bhatori	Partial shade	3712	South-east	29	33° 09'55"	76°27'40"	*Dactylorhiza hatagirea, Rheum australe,*
Huddan Bhatori	Open meadow	3654	East	32	33°06'11"	76°29'23"	*Picrorhiza kurrooa, Sinopodophylum hexandrum, Dectylorhiza hatagirea*
Loharta	Open meadow	3150	North-east	30	31° 35'53"	77°24'00"	*kurrooa, Jurinea macrocephala*
Dhel Thach	Open meadow	3538	North-east	23	31° 45'22"	77°27'55"	*Trillium govanianum, Sinopodophyllum hexandrum,*
Ritirard	Open meadow	3443	East	37	32° 01'29"	77°25'02"	*Dactylorhiza hatagirea, Picrorhiza kurrooa, Silene gonosperma*
Tosh	Open meadow	3393	East	34	32° 04'01"	77°28'59"	*Jurinea macrocephala, Rheum australe, Dactylorhiza hatagirea*
Seri	Partial shade	3472	North-east	25	32°11'40"	77°17'05"	*Sinopodophyllum hexandrum, Thymus linearis*
Hamta	Open meadow	3345	North-east	21	32°14'12"	77°16'55"	*Dactylorhiza hatagirea, Sinopodophyllum hexandrum*

particular ecosystem. Conducting appropriate ecological research and raising public awareness of the need to protect the biodiversity components of any biogeographic area are essential for the conservation of plant species and to understand forest dynamics (Barik and Adhikari 2012). There are many studies related to ecological studies carried out in the state of Himachal Pradesh (Pant and Samant 2012, Sharma and Samant 2013, Lal and Samant 2015, 2019, Adhikari et al 2018, Paul et al 2018 a&b, 2019, Devi et al 2019, Lal and Samant 2019, Lal et al 2020, Barman et al 2021, Rana et al 2022) but no such studies on the ecological status of *F. cirrhosa* has been done so far in Himachal Pradesh. *F. cirrhosa* is a common herb of the Himalayas' higher wet temperate and alpine forests. This plant species

Table 2. Population wise species richness, total density, species diversity and concentration of dominance

Populations	Species richness	Total density (Ind/m^2)	Density of *F. cirrhosa* (Ind/m^2)	Species diversity	Concentration of dominance
Mural Danda	57	61.11	1.63	2.84	0.0199
Chhajpur	36	40.6	0.7	1.72	0.0367
Chanshal	50	46	1.5	2.09	0.0296
Kalaban	61	90.29	1.73	3.00	0.0199
Chhitkul	54	54.7	0.83	2.46	0.0228
Churdhar	41	57.1	1.4	2.85	0.0267
Kagaldhar	54	64.42	0.33	2.51	0.0199
Salgran	39	44.6	1.8	1.94	0.0290
Sach Pass	69	83.51	0.83	2.13	0.0185
Sural Bhatori	33	22.39	0.47	2.64	0.0354
Huddan Bhatori	49	53.9	0.63	2.15	0.0109
Loharta	39	44.7	1.53	3.01	0.0281
Dhel Thach	45	57	1.2	2.57	0.0835
Ritirard	43	50.53	2.30	2.91	0.0369
Tosh	39	46.8	1.4	3.02	0.0350
Seri	46	51.1	1.6	2.51	0.0299
Hamta	49	49.3	0.9	2.64	0.0261

Table 3. Physico-chemical properties of soil in the studied populations

Populations	pH	EC (S/m)	Carbon (%)	Nitrogen (Kg/ha)	Phosphorus (Kg/ha)	Potassium (kg/ha)
Mural Danda	4.84	99.1	2.61	288.5	6.65	197.5
Chhajpur	6.22	128.4	1.35	175.6	8.91	122.0
Chanshal	5.95	70.8	1.89	201.4	8.72	87.1
Kalaban	6.25	162.2	2.31	218.2	6.41	129.1
Chhitkul	6.45	120.2	2.11	178.3	7.44	124,1
Churdhar	4.97	102.2	2.28	175.6	3.82	135.4
Kagaldhar	5.88	101.2	2.91	288.3	6.13	158.1
Salgran	4.72	105.6	2.11	250.8	9.95	141.1
Sach Pass	5.84	72.2	2.21	165.2	11.01	120.3
Sural Bhatori	4.21	108.7	1.72	169.0	9.52	127.1
Huddan Bhatori	4.81	105.3	1.86	170.3	9.12	135.4
Loharta	5.01	112.3	2.10	182.1	9.05	140.6
Dhel Thach	5.21	114.2	2.19	189.5	10.02	129.8
Ritirard	4.91	109.2	1.92	174.3	8.62	133.7
Tosh	5.13	113.5	2.14	192.1	11.07	141.8
Seri	5.02	115.2	2.01	190.7	11.04	139.5
Hamta	5.32	118.6	2.36	185.4	11.68	134.4

EC=Electrical conductivity

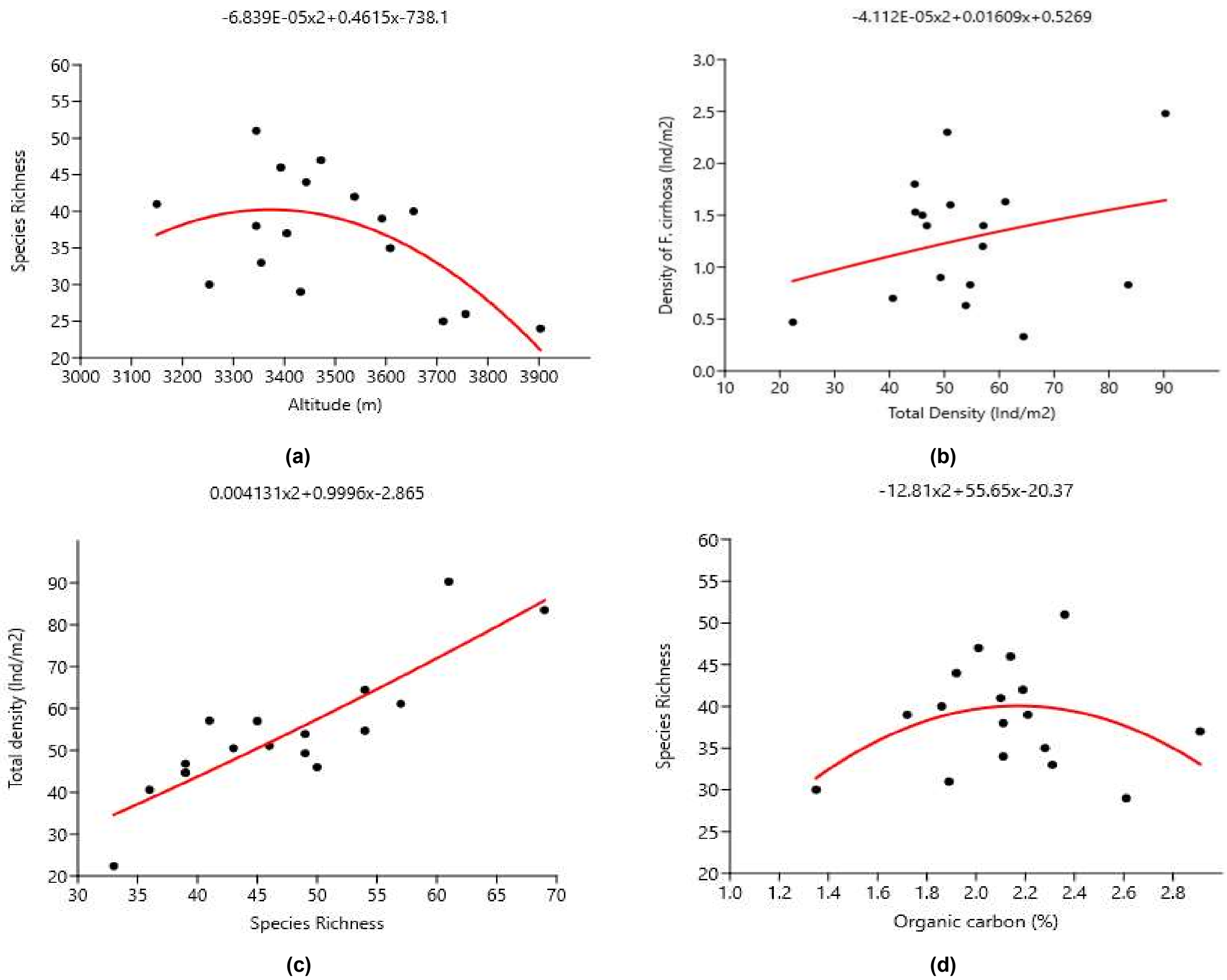

Fig. 2 (a-d). Relationship between (a) Altitude and species richness; (b) density of *F. cirrhosa* and total density; (c) Species density and total density; and (d) Species richness and organic carbon

produced bulbs that sold in markets for their high economic value due to its medicinal properties. The plant is a source of income for Himalayan tribes and an essential component of the ecosystem, customs, and lifestyle of Himachal Pradesh's tribes. In IHR, tribes and indigenous people are major ethnic groups known for their distinct traditions, cultures, and ways of life. A total of 192 herbs from 44 families were recorded from studied sites. The number of the species is less than the numbers reported from previous studies in Himachal Pradesh (Lal 2007, Rana and Samant 2009, Bhandari et al 2018, Rana et al 2022) and this is may be due to recent habitat loss or increased anthropogenic pressure. This phenomenon simply illustrates the conservation needs of forest biodiversity in the studied areas. The species diversity values are less compared with previously reported studies in Himachal Pradesh (Rana and Samant 2010, Lal and Samant 2015, Singh et al 2021, Barman et al 2021a), but comparable with Bisht et al (2016) in Dronagiri alpine meadow of Uttarakhand. The total herb density is very less than reported earlier studies (Singh et al 2021, Paul et al 2019, Rana et al 2022). This may be due to over-exploitation and increasing anthropogenic pressure on natural habitats.

CONCLUSION

The protection of forest biodiversity remains a major challenge in the management of forest resources in the era of climate induced vulnerable ecosystems. Cultivating medicinal plants domestically can have dual benefits of enhancing the financial status of the regional inhabitants and thus promotes the preservation of biodiversity elements. To ensure the continued existence of *F. cirrhosa* in the wild, it is crucial to undertake conservation measures. Due to the medicinal benefits and critically endangered status of this herb, it is essential to prioritize both *in situ* conservation and *ex situ* cultivation. To achieve this, a population assessment using standard ecological methods should be conducted to quantify the current stock of the species in its natural habitats throughout the Himalayan region. It is crucial that forest managers plant native, fire-resistant plants in appropriate, methodical ways, rigorously avoiding monotypic species. Additionally, they need to support effective control of invasive species, which eventually aids native species in thriving. Maintaining soil moisture also depends on having a thorough grasp of the dynamics and pattern of a forest's hydrology. By carefully planning ahead, the government may be able to lessen encroachments in forest regions. The research also offers in-depth details on the physical traits, richness, density, species diversity, concentration of dominance, and population ecology of *F. cirrhosa*. It is important to strictly prohibit the unscientific and illegal collection of the herb from its natural habitats. Implementing these strategies would aid in the conservation and sustainable availability of this valuable herb. The survival and ongoing existence of *F. cirrhosa* in the wild will necessitate collective efforts from a range of stakeholders.

AUTHOR'S CONTRIBUTION

Conceptualization, draft manuscript editing, identification of flora and overall coordination were performed by SL. VC contributed in the writing of the draft manuscript, field data collection and data analysis, and preparation of tables and figures. TB contributed in research design, statistical analysis, editing and reviewing of the draft manuscript. Study area map was prepared by RS and also contributed in the preparation of the manuscript.

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Carbon Stock Assessment and Prediction in the Periyar Tiger Reserve, India, Using Markov Chain and Invest Model

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Abstract: Enhancing and conserving carbon pools in vegetation is a major strategy for mitigating climate change. Carbon dynamics in terrestrial ecosystems are influenced by processes such as photosynthesis, respiration, decomposition, and combustion, as well as anthropogenic activities such as greenhouse gas emissions and climatic variations in rainfall and temperature, and it is stored as biomass in various forms carbon sequestration is evaluated in this study based on the change in total carbon in two different scenarios using the Markov chain and the InVEST model for the years 2001, 2022, and 2043 . The 1.625 Tg carbon has already been lost from 2001 to 2022 in the forest area of Periyar Tiger Reserve and another 0.415 Tg of carbon is expected to be lost in the predicted future, when we compare the forest cover in 2043 to the current scenario. The lower carbon release in 2022 compared to 2001 is due to natural disasters such as the 2018 major flood in the Idukki District. The research findings assist policymakers in simulating ecosystem carbon storage and its trade-offs for a variety of environmental and economic objectives.

Keywords: Carbon sequestration, Ecosystem services, Markov chain model

According to a report by the Forest Survey of India in 2017, India's carbon stock was estimated at 7083 million tonnes. The carbon stock has increased by 39 million tonnes since the previous assessment in 2015. AGB had the greatest carbon change when compared to SOC, litter, and deadwood carbon (Adame et al 2015, FSI Report 2017, Pechanec et al 2018). Similar study for quantifying forest carbon sequestration rate using InVEST model has been done in Three-North shelterbelt Program region, China (Chu et al., 2019). Thus, the premise of this paper revolves around carbon stocking and sequestration as one of the most significant drivers of climate change mitigation measures. The methods to assess it using geospatial techniques and machine learning algorithms for future prediction and valuation of carbon stocks is then formulated from which solutions are framed. Forest management through targeted afforestation/restoration/reforestation drives and simultaneously alleviating problems like forest land conversion and unsustainable/ illegal extraction of resources like fuelwood is also dealt with. The addition and removal of carbon dioxide (CO2) and other greenhouse gases by ecosystems regulates the Earth's climate (Smith et al. 2014). Terrestrial ecosystems, such as forests, grasslands, and peat swamps, store more carbon than the atmosphere, keeping the air clean from excessive CO2 concentrations (Eggleston et al. 2006). Moreover, it requires information about the quality of sequestered carbon or carbon lost over time and is necessary to draw spatial relationships between change in land use and its effect on carbon storage.

Forests store more carbon than the atmosphere and young forests sequester more carbon compared to older ones. However, older forests can hold a large volume of carbon for a longer time in the form of biomass and, thus, act as perfect reservoirs (Cao and Yuan 2019). Carbon sequestration has the potential to stabilize atmospheric carbon for the next few decades; however, it is not a complete solution to all carbon-related problems. Thus, there is a research gap in the application of advanced methods that allow the spatio-temporal integrated assessment of land-use change impacts on carbon storage services. Some studies applied field inventory data along with LULC maps for modeling carbon stock at land-use level with limited above-ground carbon pool (Wu et al 2019).

In this paper, the carbon stock for the PTR has been geospatially assessed. This study makes a fresh attempt at carbon sequestration studies by attempting to anticipate carbon sequestration in the tropical evergreen forests region of India. The objective of study are evaluation of forest cover and its forecast and carbon sequestration measurement of current and future years. The research output will help inform planning, development, implementation, and monitoring at the landscape level to research groups on sustainable forests and climate change such as the reduction of emission from deforestation and degradation (REDD+).

MATERIAL AND METHODS

Study area: Periyar Tiger Reserve (PTR) is an important biodiversity region in Idukki district of the state of Kerala in India. The PTR comes within the western ghats with altitude between 97 and 2017 m. The geographical extent of the area is 9° 17' 56.04" N latitude and 77° 25' 5.52 E longitude (Fig. 1). The major portion of the Reserve forms the catchment of River Periyar and the rest is that of River Pamba. Administratively, PTR falls in Idukki, Kottayam and Pathanamthitta Districts of Kerala. The 'Periyar Wildlife Sanctuary Proper' with an extent of 777 km2 comprising of Periyar Lake Reserve Forest (600.88 km^2), areas of Rattendon Valley (12.95 km^2) and Mount Plateau (163.17 km^2) was constituted in 1950. The Sanctuary was brought under Project Tiger in 1978 as the 10th Tiger Reserve in the country and named as Periyar Tiger Reserve. Presently, the total extent of PTR is 925 km^2 of which 881 km^2 is notified core or critical tiger habitat and the remaining 44 km^2 is notified buffer. PTR lies in the range of 76-2017 m above MSL. PTR with adjoining forests forms the largest remaining benchmark climax forest vegetation in the entire peninsular India. This is a representative of Bio-geographic Zone 5-B of the Western Ghats and plays a key role in maintaining regional connectivity in the otherwise fragmented forest tracts. It is contiguous with the forest areas of Theni Forest Division, Megamalai Wildlife Sanctuary, Srivilliputhur Grizzled Squirrel Sanctuary and Tirunelveli Forest Division (in Tamil Nadu) and Kottayam, Ranni, Konni, Achenkovil, Punalur and Thenmala Forest Divisions in Kerala. At landscape level, the Periyar Conservation Unit extends right up to the Arienkavu Pass and has tenuous linkages with the Agasthyamalai Conservation Unit comprising of Kalakkad-Mundanthurai Tiger Reserve in Tamil Nadu and Shendurney, Neyyar, Peppara Wildlife Sanctuaries and Thiruvananthapuram Forest Division in Kerala.

Data and methods: Forest cover for the year 2001 and 2022 was been prepared; these two were further used to develop the forest cover of the predicted year 2043 using MOLUSCE IN QGIS. Forest cover analyses of the years 2001, 2022, and 2043 have been used to develop the carbon sequestration maps using InVEST model and quantify the total carbon loss which would occur in near future.

GIS and InVEST in study: Forest cover change is attributed as the major consequence of forest degradation (IPCC 2006, Sahana et al 2018A). Remote sensing data and geospatial techniques are deliberately used to identify forest cover change and estimate forest carbon pool, especially for aboveground biomass. In this study, the InVEST model developed by Natural Capital project and LULC derived from Land sat data were used to estimate the carbon stock for the years 2001 and 2022. It also predicted the carbon stock for the year 2043 along with the mapping and estimation of carbon sequestration over the years. Modules for Land Use Change Simulations (MOLUSCE) is a plug in within QGIS aligned to the pressing problem of higher rate of land conversions. MOLUSCE interface is organized around a set of 3 major models: Change analysis, Transition potential and Change prediction. For smart development and forest management practices, the understanding of transitions into the future is very important. By using machine learning procedures, the change analyses past forest cover data to estimate, model and predict Forest cover change. The InVEST model uses maps of LULC and stocks of carbon

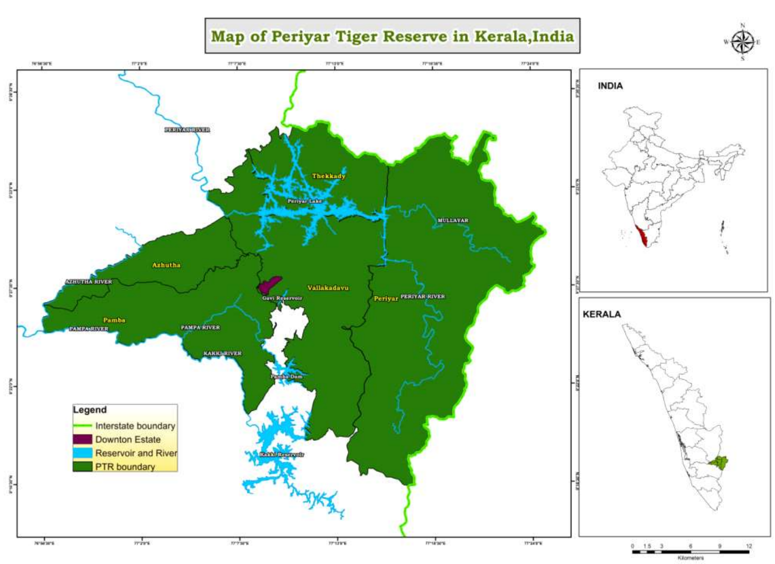

Fig. 1. Periyar Tiger Reserve in Kerala, India

pools (soil organic carbon, belowground biomass, aboveground biomass, dead organic matter) to estimate how much carbon is currently fixed in a landscape or how much has been sunk through time. The model gives outcomes using LULC maps: How much carbon is fixed in different carbon pools and net amount of carbon over the years in a landscape. InVEST is one such spatially clear-cut model that uses "ecological production functions" to forecast the supply of ecosystem services. Later, in order to find the economic value of these services, these estimates are integrated with economic valuation methods for a given landscape. The study reveals the potential of Periyar Tiger Reserve area and answers the question of how much carbon it is withstanding, how changes in LULC cover also changes the forest's potential for carbon sequestration and how much gain/loss of fixed carbon has occurred and how can manage those losses by afforestation and reforestation activities using certain specific species in the forest area. The InVEST Model used here is the most appropriate method of detecting carbon present in the study area using satellite data with the help of remote sensing and GIS. It is the best method to study any protected area without disturbing its natural habitat and wild animals living there and is also helpful in the study of inaccessible areas.

Preparation of land use land cover map: The land sat images for the years 2001 and 2022 were used to prepare the forest cover map of PTR region (Table 1). The study area was extracted from the satellite imagery. Ground truth data were applied for determining the forest cover identity of each pixel in the images. In this software analysis process, the result is an assemblage of pixels with common features without the user giving sample classes. For the preparation of Forest classification, spectral classes were grouped into 6 classes. Classes like water body, evergreen, semi evergreen, moist deciduous, thickets and grass land. Using ground truth data (for 2001 image) and Google Earth Pro (for 2022 image), accuracy assessment was also done for both the years. Random sample points were laid down with a minimum of 10 points for each forest cover class. User's accuracy, producer's accuracy and kappa statistics were generated for the forest cover map. The forest cover maps generated were used for change detection in ENVI software, and statistical changes were calculated to see the conversion of classes into one another, from the year 2001-2022 which also helped in finding the possible reasons behind it. A detailed Ground Truthing (GPS Points) field survey was carried out in 2022 to improve the accuracy of the Forest cover map. A total of 100 GPS readings were taken from the ground (Fig. 2).

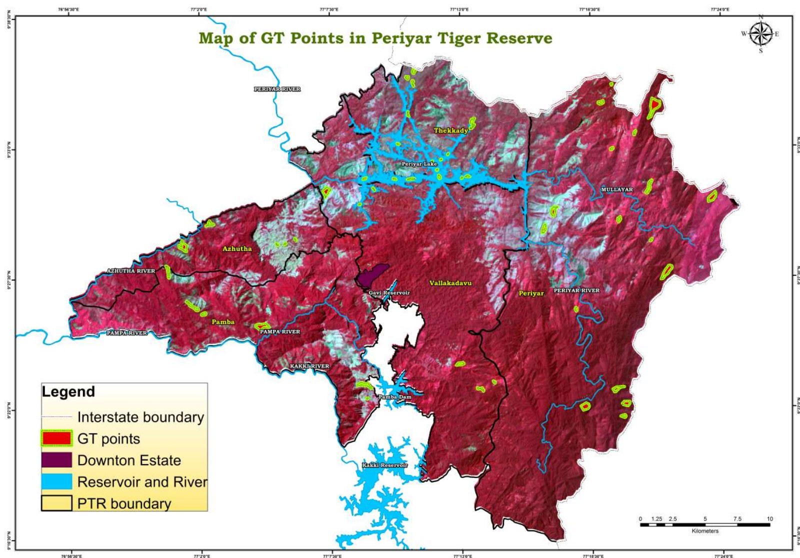

Fig. 2. GT points in PTR region

Table 1. Details of data used

Data	Data types	Source	Details	Period
Landsat-7 ETM+	Spatial	USGS Earth Explorer	30 m resolution	2001
Landsat-8	Spatial	USGS Earth Explorer	30 m resolution	2022
Vegetation type	Spatial	Kerala Forests and Wildlife Department	Polygon shape	2001, 2022

LULC prediction for the year 2043 using QGIS software: QGIS (MOLUSCE) was used to get the predicted Forest Cover map for the year 2043 using driver variables based on Cramer's value. InVEST model was used for estimation of carbon stock and carbon sequestration over the years and calculate the economic cost of carbon added or lost from the environment. The Forest cover map of the years 2001 and 2022 were used as inputs in the MOLUSCE model of QGIS as baseline map for the prediction of forest cover for the year 2043. All input maps were converted into the raster format and imported. It includes 3 steps to get the prediction map in QGIS software. Change analysis and land use transitions, transition potentials and change demand Modelling using Markov chain. Change analysis and land use transitions were done using the MOLUSCE of QGIS. The prerequisite of the model is: forest cover maps (2001, 2022 year). These layers used in order to run the change analysis.

Generation of carbon sequestration map using InVEST model: The forest cover map of current year i.e., 2022 and the predicted year i.e., 2043 were used as the input for preparation of carbon sequestration map in InVEST model. A carbon pool table was generated using FSI report and IPCC 2006 guidelines and from literature review, which shows the carbon pool in aboveground biomass, belowground biomass, soil organic carbon and deadwood carbon in different classes of Forest cover map (Table 2).

Accuracy assessment and model validation: Accuracy assessment is done using stratified random sampling and the minimum number of observations placed in each class is 30. Overall accuracy of forest cover classification shows the comparison of each pixel classified by us versus the actual conditions of the ground, as per the field survey. More the overall classification accuracy, more accurate is the classified image. Here, forest cover for the year 2022 is more accurate as compared to that for the year of 2001. Producer's accuracy measures the error of omission; this shows how well real-world land cover types can be classified. Kappa statistics evaluate the accuracy of the classification. Kappa coefficient can range from 1 to 1. The value close to 1 indicates that the classification is significantly better than random classification i.e., a value closer to 1, denotes more accurate results. Here the kappa coefficient for 2001 and 2022 Forest cover classified map is 0.83 and 0.94. This shows that the 2022 Forest cover classification is more accurate in comparison to the 2001 classification, for validation of the predicted LULC map of the year 2043. Limitations of the InVEST model include an assumption based on linear alteration in sequestration of carbon over time that the carbon cycle is oversimplified, and potential of considering inappropriate discounting rates. The detailed steps followed to develop the methodological framework for this study are given in Figure 3.

Field survey for the validation of LULC maps: Remote sensing and GIS provides an approximate idea about the study site but ground truthing validates the results. Here, in order to get more accurate results, forest field watchers were interviewed. A comparative data was generated by taking

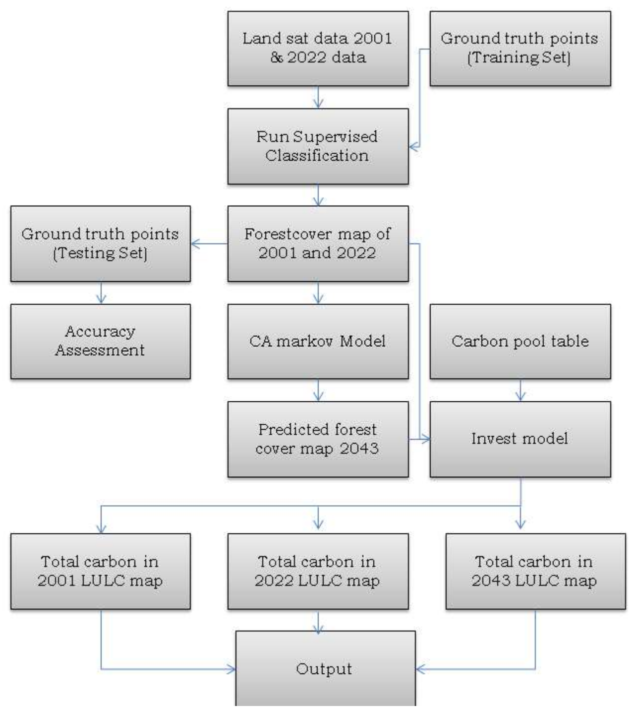

Fig. 3. Methodology

Table 2. Carbon pool table (Input of InVEST)

Lucode	LULC_name	C_above	C_below	C_soil	C_dead	C_litter
1	Waterbody	0	0	68.15	0	0
2	Moist Deciduous	72.58	14.92	79.19	1.17	4.84
3	Grassland	6.29	10.35	68.15	0	0
4	Ever Green	78.54	27.17	97.19	4.1	9.21
5	Semi Ever Green	62.91	12.94	85.19	4.1	5.94
6	Thickets	3.15	5.15	34.07	0	0

(Chacko et al 2018)

100 random GPS points and for each GPS point, past knowledge and future perception of villagers and forest range officers for that location was used.

RESULTS AND DISCUSSION

Six forest cover classes for the years 2001, 2022 and 2043 were identified in the Periyar Tiger Reserve namely; waterbody, evergreen, semi evergreen, moist deciduous, thickets and grass land (Fig. 4). During the time period 2001-2022, Semi Evergreen forest increased by 8.28 %. It could be attributed to lower climatic pressure on the forest area, as a result of better management practices followed by the forest department. Grassland decreased by 3.10 % by conversion into moist deciduous and evergreen forest area decreased by 16.2 % and converted into semi evergreen forest .There was increase in water body area by 0.16% as a result of low temperature and high annual rainfall. (Fig. 4 , Table 3) .

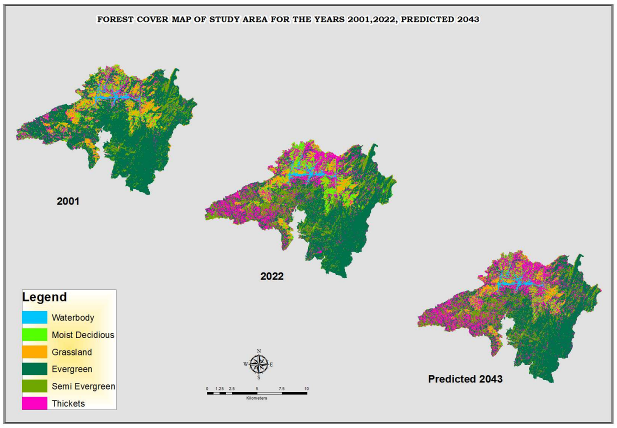

Fig. 4. Forest cover for 2001, 2022, 2043

For the year of 2001, total carbon in the PTR region is 15.95 Tg, and includes carbon present in all forest classes, i.e, water body, evergreen, semi evergreen, moist deciduous, thickets and grass lands. The forest area contains 3.81-18.6 Mg of carbon in each grid cell (Fig. 5, Table 6). The carbon stock in each grid cell for 2022 is the same as that shown in the map for the previous year (2001). Due to the exchanges that have occurred in the Forest cover classes, the total carbon in each class has differed and hence the total carbon

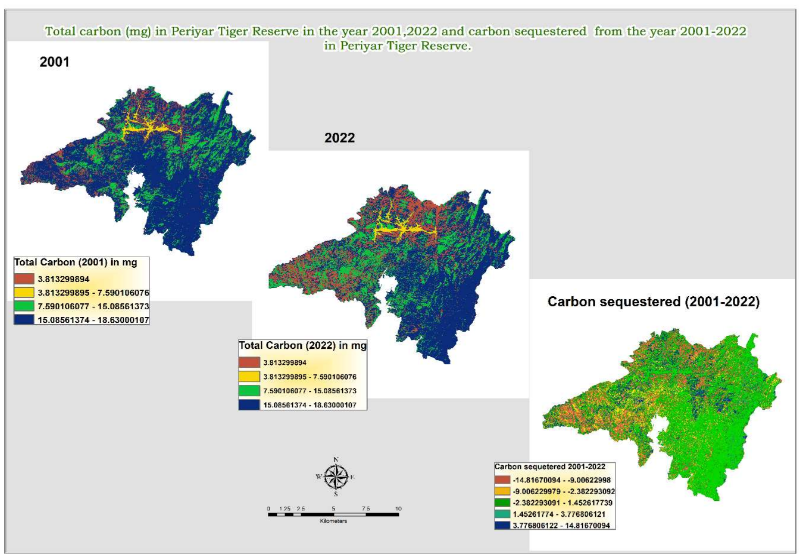

Fig. 5. Total carbon (mg) in Periyar Tiger Reserve in the year 2001, 2022 and carbon sequestrated (2001-2022)

Table 3. Forest cover statistics (2001, 2022 and 2043)

Forest type	2001		2022		2043		Change (2001-2022)		Change (2022-2043)	
	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%
Waterbody	14.11	1.52	15.61	1.68	14.01	1.51	1.5	0.16	-1.6	-0.17
Moist Deciduous	88.22	9.53	91.49	9.89	66.6	7.2	3.27	0.34	-24.89	-2.65
Grassland	84.67	9.15	55.59	6.009	53.4	5.77	-29.08	-3.1	-2.19	-0.23
Ever Green	564.8	61.06	413.07	44.65	416.77	45.05	-151.82	-16.2	3.7	0.39
Semi Ever Green	81.84	8.84	159.41	17.23	147.17	15.91	77.57	8.28	-12.24	-1.3
Thickets	91.99	9.94	190.53	20.59	227.76	24.62	98.54	10.52	37.23	3.97

stored in the study area is 14.33 Tg of carbon (2022), which is a decrease by 1.62 Tg as compared to carbon levels for the year 2001 (Table 6).

Future carbon stock of 2022 in the previous study is like the current carbon stock in 2022-2043 study. Total carbon stored as shown in the predicted map of year 2043 (Fig. 6). Total carbon stored in the PTR forest area is 13.916 Tg, which further decreased by 0.415 Tg when compared with 2022 statistics.

Survey was conducted to find out possible reasons for carbon loss like climate change i.e., declining trends in rainfall and temperature or the anthropogenic pressure from local communities. The results show that along with climatic variations, anthropogenic pressure is the main reason for carbon loss into the atmosphere. The maps generated for the years 2001 a 2043 using the InVEST software match with the past and future perceptions of local people and forest officers. The Forest cover changes inside PTR is majorly because of climatic variations.

Ecosystem history and trajectory of the ecosystem at present are helpful to assess the potential carbon storage of any region (Lubowski et al 2006, Zhao et al 2019). InVEST model was used to predict provision of ecosystem services and carbon sequestration for three contrasting scenarios including the past (year 2001), present (year 2022) and future (year 2043) Forest cover. Forests have the potential to sequester carbon which may otherwise contribute to global warming. The economic view of carbon emission reductions as given by the Kyoto protocol helps forest owners to realise revenue. specifically for regulating climate, quantifying biomass/carbon in highland forests is crucial in numerous ways. Due to the fragile, inhospitable, and difficult-to-access terrains, predicting the spatial distributions of carbon stocks in the varied alpine ecosystems has always been difficult. Research on modelling carbon stock at landscape levels is unusually scarce in emerging nations like India. However, these countries mostly contain mountainous regions where climate regulation is highly delicate to the process of climate change and global warming and from both environmental and intense human-induced activities. Therefore, it is necessary to evaluate inadequate carbon pools for these mountainous regions in developing countries in their whole. By fusing remote sensing with the carbon storage and sequestration InVEST model, this research intended to spatially estimate the carbon stock in the Periyar Tiger Reserve. In developing nations with little access to data, calibrating such complicated models at broad scales is difficult. Using field inventory data, we classified Landsat imagery using an object-based approach. The amount of carbon used for each pool has a significant impact on the total carbon stock estimated by the InVEST model. However, the carbon inventories predicted by the model and their economic values are crucial for upcoming efforts to reduce the effects of climate change.

Table 4. Carbon values and total carbon sequestrated in 2001, 2022, 2043

Year	Carbon (mg)	Year	Sequestered carbon (mg)
2001	15957018.2	2001	NA
2022	14331629.72	2001-2022	-1625388.45
2043	13916396.26	2022-2043	-415233.46

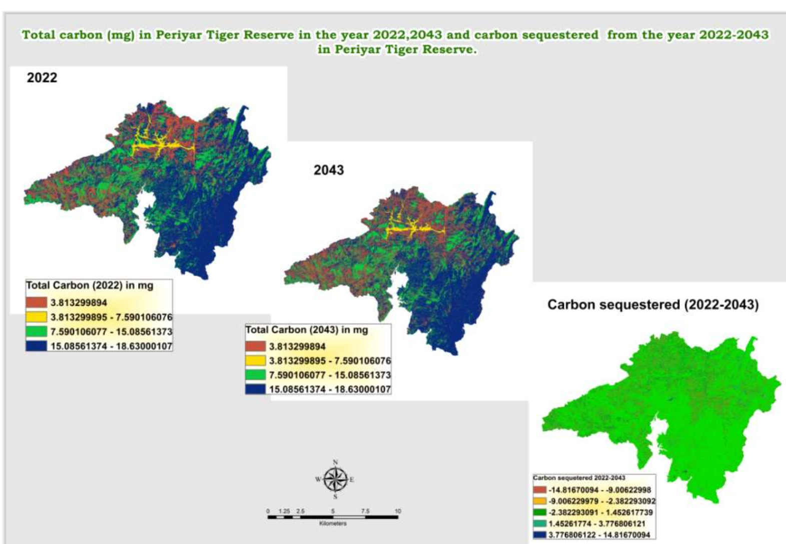

Fig. 6. Total Carbon (mg) in Periyar Tiger Reserve and carbon sequestrated (2022-2043)

CONCLUSION

The study shows that carbon content in the PTR region has decreased from the year 2001-2022 and stands to decrease further from 2022 to the predicted year 2043. The carbon sequestration results show that the change in carbon from the year 2001-2022 was 1.625 Tg. So, in order to avoid this carbon getting lost into the atmosphere in near future and experience its worst effects must plan for its sequestration. The maps generated from the InVEST model depict the total carbon stock present in the total study area, for the respective years (2001, 2022, 2043), with the description of carbon present in each grid of the different LULC classes. It also generates a carbon sequestration map for the time period 2001 to 2022 and 2022 to 2043 which helps to understand a general trend of whether carbon is sequestered or lost to the atmosphere over time. This helps us to take protective measures for the forested area via providing guidance to stakeholders, NGOs, governments, and businesses. Such maps are useful as they help them in supporting their decisions, for example, to grab opportunities like earning credits for REDD. Governments can use them for detecting the target landscape home to most of the carbon fixed and provide incentives to land- owners as a trade-off for forest conservation.

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Stand Structure, Regeneration Potential and Biomass Carbon Stock of Subtropical Forest of Mizoram, Northeast India

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Abstract: The present study deals with tree community attributes such as species diversity, composition, population structure and biomass carbon stock (above- and below ground) of subtropical forest of Lalsavunga Park, Mizoram, Northeast India. A total of 41 tree species (37 genera and 29 families) were recorded from the study area. Moraceae was the most dominant family contributing 10% of the total family recorded in the area. The dominant species were *Engelhardia spicata, Litsea cubeba*, *Macaranga peltata*, *Nyssa javanica* and *Schima wallichi.* These dominant species together contributed 60% of the total species in the forest area. The total tree density (individuals ha^{-1}) and basal area (m^2 ha^{-1}) in the forest was 784 and 53.36 respectively. The diversity indices such as Shannon diversity index and Simpson dominance index were 3.48 and 0.04 respectively. The present study showed that 37% of the species exhibited good regeneration whereas 17% of species exhibited poor regeneration. About 80% of the plant species followed clumped distribution pattern in the study area. The total tree biomass and carbon stock recorded in the present study were 314 Mg ha^{-1} and 147.53 Mg C ha^{-1}, respectively. Young trees (belonging to 10 – 60 cm girth class) contributed 41% of the total tree biomass. The findings of the present study will serve as baseline information that can be used by forest managers and policy makers to develop strategies for conservation, climate mitigation by enhancing vegetation carbon stock and sustainable use of forest resources of Mizoram, Northeast India.

Keywords: Tree diversity, Species composition, Regeneration, Biomass, Carbon stock

Climate change has become a major concern for global leaders, scientists and citizens due to increasing of greenhouse gases and rapid rise in temperature. For instance, the atmospheric CO_2 concentration has increased to over 50% from the pre-industrial era (i.e. 280 ppm) to current level of 420 ppm (Alli et al 2023). Thus, the rapid increase of CO_2 in the atmosphere can be mitigated by reducing carbon emission and increasing carbon sink in the biosphere through carbon sequestration in plant biomass and the soil (Mahajan et al 2023). Tropical forests are one of the important components of terrestrial biosphere as it represents ~40% of the total terrestrial biomass carbon stock and 30-50% terrestrial productivity (Pan et al 2011). These forests are the living biomass of both trees and understory vegetation and contain high carbon storage in dead mass of woody litters, debris and soil organic matter (Pillay et al 2021, Zuleta et al 2023). However, despite high carbon storage potential and rich biodiversity, tropical forests are facing high anthropogenic activities, which lead to alter forest structure, create mosaic landscape and set the initial condition for succession dynamics and structural development of these forests (Chen et al 2018). According to FAO and UNEP (2020), estimated global deforestation rate of 10.3 M ha yr^{-1} is responsible for the release of carbon stored in trees biomass to the atmosphere. Nevertheless, tropical forest has a high carbon storage potential than any other land covers and thus this land use has been the primary focus for scientific research and also gaining importance on carbon stock studies.

The Northeast region of India is consisting of eight states with a total geographic area of 26.2 million hectares, which can be physio graphically categorized as Eastern Himalaya and the plains of Barak valley. The region is identified as one of the biodiversity hotspots based on the high number of endemic species and the degree of threat to the biodiversity of the area (Ao et al 2023). Out of 68 million hectares of India's forest cover, the Northeastern region signifies approximately 17 million hectares which is one-fourth of the total forest cover of India (Joshi 2020). The tropical and subtropical forest of Mizoram is one of the largest biodiversity in India with a total record of 2358 plant species of which 2141 species belongs to angiosperm class distributed over 176 families and 905 genera where about two-third of plant species are dicots and one-third monocots (Singh 1997). Furthermore, it has also been reported that about 500 species recorded from the state forest has ethno medicinal properties (Devi et al 2018). However, the tropical forest of Mizoram has undergone an abrupt land transformation due to existing agricultural practices like shifting cultivation, tree felling for timber, fuel wood and cutting of hills for road constructions resulting to degradation of natural forest. The present study was carried out in the tropical forest of Lalsavunga park in Aizawl district of Mizoram with an aim to characterize the tree species composition, diversity and regeneration potential along with biomass carbon stock within tree community and its role in climate change mitigation.

MATERIAL AND METHODS

Study area: The Lalsavunga Park is located in the South Hlimen regions, in Aizawl district of Mizoram, Northeast India. It is located between 23°39'59.01" N latitude and 92°43'13.05" E longitude. The park is distributed in about 51 ha of land in the vicinity of the Aizawl. The area is a hilly landscape which is situated at an elevation between 1000 and 1200 meters above mean sea level. The study area has a diverse landscape with rich floristic diversity and provides habitat to large number of mammalians, birds and invertebrates. The park also provides various ecological services to the society such as improving air and water quality, protecting groundwater and providing a place to connect with nature. The area is largely constituted by Tertiary rocks of Bhuban sub group and the rocks are covered by an uneven layer of soil which is composed mainly of alternate thinly bedding shale (Beingachhi and Vanlalhmangaihsangi 2017). The park is composed of thick natural vegetation of subtropical evergreen forest with an average annual rainfall of 2500 mm. The mean minimum and maximum temperature varies from 17°C in winter and 27°C in summer season.

Sampling design: The present study was conducted during February-March 2020 following random sampling method. Tree species composition and population structure were assessed by establishing forty randomly located plots (10 x 10 m) within the park. Species regeneration status was determined based on population size of seedling, sapling and adult trees. All the individuals ≥10 cm (GBH) were considered as woody species, whereas individuals with girth ≥3 and ≤10 cm girth with >10 cm height were considered as saplings and individuals with <3 cm girth and upto 10 cm height were considered as seedlings. The girth of trees at breast height (1.37 m) was measured using a measuring tape. The specimens were collected and identified with the help of regional floras (Hooker 1872-1897, Kanjilal et al 1934-1940) and Botanical Survey of India, Eastern Regional Circle, Shillong, Meghalaya. The herbarium was prepared following Jain and Rao (1977) and deposited in the in the Mizoram University.

Data analysis: The vegetation parameters such as frequency, density, basal area, dominance and the Important Value Index (IVI) of species were quantatively analyzed by following the formula given by Misra (1968). The Importance Value Index of tree species was determined by summing up the values of relative frequency, relative density and relative dominance (Curtis and McIntosh 1950). To understand the population dynamics of species in the study area, the recorded individuals were categorized into eight girth classes (10-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm). Regeneration status of each individual species was studied based on the size of population of seedling, sapling, and adult trees (Khumbongmayum et al 2006). The regeneration is considered as good, if seedlings > or < saplings > adults; fair, if seedlings > or ≤ saplings ≤ adults; poor, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); none if a species survives only in adult stage and new regeneration if a species is present only in seedling and sapling stage but no adults. The distribution pattern of species in the forest was determined by following Whitford's index (Whitford, 1948).

Tree species diversity: The diversity of tree species was measured by Shannon-Weiner diversity index (H') proposed by Shannon and Weaver (1963). It basically assumes that all species are represented in a sample and they are randomly sampled.

$$H' = -\sum pi \, ln \, pi \quad (1)$$

where, pi = the proportion of density of the i-th species ($pi = ni/N$), *ni* is the density of i-th species and *N* is the density of all the species.

Concentration of dominance (CD) of trees was estimated using the formula given by Simpson's index (1949). It reflects the probability of any two individuals drawn at random from an infinitely large community belonging to the same species.

$$CD = \sum (pi)^2 \quad (2)$$

The evenness refers to the degree of the relative dominance of each species in the forest. It was calculated according to Pielou (1966).

$$\text{Evenness (e)} = H'/ \, ln \, S \quad (3)$$

Where, H'= Shannon index of diversity, S= Number of species in the community

The species richness was calculated using Margalef species richness index (Dmg) (Margalef 1958)

$$Dmg = S\text{-}1/ \, ln \, N \quad (4)$$

Where, S = the number of species, N = Number of individuals

Total biomass (aboveground) of trees was estimated using the allometric equation developed for different forest types in Northeast India by Nath et al (2019)

$$AGB_{est} = 0.32 \, (D^2H\delta)^{0.75} x \, 1.34 \quad (5)$$

Where, D is the DBH, H denotes the height of the tree and δ as specific wood gravity

Belowground biomass was estimated by using the equation developed by Cairns et al (1997)

$$BGB = \exp[-1.085 + 0.9256 \times \ln(AGB)] \quad (6)$$

The total C stock of trees was calculated by the sum of AGB and BGB by assuming that the carbon content 47% of the total biomass (Martin and Thomas 2011)

RESULT AND DISCUSSION

Floristic diversity and composition: A total of 41 species belonging to 37 genera and 29 families were recorded from the subtropical forest of Lalsavunga park, Mizoram, Northeast India (Table 1). Most of the tree species (over 90%) recorded in the present study was indigenous. The Moraceae family was the most dominant family contributed 10% of the total number of species followed by Anacardiaceae, Euphorbiaceae, Lamiaceae, Lauraceae, Leguminosae, Magnoliaceae, Rutaceae and Styracaceae, each contributed 5% of the total number species and the other families were represented by a single species. The number of tree species recorded in the present study can be compared to tree species recorded from the tropical forest of Northeast India such as Bhuban hills of Southern Assam (Borah et al 2013, 49 species), subtropical forest of Manipur (Meetei et al 2017, 43 species) and Rowa Wildlife Sanctuary, Tripura (Debnath et al 2021, 44 species). However the tree species richness of the present study was found to be lower as compared to tree species recorded by various researchers in other tropical forest in India (Selvan 2014, 62 species, Joshi 2020, 71 species, Ao et al 2020, 60 species, Dash et al 2021, 60 species). Existing anthropogenic pressures such as agriculture expansion, tree feeling for timber, stone quarry and forest fire has taken a toll in the species richness of the park and may likely result to reduction of species in the community and change in forest structure, if no proper management of the park in ecological perspective is adopted (Tripathi et al 2016, Wapongnunsang et al 2020). The presence of high diversity of woody species in the present study suggests the result of successional process in the forest (Naidu et al 2021). Based on Important Value Index (IVI), the dominant species were *Schima wallichii* (44.30), *Engelhardia spicata* (23.01), *Macaranga peltata* (18.14), *Nyssa javanica* (11.76) and *Litsea cubeba* (10.71). These species together contributed over one-third of the total IVI of the tree community (Table 2).

Table 1. Phytosociological attributes, biomass and carbon stock of Lalsavunga Park, Mizoram

Parameters	Value
Number of species	41 ± 0.32
Number of genera	37 ± 0.29
Number of family	29 ± 0.28
Density (individuals ha^{-1})	784 ± 2.67
Basal area ($m^2 ha^{-1}$)	53.36 ± 3.45
Shannon wiener index (H')	3.48 ± 0.04
Simpson index (CD)	0.04 ± 0.02
Margalef species richness index (Dmg)	7.58 ± 0.09
Evenness index (e)	0.94 ± 0.03
AGB (Mg ha^{-1})	256.64 ± 2.94
BGB (Mg ha^{-1})	57.26 ± 0.71
TBC (Mg ha^{-1})	147.53 ± 1.35
Elevation	1179 m
Latitude	23°39'59.01" N
Longitude	92°43'13.05" E

The total tree density and basal area in the present study were 784 individuals ha^{-1} and 53.4 $m^2 ha^{-1}$, respectively. The tree density recorded in the present study was found to be similar with the tree density value (245-1620 individuals ha^{-1}) recorded from the tropical and subtropical forest of Northeast India as reported by various workers (Nohro and Jayakumar 2020, Joshi 2020, Suchiang et al 2020). Similarly the basal area recorded at the present study was comparable with the basal area value reported for various natural forests in tropical and subtropical regions in the country (Meena et al 2019, Bhat et al 2020, Sajad et al 2021). According to Vospernik (2021), forest trees in a natural habitat exhibits a large variations in basal area increment, which majorly depends on three key factors (a) tree specific factor (b) inter-tree relations (c) the environment. Wright et al (2018) also stated that basal area value could also be influenced by the level of stand disturbance in the forest.

An estimation of plant diversity indices in a forest community reveals the diversity patterns and abundance of species in the region (Shen et al 2016). The Shannon-Wiener diversity index (H') and Simpson dominance index (CD) recorded in the present study were 3.48 and 0.04, respectively (Table 1). According to Spies (2004) high diversity value and low dominance is the characteristic feature of any natural forest which is also supported by our findings. The Shannon-Wiener diversity index for tropical forest of Indian subcontinent ranges from 0.80-4.15 (Lynser and Tiwari 2015, Shaheen et al 2015, Suchiang et al 2021) where the present value recorded (3.48) is well within the range reflecting high tree species diversity in the community. Similarly, the Simpson index (0.04) recorded from the present study is also well within the range (0.03-0.09) for different Indian forest reported by various workers (Kushwaha and Nandy 2012, Akash et al 2018, Naidu et al 2018, Ao et al 2021).

Table 2. Tree species density (individual ha^{-1}), basal area (m^{2}ha^{-1}), important value index (IVI) and regeneration status of Lalsavunga Park, Mizoram

Family	Species name	Density	Basal area	IVI	Regeneration
Aceraceae	*Acer oblongum* Wall. ex DC.	16	0.58	6.18	P
Rutaceae	*Aegle marmelos* (L.) Correa	20	0.15	5.12	P
Mimosaceae	*Albizia chinensis* (Osbeck) Merr.	16	0.62	4.73	G
Combretaceae	*Anogeissus acuminata* (Roxb. ex DC.) Guill.	16	0.66	6.34	G
Phyllanthaceae	*Aporosa octandra* (Buch.-Ham. ex D. Don) Vickery	12	1.37	5.63	G
Moraceae	*Artocarpus heterophyllus* Lam.	4	0.62	2.43	N
Styracaceae	*Bruinsmia polysperma* (C.B.Clarke) Steenis	16	1.66	7.45	P
Verbenaceae	*Callicarpa arborea* Roxb.	24	1.78	9.45	G
Theaceae	*Camellia sinensis* (L.) Kuntze	16	0.20	5.46	F
Fagaceae	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	4	1.19	3.49	G
Rutaceae	*Citrus spp.*	12	0.59	4.92	P
Papilionaceae	*Dalbergia spp.*	36	0.52	8.63	F
Leguminosae	*Derris robusta* (DC.) Benth.	12	0.52	3.28	G
Juglandaceae	*Engelhardia spicata* Lesch. ex Blume	12	10.24	23.01	G
Leguminosae	*Erythrina variegata* Lam.	12	0.70	5.13	F
Moraceae	*Ficus auriculata* Lour.	20	1.26	6.45	G
Moraceae	*Ficus elastica* Roxb. ex Hornem.	20	0.33	5.47	N
Moraceae	*Ficus acuminata* Roxb.	36	1.23	9.96	F
Lamiaceae	*Gmelina oblongifolia* Roxb.	28	1.11	9.46	F
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	4	0.37	1.96	G
Araliaceae	*Heteropanax fragrans* (Roxb.) Seem.	40	0.29	8.71	G
Iteaceae	*Itea macrophylla* Wall.	12	0.18	4.15	G
Lythraceae	*Lagerstroemia speciosa* (L.) Pers.	12	0.73	5.19	F
Oleaceae	*Ligustrum robustum* (Roxb.) Blume	20	0.51	7.32	P
lauraceae	*Litsea cubeba* (Lour.) Pers.	32	0.28	10.71	G
lauraceae	*Litsea Iteodaphne* (Nees) Hook. f.	12	0.23	3.49	P
Euphorbiaceae	*Macaranga peltata* (Roxb.) Müll.Arg.	60	2.34	18.14	G
Magnoliaceae	*Magnolia champaca* (L.) Baill. ex Pierre	24	0.30	8.21	G
Magnoliaceae	*Magnolia schiedeana* Schltl.	12	0.01	2.31	F
Anacardiaceae	*Mangifera sylvatica* Roxb.	8	0.25	3.02	N
Cornaceae	*Nyssa Javanica* (Blume) Wangerin	28	2.33	11.76	P
Euphorbiaceae	*Phyllanthus emblica* L.	8	0.06	1.90	F
Lamiaceae	*Premna racemosa*Wall. ex Schauer	20	0.43	4.88	G
Rosaceae	*Prunus cerasoides* D. Don	16	1.59	6.54	N
Gesneriaceae	*Rhynchotechum ellipticum* (Wall. ex D. Dietr.) A. DC.	24	0.12	4.81	G
Theaceae	*Schima wallichii* Choisy	64	14.80	44.30	G
Bignoniaceae	*Spathodea campanulata* P.Beauv.	20	1.27	6.47	N
Anacardiaceae	*Spondias pinnata* (L.f.) Kurz.	4	0.73	2.65	N
Styracaceae	*Styrax serrulatus* Roxb.	4	0.32	1.87	N
Myrtaceae	*Syzygium cumini* (L.) Skeels	16	0.22	4.75	G
Ulmaceae	*Trema orientalis* (L.) Blume.	12	0.68	4.33	F
	Total	784	53.4	300	

*G=Good regeneration, *F=Fair regeneration, *P=Poor regeneration, *N=No regeneration

Population structure: The tree density and basal area varied in different girth classes. However, majority (over 90%) of the total tree density was contributed by lower to middle girth classes of 10-90 cm showing high dominance of young individuals in the area (Fig. 1). Similarly tree basal area was recorded highest in 10-90 cm girth class which together contributed 54% of the total basal area of the tree community. The contribution of older tree density was only 6% where only three individuals were recorded each from girth class 120-150, 150-180 and 180-210 cm. However, the distribution of tree basal area in higher girth classes was almost evenly distributed. Tree basal of 5.08, 3.52, 6.12 and 9.52 $m^2 ha^{-1}$ represented girth class of 90 – 120, 120 – 150, 150 – 180 and 180 – 210 cm, respectively (Fig. 1). The overall population structure showed a reverse *J*-shaped population curve indicating a good forest health and high species richness in the area.

Regeneration status: The study showed that density (individuals ha^{-1}) of seedling was highest (5800) followed by sapling (1456) and trees (784). The maximum species (37% of the total species) exhibited good regeneration followed fair regeneration by 22%, and poor and no regeneration by 17%. Only 7% of the total recorded species exhibited new regeneration (Table 2).

Species distribution pattern: The Whitford similarity index revealed that most of the species in the present study exhibited clumped/contagious distribution pattern. About 80% of the total plant species exhibited clumped distribution, while 12% of the species distributed randomly and only 7% species showed regular distribution pattern (Fig. 2). Das et al (2017) observed that most of the plant species in natural forest follows clumped/contagious distribution pattern. Clumped distribution pattern are considered as the most universal pattern in a natural forest whereas random distribution are general found in uniform environment where individuals are distributed without any apparent pattern and regular distribution indicates high competition among species (Odum 1971). Several workers have also reported similar type of distribution pattern for different tropical and subtropical forest in the country (Gazal 2015, Da et al 2017, Joshi 2020).

Total tree above ground biomass and carbon stock: Tropical forests are distinguished for their rich biodiversity and high carbon storage over the world. In the present study, out of total standing biomass of 314 Mg ha^{-1} (AGB + BGB), the total tree above ground biomass and below ground biomass were 256.64 and 57.26 Mg ha^{-1}, respectively (Table 1). The estimated above ground biomass in the present study is well within the range reported (32.75 – 280.71 Mg ha^{-1}) for various tropical forest of Northeast India (Thokchom and Yadava 2017, Deb et al 2019, Sajad et al 2021). The distribution of tree biomass across different girth classes showed higher biomass in 30 – 60 cm girth class (33%) followed by 60 – 90 cm girth class (28%) and lowest in 120 – 150 cm girth class (only 5%) (Fig. 3). The domination of the biomass in the girth class was mainly depended on the density in these girth classes. Various studies also reported that species wood density plays a vital role in variations of forest biomass and contribute largely in the total living biomass of forest (Robiansyah 2018, Joshi and Dhyani 2019). In addition, there are also reports suggesting factors such as change in stand structure and species composition because of various anthropogenic pressures can lead to variation in total biomass and carbon stock in a forest ecosystem (Bradford et al 2012, Deb et al 2021, Ao et al 2023).

The tree biomass carbon recorded in the present study (147.53 Mg C ha^{-1}) also showed well within the reported range (90.1 – 291.6 Mg C ha^{-1}) of various tropical and subtropical forest of Northeast India (Giri et al 2014, Hrasel et al 2018, Deb et al 2021). Species such as *Schima wallichii* (61.01 Mg ha^{-1}) and *Engelhardtia spicata* (25.93 Mg ha^{-1})

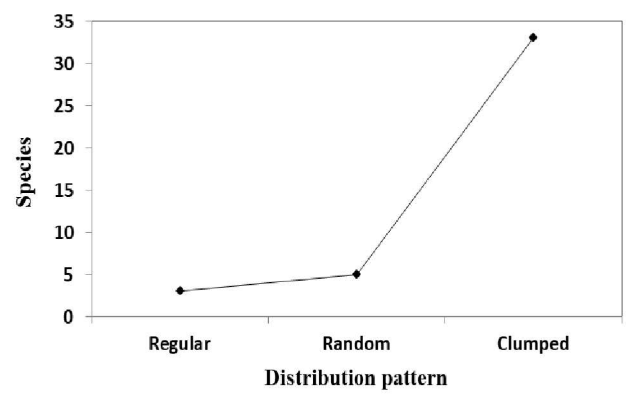

Fig. 1. Tree density and Basal area in different girth classes of Lalsavunga Park, Mizoram

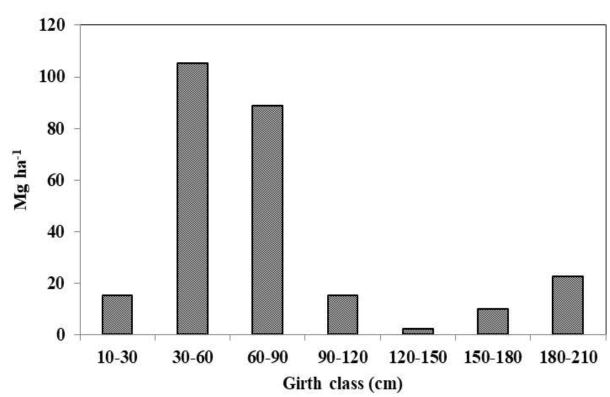

Fig. 2. Distribution pattern of species at Lalsavunga Park, Mizoram

recorded the maximum carbon stock and these two species together contributed about 40% of the total above ground biomass carbon in the forest.

CONCLUSION

The present study provides important insight about rich biodiversity of Lalsavunga Park and its potential to store high biomass carbon within the tree community. The lower and middle girth classes (10 – 30 cm and 30 – 90 cm) stored significantly greater carbon than other girth classes in the forest, and thus these girth classes may be protected to have considerable potential to sequester greater amount of carbon in the biomass in the future. Species such as *Schima wallichii* and *Engelhardtia spicata* exhibited maximum (40%) carbon storage as compared to other species indicating that these species need to be conserved to act as a potential species for carbon sink with possible implication in future climate mitigation programs. The study also suggest that the species has good regeneration potential in the present forest with higher density of seedling, sapling and young trees that can be endured with proper management technique and sustainable use. At the same time, about one-fourth of the species has poor and no regeneration in the area because of prevailing stress conditions due to various anthropogenic disturbances such as timber felling, agriculture expansion, stone quarry and forest fire in the region. Special ecological emphasis is required to promote the regeneration of these species to ensure the proper ecological balance of the region. Finally, the present findings provide baseline information to prepare a proper management plan to conserve the vegetation and sustainable use of natural resources and climate change mitigation.

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Influence of Land Configurations on Growth, Yield and Profitability of Mustard and Chickpea Intercropping Systems under Organic Management in Bundelkhand

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Abstract: Field experiment was conducted involving eight treatments during *Rabi* season 2018-19 at Bundelkhand University Campus, Jhansi India. The various metrics were significantly higher in the different inter-cropping systems of mustard + chickpea among row ratios. The plant height of the mustard increased up to 199.9 cm in the 2:1 ratio of mustard (SLB) + chickpea (R). Highest plant fresh 240.3 g and dry weights 58.7 g were achieved in the 1:1 ratio of mustard (F) + chickpea (R). The linked crops mustard (LB) + chickpea (UB) in a 2:2 ratio produced 725 capsules, 16.37 seeds per capsule, and 6.98 g of weight per 1000 seeds, respectively. On individual crop basis highest seed yield of mustard (31.41 q ha^{-1}) and chickpea (20.21 q ha^{-1}) was obtained when crops were sown alone on FB mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under Broad bed and furrow system gave highest mustard equivalent yield, chickpea equivalent yield, land equivalent ratio, gross returns (ha^{-1}), net returns (ha^{-1}), benefit cost ratio and profitability. In terms of land equivalent ratio (1.50), intercropping mustard (F) and chickpea (BB) in a ratio of 1:3 was more productive than seeding chickpea and mustard in solo stands.

Keywords: Mustard, Chickpea, intercropping, Land configurations, Organic management

Mustard and chickpea are raised as sole crops as well as intercropping system under organic management. Intercropping is the production of growing two or more crops simultaneously in the same piece of land at the same time. Intercropping is a simple but inexpensive strategy and has been recognized as a potentially benefited technology for increasing crop production. It can ensure substantial yield advantages as compared to sole cropping (Gangwar et al 2018). The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Launayet et al 2009). Intercropping is one of the best agronomical options to minimize risk and will be act as insurance against main crop failure in the vast rainfed tracts in the country (Sankaranarayanan et al 2010). The selection of compatible crops is one of important consideration in deciding an economically viable and feasible intercropping system. Mustard + chickpea is a prominent intercropping system in Indian sub-continent. The majority of the farmers adopt this system under resource constraint conditions (Kour and Sharma 2016). Land management system plays a major role in minimizing soil erosion and improving water use efficiency of field crops. Easy and uniform germination as well as growth and development of plant are provided by manipulation of sowing method. Land configuration increases water use efficiency as reported by (Deshmukh et al 2016). Land configuration methods including the alteration of shape of seed bed and land surface among the various methods the broad bed and furrow sowing, Furrow sowing, ridge sowing, ridge with mulches and alternate furrow sowing are adopted by the crop growers for mustard and other crops for obtaining the better yield over the flat bed or conventional method of sowing. Better conditions for plant growth are provided in furrow planting due to higher soil moisture, higher salt leaching and reduction in evaporation from the soil surface (Singh et al 2017). Modified land configuration, such as furrow irrigated raised bed (FIRB) has shown good promise in enhancing chickpea performance (Jat et al 2005, Ahlawat et al 2010). Therefore, present study was undertaken with the view to find out the influence of sowing methods using land configurations on growth, yield and profitability of mustard and chickpea intercropping system under organic management.

MATERIAL AND METHODS

The field experiment was conducted at Bundelkhand University, Jhansi during winter Season 2018-19, under Bundelkhand Agro climatic Zone (6) of Uttar Pradesh and is situated at 25.44° N and 78.56° E longitude at a height of 258 meters above sea level during *Rabi* season 2018-19.The soil of experimental field was sandy loam texture. The experiment was laid out in randomized block design with three replication having unit plot size of 5.67 m^2 (2.7×2.1 m) comprising of eight treatments of mustard and chickpea in different row combinations i.e. alone, 1:1, 2:2, 2:1, 1:2 and 1:3 and six land configurations as sowing methods i.e. flat bed, pair row, shallow lower bed and ridge, broad bed and furrow, narrow bed and furrow, furrow irrigated ridge bed system under organic management. The sketch of land configurations as used in the sowing methods is depicted in Figure 1. Soil samples from each treatment were collected and analyzed for soil nutrient analysis. Agronomic advantages, competition functions and monetary indices were calculated.

Organic carbon was estimated using Walkley and Black's Method while available nitrogen was estimated using alkaline potassium permanganate Method (Subbiah and Asija, 1956), available phosphorus by Olsen's method and available potassium by flame photometer (Table 1). The data was statistically analyzed through M-STAT software.

Mustard equivalent yield: Yield of individual crop was converted into equivalent yield (q ha^{-1}) on the basis of prevailing market price of the crop as per Katyal and Gangwar (2011). Mustard equivalent yield (MEY) was calculated by the following formula:

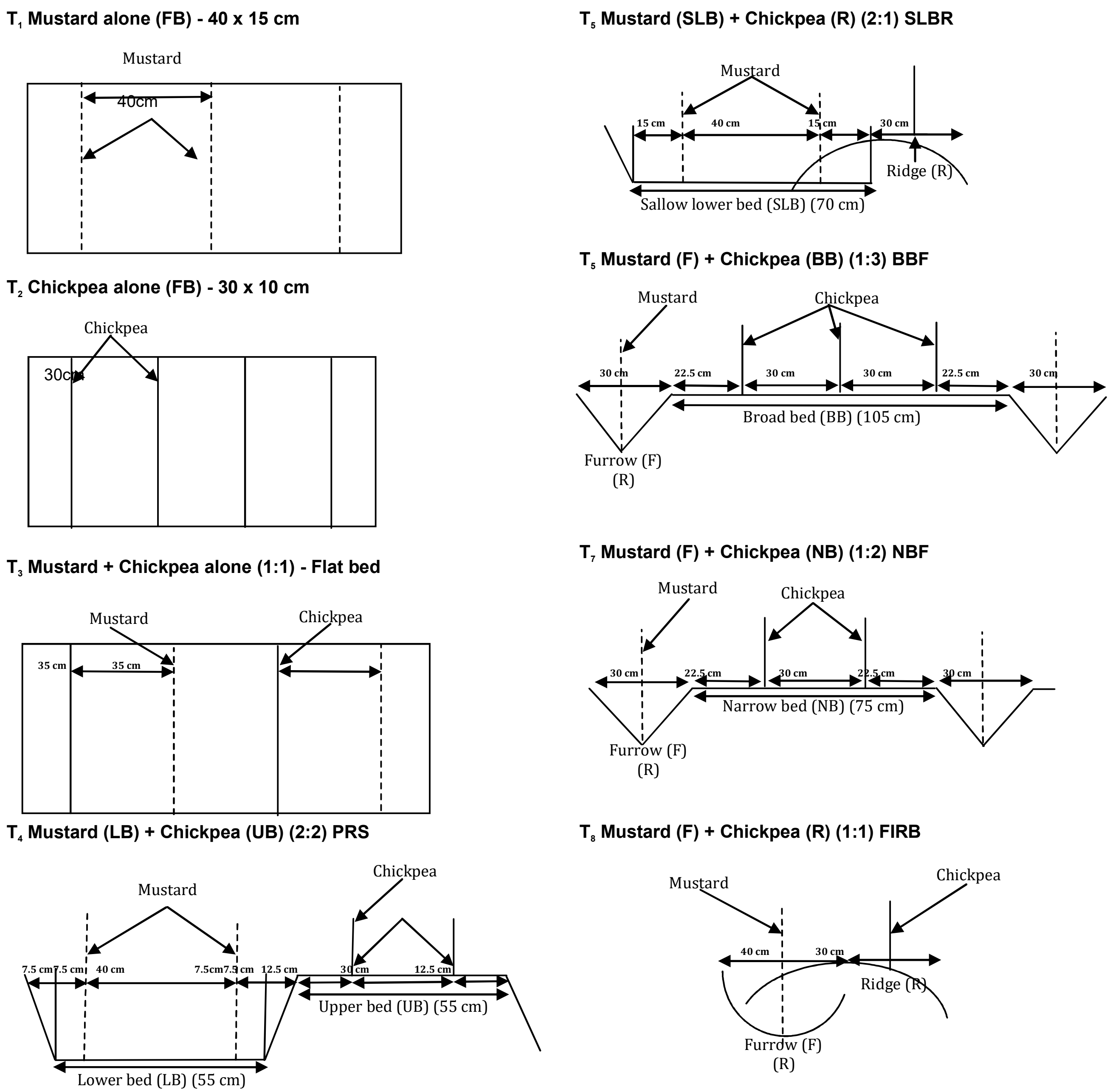

Fig. 1. Land configurations used as sowing methods

$$\text{MEY}=\frac{\text{Grain Yield of chickpea}\times\text{Price of chickpea}}{\text{Price of mustard}}$$

$$\text{CEY}=\frac{\text{Grain Yield of mustard}\times\text{Price of mustard}}{\text{Price of chickpea}}$$

Land equivalent ratio: The relative advantage of intercropping compared to sole cropping was calculated for each proportion using total LER. LER was calculated as the sum of the ratios of yield of each component crop in intercropping systems to its corresponding yield under sole crop (Rao and Willey 1980). Land equivalent ratio (LER) was calculated:

$$\text{LER}=\frac{Yab}{Yaa}+\frac{Yba}{Ybb}$$

Where Yaa and Ybb are the sole crop yields of crops a and b, respectively, Yab is the intercrop yield of crop a, and Yba is the intercrop yield of crop b. In this calculation crop is mustard and crop b is chickpea.

Aggressivity: Aggressivity was calculated by the formula proposed by Gilchrist (1965).

$$Aab=\frac{Yab}{Yaa\times Zab}-\frac{Yba}{Ybb\times Zba}$$

Where Aab aggressivity for the component crop 'a' Yaa and Ybb are the pure stand crop of crops a and b, respectively, Yab intercrop yield of crop 'a' and Yba intercrop of crop 'b', in this equation a is denoted for mustard and b for chickpea.

Economics: The cost of cultivation was worked out by taking all the expenses incurred into consideration. Gross income was worked out by multiplying grain and straw yield of the crop with their prevailing market prices. The cost of field preparation, manures, seed and sowing, plant protection etc. was also calculated based on prevailing market prices. Net returns (INR ha^{-1}), B: C and Profitability (INR day^{-1}) was calculated with the help of standard formulas which are as follows.

Gross return = Crop yield (q/ha) X Price of crop (Rs/q)

Net return = Gross return - Total cost of cultivation

$$\text{BCR}=\frac{\text{Net return (Rs/ha)}}{\text{Cost of cultuvation (Rs/ha)}}\quad \text{Profitability}=\frac{\text{Net return (Rs/ha)}}{\text{Duration of crops (in days)}}$$

RESULTS AND DISCUSSION

Effect of Chickpea Intercropping

Growth attributes of mustard: The growth attributes of mustard were significantly influenced in intercropping of chickpea using different land configuration (Table 2). The maximum plant height (24.54 cm) of mustard was at 30 DAS when mustard grown in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under paired row system (PRS) of intercropping. At 60 and 90 DAS the maximum plant height was when mustard was grown in shallow lower beds (SLB) + chickpea on ridges (R) in ratio of 2:1 intercropping system as compared to the other row ratios using land configurations. Different planting pattern had significant effect on plant height and maximum plant height was attained when sown on wide beds (Malik et al 2006, Allolli et al 2008). The maximum fresh weight of plant , was recorded at 30, 60 and 90 DAS (16.50 g, 136.30 and 240.33 g respectively) when mustard grown in furrows (F) + chickpea on ridges (R) in ratio of 1:1 under FIRB system of intercropping .This was statistically at par with mustard grown in shallow lower beds (SLB) + chickpea on ridges (R) in ratio of 2:1 under SLBR system of intercropping using land configurations which was higher compared to the mustard alone on flat bed (FB) system. Ambika et al. (2019)reported that BBF system of planting recorded more haulm yield than flat-planted in urdbean The maximum dry weight accumulation of 2.19, 30.30 and 58.67 g, per plant was at 30, 60 and 90 DAS respectively when mustard grown in furrows (F) + chickpea on ridges (R) in ratio of 1:1 under FIRB system of intercropping. However, it was statistically at par with mustard grown in shallow lower beds (SLB) + chickpea on ridges (R) in ratio of 2:1 under SLBR system of intercropping

Table 1. Initial soil properties of experimental site

Particular	Values	Analytical method applied
Texture	Sandy loam	Deshpande et al (1971)
Sand (%)	42.0	
Silt (%)	38.0	
Clay (%)	20.0	
$pH_{1:2.5}$	7.4 (Neutral)	Potentiometric
Organic carbon (%)	0.48 - 0.50 (Low)	Walkley and Black's rapid titration method
Available nitrogen (kg ha^{-1})	212 (Low)	Alkaline $KMnO_4$ method
Available phosphorus (kg ha^{-1})	14 (Medium)	Olsen's method
Available potassium (kg ha^{-1})	185 (Medium)	Flame photometric method

and mustard in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under PRS of intercropping with using land configuration which was higher compared to the mustard alone under flat bed (FB) system. Similar results were obtained by Allolli et al (2008).

Yield attributes of mustard: The maximum number of siliqua plant^{-1} was in mustard when grown in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under PRS(725.00). However, it was statistically at par with mustard alone flat bed (FB) system, which was significantly higher as compared to all other mustard + chickpea intercropping systems and sole cropping (Table 3). The maximum number of grains capsule^{-1} (16.37) was in mustard grown in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under (PRS). However, it was statistically at par with mustard alone flat bed (FB) system, which was significantly better as compared to all other mustard + chickpea intercropping systems and sole cropping. The maximum 1000-grain weight (6.98) was in mustard in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under PRS, which was statistically higher than all other mustard + chickpea intercropping systems and sole cropping.

Yield and yield index of mustard: The seed and stover yield of mustard was significantly higher in sole mustard (31.41 q ha^{-1}) sown in flat bed system, which was higher than all other mustard + chickpea intercropping systems.These results agree to the findings of Kumar and Singh, (2006) and Kour et al., (2014). Similarly, higher straw yield of mustard (97.94 q ha^{-1}) was obtained in mustard alone flat bed system, which was significantly higher than all the mustard + chickpea intercropping row ratios using land configurations. Significantly highest harvest index of mustard (30.98%) was when mustard grown in furrows (F) + chickpea on narrow beds (NB) in ratio of 1:2 under NBF system which was higher than all the mustard + chickpea row ratios using land configurations.

Influence of Mustard Intercropping on Chickpea

Growth attributes of chickpea: The significantly maximum plant height (14.25cm) of chickpea was recorded at 30 DAS when mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system. However, at 60 and 90 DAS of crop growth, the maximum plant height 13.52 and 35.94cm, respectively was recorded in chickpea alone under flat bed system as compared to the all-other row ratios (Table 4).

Table 2. Effect of intercropping systems using land configurations on periodic plant height, fresh and dry weight of mustard under organic management

Treatments / Intercropping system	Plant height at DAS (cm)			Plant fresh weight at DAS (g)			Plant dry weight at DAS (g)		
	30	60	90	30	60	90	30	60	90
T_1 Mustard alone (FB)	20.4	120.7	196.3	11.2	122.2	204.7	1.01	15.90	41.00
T_3 Mustard (FB) + Chickpea (FB) (1:1) FB	14.7	104.2	175.6	10.2	122.6	209.8	0.54	16.08	44.34
T_4 Mustard (LB) + Chickpea (UB) (2:2) PRS	24.5	110.3	190.9	13.9	126.2	219.9	1.21	27.50	52.22
T_5 Mustard (SLB) + Chickpea (R) (2:1) SLBR	24.0	127.3	199.9	10.6	132.8	231.2	0.53	29.55	56.00
T_6 Mustard (F) + Chickpea (BB) (1:3) BBF	23.2	107.0	184.7	13.4	124.0	213.4	1.18	21.53	51.00
T_7 Mustard (F) + Chickpea (NB) (1:2) NBF	15.9	116.5	194.1	9.9	103.8	195.0	0.49	14.37	40.78
T_8 Mustard (F) + Chickpea (R) (1:1) FIRB	23.5	124.8	197.3	16.5	136.3	240.3	2.19	30.30	58.67
CD (p=0.05)	1.66	4.86	7.14	1.60	5.31	13.09	0.57	1.91	2.76

Table 3. Effect of intercropping systems using land configurations on yield attributes of mustard under the organic management

Treatments	Number of siliqua plant^{-1}	Number of seeds siliqua^{-1}	1000-grain weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	HI (%)
T1	718.33	16.13	6.63	31.41	97.94	24.28
T3	590.00	13.33	5.78	26.41	62.86	29.60
T4	725.00	16.37	6.98	27.85	86.23	24.41
T5	696.00	15.12	6.53	29.28	97.48	23.09
T6	658.67	13.80	6.24	18.05	64.81	21.79
T7	602.00	13.67	5.84	23.03	51.30	30.98
T8	676.67	14.97	6.27	24.50	67.60	26.60
CD (p=0.05)	31.64	1.67	N.S.	1.81	2.46	2.13

See details of treatments in Table 2

Significantly maximum fresh weight 2.22, 12.16 and 35.89 g, of chickpea was at 30, 60 and 90 DAS respectively when mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system. It was statistically followed by mustard grown in lower beds (LB) + chickpea on ridges (R) in ratio of 2:1 under PRS and chickpea alone on flat bed (FB) system. Significantly maximum dry weight accumulation, was recorded at 30, 60 and 90 DAS respectively when mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system. It was statistically at par with mustard grown in shallow lower beds (SLB) + chickpea on ridges (R) in ratio of 2:1 under SLBR, which was significantly higher as compared to other all other treatments.

Yield attributes of chickpea: The maximum number of pods plant^{-1} (69.44) and number of grains pod^{-1} (1.73) were in chickpea alone and was statistically at par with mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system of intercropping but was significantly higher than all other mustard + chickpea row ratios using land configurations and sole cropping (Table 4).

Similarly, maximum 1000-grain weight (199.78) was recorded in chickpea alone under flat bed (FB) system, which was significantly at par with mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system, which was statistically higher than all other mustard + chickpea intercropping systems and sole cropping.

Yield and yield index of chickpea: The maximum grain yield (20.21 q ha^{-1}) and straw yield (47.28 q ha^{-1}) were obtained in chickpea alone under flat bed (FB) system, which was significantly higher than all other mustard + chickpea intercropping systems. Among the mustard grown in furrows (F) + chickpea broad beds (BB) in ratio of 1:3 under BBF system was obtained significantly higher grain yield (29.28 q ha^{-1}) all other row ratios using land configurations, the lowest grain yield (5.90 q ha^{-1}) was obtained in mustard grown on flat beds (FB) + chickpea on flat beds (FB) in ratio of 1:1 under flat bed system. Significantly highest harvest index of chickpea (40.63%) was observed when mustard grown in furrows (F) + chickpea on ridges (R) in ratio of 1:1 under FIRB system than all other treatments, it was statistically at par with mustard in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under PRS.

Table 4. Effect of intercropping systems using land configurations on growth parameters of chickpea under of organic management

Treatments / Intercropping system	Plant height (cm) at DAS			Plant fresh weight (g) at DAS			Plant dry weight (g) at DAS		
	30	60	90	30	60	90	30	60	90
T_2 Chickpea alone (FB)	13.52	35.94	69.56	1.89	9.02	30.44	0.31	1.88	6.78
T_3 Mustard (FB) + Chickpea (FB) (1:1) FB	13.36	31.11	63.44	1.61	6.7	21.66	0.23	1.76	5.44
T_4 Mustard (LB) + Chickpea (UB) (2:2) PRS	12.67	31.47	64.00	1.36	6.42	18.00	0.15	1.38	4.33
T_5 Mustard (SLB) + Chickpea (R) (2:1) SLBR	12.55	30.67	62.28	2.11	10.89	31.22	0.34	2.07	7.08
T_6 Mustard (F) + Chickpea (BB) (1:3) BBF	14.25	33.67	65.22	2.22	12.16	35.89	0.37	3.20	9.76
T_7 Mustard (F) + Chickpea (NB) (1:2) NBF	11.74	30.11	61.56	1.53	6.65	19.89	0.20	1.46	4.71
T_8 Mustard (F) + Chickpea (R) (1:1) FIRB	11.84	29.22	57.11	1.5	7.89	29.11	0.17	1.80	5.73
CD (p=0.05)	0.74	2.82	4.21	0.59	1.38	1.67	0.01	0.83	1.19

Table 5. Effect of intercropping systems using land configurations on yield attributes of chickpea under the organic management

Treatments	Number of pods plant^{-1}	Number of seeds pod^{-1}	1000-grain weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	HI (%)
T2	69.44	1.73	199.78	20.21	47.28	29.93
T3	37.78	1.37	179.45	5.90	12.13	32.94
T4	43.56	1.40	185.78	8.50	13.09	39.41
T5	45.89	1.47	187.92	6.04	11.72	34.02
T6	54.78	1.67	194.98	18.73	37.61	33.17
T7	53.89	1.63	192.66	12.73	19.66	39.28
T8	53.11	1.50	189.53	10.46	15.31	40.63
CD (p=0.05)	1.25	N.S.	1.79	1.47	2.29	5.60

See details of treatments in Table 4

Agronomic Benefits and Competition Functions of Intercropping

Mustard equivalent yield: The highest mustard equivalent yield (38.66 q ha^{-1}) was recorded when mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system of intercropping, which was statistically at par with mustard grown in lower beds (LB) + chickpea on upper beds (UB) in ratio of 2:2 under PRS. It was significantly higher than all other mustard + chickpea intercropping systems and sole cropping (Table 6).

Land equivalent ratio: Mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF of intercropping recorded maximum land equivalent ratio of 1.50, which was statistically at par with mustard grown in furrows (F) + chickpea (NB) (1:2) NBF system and Mustard grown in furrows (F) + chickpea on ridges (R) in ratio of 1:1 under FIRB system of intercropping (1.36 and 1.31) respectively while it was significantly higher than all other mustard + chickpea intercropping systems and sole cropping. Similar results reported Singh et al (2019).

Aggressivity: In all the treatments mustard dominated the chickpea in mustard + chickpea intercropping systems. The highest positive aggressivity (0.55) in mustard was in mustard grown on flat beds (FB) + chickpea on flat beds (FB) in ratio of 1:1 under flat bed system of intercropping using land configurations.

Competitive ratio (CR): The highest competitive ratio (CR) of 2.88 in mustard was in mustard + chickpea grown in ratio of 1:1 under flat bed (FB) system. In all the mustard + chickpea intercropping systems, the CR values more than unity indicating its superior ability of competition to chickpea. The lowest difference (0.85) between CR value off mustard (1.51) and chickpea (0.66) was in mustard grown in furrows (F) + chickpea on ridges (R) in ratio of 1:1 under FIRB system row ratio using land configurations.

Economics of intercropping: The highest cost of cultivation (Rs 33,100 ha^{-1}) was incurred in chickpea alone grown on flat beds (FB) under flat bed system, which was

Table 6. Effect of intercropping systems using land configurations on yield attributes of chickpea under the organic management

Intercropping system	MEY (q ha^{-1})	CEY (q ha^{-1})	LER	Aggressivity		Competitive ratio	
				Mustard	Chickpea	Mustard	Chickpea
Mustard alone (FB)	31.41	28.55	1.00	-	-	-	-
Chickpea alone (FB)	22.23	20.21	1.00	-	-	-	-
Mustard (FB) + Chickpea (FB) (1:1) FB	32.89	29.90	1.13	0.55	-0.55	2.88	0.35
Mustard (LB) + Chickpea (UB) (2:2) PRS	37.20	33.82	1.31	0.23	-0.23	2.11	0.48
Mustard (SLB) + Chickpea (R) (2:1) SLBR	35.92	32.66	1.23	0.17	-0.17	1.56	0.64
Mustard (F) + Chickpea (BB) (1:3) BBF	38.66	35.14	1.50	0.27	-0.27	1.86	0.54
Mustard (F) + Chickpea (NB) (1:2) NBF	37.04	33.67	1.36	0.42	-0.42	2.33	0.43
Mustard (F) + Chickpea (R) (1:1) FIRB	36.01	32.73	1.30	0.26	-0.26	1.51	0.66
CD (p=0.05)	2.68	2.44	0.10	N.S	N.S	N.S	N.S

Table 7. Effect of intercropping system using land configurations on cost of cultivation, gross returns, net returns, benefit cost ratio (BCR) and profitability under the organic management

Treatments / Intercropping systems	Field remained occupied (No. days)	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B : C	Profitability (Rs ha^{-1} day^{-1})
Mustard alone (FB)	135	30,350	1,25,620	95,270	3.14	706
Chickpea alone (FB)	133	33,100	88,905	55,805	1.69	420
Mustard (FB) + Chickpea (FB) (1:1) FB	137	31,725	1,31,572	99,847	3.15	729
Mustard (LB) + Chickpea (UB) (2:2) PRS	137	31,725	1,48,797	1,17,072	3.69	855
Mustard (SLB) + Chickpea (R) (2:1) SLBR	137	31,266	1,43,685	1,12,419	3.60	821
Mustard (F) + Chickpea (BB) (1:3) BBF	137	32,183	1,54,618	1,22,435	3.81	894
Mustard (F) + Chickpea (NB) (1:2) NBF	137	32,412	1,48,150	1,15,738	3.57	845
Mustard (F) + Chickpea (R) (1:1) FIRB	137	31,725	1,44,018	1,12,293	3.54	820
CD (p=0.05)	N.S	N.S	10714	10713	0.34	N.S

higher than all other treatments. All the mustard + chickpea row ratios using land configurations recorded significantly higher gross and net returns as compared to the sole cropping of mustard and chickpea. The maximum gross returns of Rs1,54,618 ha^{-1} and net returns Rs 1,22,436 ha^{-1} were obtained when mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under Broad bed and furrow (BBF) system of intercropping. The highest benefit cost ratio (3.81) was obtained from mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under BBF system of intercropping which was significantly higher than mustard alone and chickpea alone under flat bed (FB) system and all other mustard + chickpea row ratios. The maximum profitability (Rs. 893.69 ha^{-1}day^{-1}) was noted when in mustard grown in furrows (F) + chickpea on broad beds (BB) in ratio of 1:3 under broad bed and furrow (BBF) system of intercropping.

CONCLUSION

The mustard with chickpea can successfully be grown under organic management using land configurations. The sowing of mustard and chickpea under broad bed and furrow system was found to be better method of intercropping compared to sole cropping of both as the growth attributes were slightly reduced but ultimately the yield in equivalent term was apparently higher. The Broad bed and Furrow system was identified to be most suitable sowing method for obtaining higher yield and net return from mustard and chickpea intercropping system under organic farming in Bundelkhand.

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Effect of Tillage Practices Amended with Burnt Rice Husk Dust on Chemical Properties of Degraded Sandy Clay Loam and Impact on Soil and Cocoyam (*Xanthosomonas sagittifolium*) in Abakaliki Southeast Nigeria

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Abstract: The objective of this study was to find out the effect of tillage practices amended with burnt rice husk dust on soil chemical properties, content of carbohydrate, corm nutrient, heavy metal and yield of cocoyam in a degraded sandy clay loam. The field experiment was in split plot in randomized complete block design with six treatments. The treatments were; mound tillage (no treatment), ridge tillage (no treatment) mound + 10 t ha^{-1} burnt rice husk dust (MBRDH$_{10}$), Ridge + 10 t ha^{-1} burnt rice husk dust (RBRHD$_{10}$), mound + 20 t ha^{-1} burnt rice husk dust (MBRHD$_{20}$) + Ridge +20 t ha^{-1} burnt rice husk dust (RBRHD$_{20}$). Tillage practices amended with burnt rice husk dust significantly increased soil chemical properties compared to tillage practices alone. Soil extractable carbohydrate (cold water soluble, hot water soluble, dilute acid soluble) content was increased in tillage practices amended with rice husk dust. Corm nutrient content and shoot heavy metal (Cu, Pb, Zn, Fe) were significantly higher in tillage practices amended with burnt rice husk dust than tillage practices alone. The heavy metal was increased to levels that are non toxic to humans in food crops in the amended plots. The use of burnt rice husk dust as soil amendment could be recommended for reclamation of the productivity of degraded soil of the area and improve in crop quality without increase of heavy metal content of crops to toxic levels.

Keywords: Degraded soil, Heavy metal, Nutrient uptake, Tropical soil, Waste management

In most rural settings all over the world a number of indigenous plant species that serve as food and fight hunger by using underutilized plants (Agulana 2020). Abakaliki the study area has a rich resource of indigenous and underutilized crops such as cocoyam (*Xanthosomonas sagittifolium*) which the corms and shoot (stem and leaves) are consumed as food by the people. The crop possess health or physiological benefits over and above the normal nutritional value they provide. Tillage is the physical manipulation of soil performed to create conditions suitable for germination of seeds and seedling emergence, and root growth to reduce competition of weeds (Prihar et al 2000). Arcangelo (2019) reported that organic wastes used as nutrient source for crops increase nutrient recycling and reduce cost related to acquisition of inorganic fertilizer.

There is a growing demand for environmentally correct foods, such as agroecological and/or organic foods which use large amounts of organic wastes (Dias et al 2016). Successive applications of organic residues can cause changes in soil characteristics such as carbon content (Comin et al 2013), nitrogen (Glacomini et al 2013), soil aggregation (Loss et al 2017) and on biological parameter such as biological diversity and microbial activity (Gonzalez-Mancina et al 2013). Qian (2019) reported increased grain yield of soybean when they studied the effect of biochar on grain yield and leaf photosynthetic physiology of soybean cultivars with different phosphorus efficiencies. Nnadi et al (2019) observed improved soil properties and increased castor seed yield when they used wood ash as soil amendment in different tillage practices. Mbah and Njoku (2012) reported that over 10 million t year^{-1} of burnt and urburnt rice husk dusk are produced in urban and rural areas in Abakaliki on yearly basis. Research data on safe disposal or effective utilization of these wastes which constitute environmental and health problems are limited.

Similarly, the contributions of burnt rice husk dust to soil carbohydrate (CHO) content and their effect on crop nutrient and shoot heavy metal uptake by crops in soils of the study area have not been documented. The objective of this study was to find out the effect of tillage practices amended with burnt rice husk dust on soil chemical properties, carbohydrate content, corm nutrient content and shoot heavy metal uptake of cocoyam (*Xanthosomonas sagittifolium)* in a degraded sandy clay loam in Abakaliki Southeast Nigeria.

MATERIAL AND METHODS

Study area: This study was carried out for two cropping seasons (2016 and 2017) at the Faculty Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki, Nigeria. The area lies within latitude 06° 4^{1}N and longitude 08° 65^{1}E within the derived savannah zone of south east Nigeria. It has annual temperature of between 27-37 °C with mean annual rainfall of 1700 mm, received between April and November. The soil is an ultisol and classified as Typic Haplustult (FDALR 1985).

Land Preparation and application of treatments: The land used for the study measured 11 m by 63.5 m equivalent to 698.5 m^2. The experiment was arranged as a split plot in randomized complete block design. The area was divided into 6 blocks with each block separated by 1 m guard row. A total of 18 experimental units measuring 3 m x 3 m each were in each block. Plots were separated by buffer of 0.5 m and each replicate 1 m apart. The treatments were; mound tillage (no treatment=M), ridge tillage (no treatment=R) mound + 10 t ha-^{1} burnt rice husk dust (MBRDH$_{10}$), ridge + 10 t ha^{-1} burnt rice husk dust (RBHD$_{10}$), mound + 20 t ha^{-1} burnt rice husk dust (MBRHD$_{20}$) + ridge +20 t ha^{-1} burnt rice husk dust (RBRHD $_{20}$).

The burnt rice husk dust were collected from the rice mill site at Abakaliki and sieved with < 2.0 mm sieve. The mounds were prepared to a height and width of 16-20 cm and 20-25 cm respectively, using traditional hoe. Ridges measuring 18-25 cm high and 90-105 cm wide were also prepared using hoe. The treatments were spread uniformly and incorporated into their respective plots during cultivation. The main plot treatment was the tillage practices while the subplot treatment was the application of the BRHD.

Corm planting and cultural practices: Cocoyam setts with weights 20-25 g were planted at a depth of 5 cm and 30 cm apart to give a planting population of 40,000 corms/ha. Weeding was carried out manually at interval of 6 weeks with hoe, At maturity (18 months after planting) eight plants from each plot were selected and harvested by shelling up and uprooting the plant. This method brought out the corms while the remains in the soil were dug out. The corms were dried in the sun for 4-5 days. The shoot (stem and leaves) were cut of from the base of the corm, air dried for 3 days. The tillage practices were carried out in the second season and new setts of cocoyam were planted without application of amendments to test their residual effect.

Soil sample: A composite soil sample collected from 8 points (at a depth of 20 cm) in the entire plot before the experiment started in March 2016 was analysed for particle size, exchangeable bases (Ca, Na, Mg, K), pH, organic carbon, total N, and available P. After harvest each year three soil samples were collected from each plot and composited. The soil samples were air dried and taken to the laboratory for determination of soil chemical properties (particle size, exchangeable bases (Ca, Na, Mg, K,), pH, organic carbon, total N, and available Phosphorus).

Plant sample: At maturity eight cocoyam plants per plot were sampled and tagged. The shoot (comprising the stem and the leaves) were cut of from the base of the harvested corms. The shoot samples were air dried for 3 days. The dried shoots were grinded and taken to the laboratory for analysis of heavy metal (Cu, Zn, Fe, Pb). Similarly the corms were dried, grinded and analysed for Ca, Na, Mg and K.

Laboratory methods: The soil exchangeable bases (Ca^{2+}, K^+, Mg^{2+}, Na^+) were determined by the method of Thomas (1982). Particle size was determined hydrometer method (Gee and Bauder 1986). The pH was determined according to the method described by Peech (1965). Total nitrogen was determined using the micro-Kjeldhal distillation method (Bremner and Mulvaney 1982). Available P was determined by the Bray-2 method (Page, 1982) while organic carbon was determined using the method described by Nelson and Somners (1982). The same procedure was used to determine the nutrient content of cocoyam corm.

Determination of soil carbohydrate (CHO) content: The carbohydrate fractions in the soil sample was determined in duplicate in three types of soil extract viz dilute acid soluble, hot water soluble and cold water soluble by method (Adesodun et al. (2001).

Determination of heavy metal (Cu, Zn, Fe, Pb) content of cocoyam shoot: Concentrations of heavy metals (Cu, Zn, Fe, Pb) in cocoyam shoot was carried out using the analytical procedure by APHA (American Public Health Association 1998).

Statistical analysis: Data was analysed using the general linear model of SAS software for randomized complete block design (SAS institute 1999).

RESULTS AND DISCUSSION

Initial properties of the soil and burnt rice husk dust: The texture was sandy clay loam. The soil had low nutrient content compared to the burnt rice husk dust. The available P mg kg^{-1}, K cmol kg^{-1}, total N (%) and organic carbon (%) were

29.6, 0.19, 0.06 and 0.40 respectively while burnt rice husk dust had 52.1 mg kg^{-1} available P, 0.16% total N, 18.9 cmol kg^{-1} K, and 3.06% organic carbon. Higher levels of Cu (41) , Pb (50), Fe(33) and Zn (31) mg kg^{-1} were observed in burnt rice husk dust compared to the soil with 18, 22, 28 and 23 mg kg^{-1} for Fe, Cu, Zn and Pb, respectively. Analysis of the soil and burnt rice husk dust showed pH of 4, 81and 9.87, respectively.

Effect of Tillage Practices and Burnt Rice Husk Dust

Soil Ca, Mg, K, and Na (cmol kg^{-1}): Application of burnt rice husk dusk on tillage practices significantly increased soil Ca, Mg, and K, contents compared to tillage practices alone in the first and second cropping seasons (Table 1). In the first cropping season soil Ca content ranged between 0.17- 0.20 cmol kg^{-1} in tillage practices amended with burnt rice husk dust compared to 0.11 cmol kg^{-1} in tillage practices alone. The order of increase in soil K content in the first and second cropping seasons were mound<ridge<$RBRHD_{10}$ <$MBRHD_{10}$<$RBRHD_{20}$<$MBRHD_{20}$ and mound <ridge< $RBRDH_{10}$ <$RBRHD_{20}$< $MBRHD_{10}$ <$MBRHD_{20}$, respectively. The increase in Ca, K, and Mg observed in tillage practices amended with burnt rice husk dust compared to tillage practices alone could be attributed to higher levels of these nutrients in the burnt rice husk dust. Angelova et al (2013) reported apparent increase in soil exchangeable nutrients of Ca, K, and available P. Similarly, Anna and Sirpa (2001) showed significant increase is soil content of Ca, Mg and K when they studied the effect of wood ash fertilization on forest soil chemical properties. In, An and Park (2021) reported improvement in soil Ca, K and Mg. Mbah et al (2012) observed increase in soil Ca, K and Mg when studied the use of ash to improve the nutrient content of an ultisol and its effect on the growth and dry matter yield of maize. Couch et al (2020) reported no positive difference in soil content of exchangeable cations when they studied the short time effects of wood ash application on soil properties, growth and foliar nutrition of *Picea glauca mariana* and *P. glauca* seedlings

Soil pH, total N (%), Avail P (mg kg^{-1}) and OC (%): The tillage practices amended with burnt rice husk dust significantly increased soil organic carbon , available P , total nitrogen and pH compared to tillage practices alone in both cropping seasons (Table 2). In the first cropping the highest OC value of 80% was observed in $MBRHD_{20}$. This value was 47.5, 46.3, 15, 10 and 2.5% higher than mound tillage, ridge tillage, $MBRHD_{10}$, $RBRHD_{10}$ and $RBRHD_{20}$, respectively. In the second cropping season the order of pH increase was mound =ridge < $MBRHD_{10<}$$RBRHD_{10}$<$RBRHD_{20}$<MBRHD20. The observed increases in the values of these parameters in tillage practice amended plots could be attributed to the higher values of these nutrients in the initial burnt rice husk dust. Anna and Sirpa (2001) observed increased soil

Table 1. Effect of tillage practices and burnt rice husk dust on soil Ca, Mg, K, and Na

Parameter	2016				2017			
	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})
Mound	0.11a	0.21g	0.18bb	0.08ab	0.09ac	0.12ac	0.11ad	0.03c
Ridge	0.11a	0.20g	0.19bb	0..08ab	0.08ac	0.11ac	0.12ad	0.04c
$MBRHD_{10}$	0.17b	0.28h	0.29aa	0.10ab	0.13bb	0.17bd	0.16cc	0.07c
$MBRHD_{20}$	0.20c	0.32n	0.31aa	0.11ab	0.16cd	0.19bd	0.17cc	0.07c
$RBRHD_{10}$	0.16b	0.28h	0.26c	0.10ab	0.12bb	0.16bd	0.15cc	0.05c
$RBRDH_{20}$	0.20c	0.33n	0.30aa	0.10ab	0.13bb	0.16bd	0.15cc	0.05c

Means in the same column with the same letter do not differ significantly (p<0.05).
Mound tillage (no treatment), Ridge tillage (no treatment), $MBRDH_{10}$ = mound + 10 t ha-^{1} burnt rice husk dust, $RBRHD_{10}$, = ridge + 10 t ha-^{1} burnt rice husk dust , $MBRHD_{20}$ =mound + 20 t ha-^{1} burnt rice husk dust, RBRHD $_{20}$= ridge +20 t ha-^{1} burnt rice husk dust

Table 2. Effect of tillage practices and burnt rice husk dust on soil pH, total N, avail P and OC

Parameter	Avail.P Mg kg-^{1}	OC %	pH	Total N %	Avail.P Mg kg-^{1}	OC %	pH	Total N %
	2016				2017			
Mound	0.09bb	0.42a	4.6a	0.06s	0.06d	0.29s	4.4	0.02ar
Ridge	0.10bb	0.43aa	4.6a	0..07s	0.06d	0.30s	4.4	0.02ar
$MBRHD_{10}$	0.19a	0.68be	6.4ac	0.10a.	0.15c	0.43a	5.0	0.08ee
$MBRHD_{20}$	0.23d	0.80cd	6.9xa	0.13cx	0.18x	0.50ee	5.6	0.09ee
$RBRHD_{10}$	0.19a	0.72da	6.4ac	0.10ad	0.13c	0.45a	5.2	0.06as
$RBRDH_{20}$	0.23d	0.78as	6.9xa	0.14cx	0.15a	0.48ee	5.3	0.06as

See Table 1 for details

contents of OC, total N, available P and pH in ash amended soil relative to the control. Nnadi et al (2019) reported increased total N, available P, OC and pH in tillage amended with wood ash relative to unamended tillage practices. Njoku and Mbah (2012) studied the effect of burnt and unburnt rice husk dust on soil properties and reported increase in soil contents of OC, total N, available P and pH. Mbah et al (2012) also observed similar effect of poultry manure and wood ash on soil chemical properties and yield of maize (*Zea mays* L).

Soil carbohydrate content (mg kg^{-1}): Tillage practices amended with burnt rice husk dust significantly increased soil carbohydrate (CHO) content relative to tillage practices alone in the both cropping seasons (Table 3). In the first cropping season cold water soluble, hot water soluble and dilute acid soluble carbohydrates ranged between 42-83, 160-395 and 201-511 mg kg^{-1}, respectively. The order of increase in soil CHO content in the second cropping season was mound < ridge< RBRHD$_{10}$ < MBRHD$_{10}$ < RBRHD$_{20}$ < MBRHD$_{20}$ for cold water stable CHO., mound < ridge< RBRHD$_{10}$ < MBRHD$_{10}$ < RBHD$_{20}$ < MBRHD$_{20}$ for hot water stable CHO and mound < ridge< RBRHD$_{10}$ < RBRHD$_{20}$ MBRHD$_{10}$ < MBRHD$_{20}$ for dilute acid stable CHO. In both cropping seasons dilute acid soluble gave the highest levels of soil CHO. Bonglovanni and Lobertini (2006) observed that the lower contents of CHO extracted by cold and hot water when compared to dilute acid extraction method were due to the fact that dilute acid procedure extracted soluble CHO and also CHO from hemicellulose whereas cold and hot water extraction failed to produce hydrolysis of the hemicellulose. Rene (2016) mentioned that plants got CHO which plays a major role as their structural components and provides a major source of energy for soil microbial process from the soil. Gumina and Kuzyakov (2015) reported soil carbohydrate play essential role in soil by contributing to the maintenance and stimulation of microbial activities and functions. Spaccini et al (2002) mentioned waste management technique in some cases were successful in increasing the CHO content of the soil. Ratnayaka et al (2011) reported that carbohydrates are important parameters in determining soil fertility in different land uses. Mbah et al (2007) reported increased soil CHO contented when they used animal wastes as soil amendment. Similarly, Spaccini et al (2004) observed increased soil CHO in soils amended with organic wastes in Nsukka southeast Nigeria. Adesodun et al (2001) showed increased CHO content of soil amended with organic wastes in study on the structural stability and carbohydrate content of an ultisol under different management systems.

Ca, Mg, K and Na (cmolkg-^{1}) uptake of cocoyam corm: Tillage practices amended with burnt rice husk dust significantly increased cocoyam uptake of Ca, Mg and K compared to tillage practices alone) in the first and second cropping seasons (Table 4). Ca contents Cocoyam corm ranged between 0.18-0.26 and 0.16-0.19 in the first and second cropping seasons, respectively. In the first and second cropping seasons the highest K corm content was observed in MBRHD$_{20}$ amended plots. The increase in Ca, Mg, K and Na contents of cocoyam corm could be attributed to higher level of these nutrients in the burnt rice husk dust. Ojeniyi et al (2013) reported increased nutrient uptake by cocoyam corm in an alfisol in south west Nigeria when they used poultry manure as soil amendment. Hargreaves et al (2008) showed increased nutrient uptake in raspberries amended plots relative to the control. Nwokocha et al (2016) reported increased nutrient up take by maize (*Zea mays* L) when they studied the effects of organic amendments on some soil properties and nutrient uptake by maize in soils of different parent materials. Agegnehu et al (2016) observed that crop yield, plant nutrient uptake and soil physicochemical properties improved under organic soil amendments and nitrogen fertilization on Nitosols.

CU, Zn, Fe an Pb (Mg kg^{-1}) uptake by cocoyam shoot: There was significant increase in cocoyam shoot uptake of Cu, Zn and Fe in tillage practices amended with burnt rice husk dust relative to tillage practices alone (Table 5). Fe, Cu, Zn and Pb in shoot ranged between 0.13-0.23, 0.66-1.20, 36-

Table 3. Effect of tillage practices and burnt rice husk dusk on soil carbohydrate content

Parameter	Cold water stable	Hot water	Dil. acid stable	Cold water	Hot water	Dil. acid stable
		2016			2017	
Mound	42ac	160dd	205e	28ed	38b	184ax
Ridge	41ac	162dd	201e	29ed	38b	180ax
MBRHD$_{10}$	72bb	334bc	400h	58a	289as	251dd
MBRHD$_{20}$	83cx	416ee	483n	75s	310ed	270ef
RBRHD$_{10}$	63de	309dd	311av	55e	230xc	229gg
RBRDH$_{20}$	80cx	398ss	326er	65g	290er	240ss

See Table 1 for details

Table 4. Effect of tillage practices and burnt rice husk dust on corn Ca, Mg, Na and K uptake

Parameter	2016				2017			
	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})
Mound	0.19b	0.96a	0.92d	0.05b	0.12d	0.46g	0.32d	0.04a
Ridge	0.18b	0.94a	0,93d	0.05b	0.12d	0.40g	0.34d	0.04a
$MBRHD_{10}$	0.23az	1.02c	0.99v	0.06b	0.19g	0.60h	0.49e	0.06a
$MBRHD_{20}$	0.26vx	1.10s	1.09e	0.07b	0.18g	0.65a	0.51s	0.05a
$RBRHD_{10}$	0.24vx	1.05e	0.96s	0.07b	0.18g	0.61d	0.50s	0.05a
$RBRDH_{20}$	0.24vx	1.08s	1.03g	0.08b	0.19g	0.62d	0.53g	0.06a

See Table 1 for details

Table 5. Effect of tillage practices and rice husk dust on uptake of Cu, Zn, Pb, and Fe by the cocoyam shoot

Parameter	2016				2017			
	Cu (Mg kg^{-1})	Zn (Mg kg^{-1})	Pb (Mg kg^{-1})	Fe (Mg kg^{-1})	Cu (Mg kg^{-1})	Zn (Mg kg^{-1})	Pb (Mg kg^{-1})	Fe (Mg kg^{-1})
Mound	0.76aa	44ee	0.001bb	0.13ac	0.64d	32aa	0.001as	0.10as
Ridge	0.78aa	56ee	0.001bb	0.15ac	0.68d	29aa	0.002as	0.10as
$MBRHD_{10}$	1.01cc	89abc	0.002bb	0.22ee	0.81b	63cx	0.002as	0.15cv
$MBRHD_{20}$	1.04cc	98ff	0.002bb	0.21ee	0.80b	68ee	0.002as	0.13cv
$RBRHD_{10}$	0.98sa	88abc	0.002bb	0.23ee	0.70.a	67ee	0.002as	0.13cv
$RBRDH_{20}$	0.99sa	95rr	0.002bb	0.21ee	0.81b	68ee	0.002as	0.14cv

See Table 1 for details

101 and 0.001-0.003 Mg kg^{-1}, respectively, in the first cropping season. In the second cropping season the highest values of 63 Mg kg^{-1} for Zn, 81 Mg kg^{-1} for Cu, and 0.15 Mg kg^{-1} for Pb were obtained in $MBRHD_{20}$ amended plots. The higher level of Zn obtained in the tillage practice amended plots relative to tillage alone could be attributed to higher levels of organic matter in the burnt rice husk dust. Dawar et al. (2022) observed that poor organic matter results in lower availability of Zn micronutrient in plants. Oti Wilberforce and Nwabue (2013) reported that Zn is essential for growth and development of foetus and the normal functioning of the brain cells. According to Gibson (2012) Zn deficiency in humans adversely affects the development of the brains, immunity, skin, the brain and reproduction. Demizen and Atkay (2006) reported that the acceptable level for Zn in produce for human consumption according to World Health Organization (WHO) is 150 Mg kg^{-1} (Brown 1977). The level of Zn in cocoyam shoot in this study is within acceptable level. Copper (Cu) is an essential element for humans, animal and plants. Shabir et al (2020) reported that excess Cu induces oxidative stress inside plants through enhanced production of reactive oxygen species. The observed Zu level in cocoyam shoot in this study is within acceptable level. Iron (Fe) is an essential micronutrient for almost all living organisms. The concentration of Fe in cocoyam shoot is within the acceptable limit of 0.3 Mg kg^{-1} (Brown 1977). Lead is a harmful and toxic heavy metal. Lead accumulation in excess according to Collins et al (2022) cause up to 42% reduction in growth of roots. World health organization (WHO 1996) reported that the level of pb acceptable in produce for human consumption is 0.001-0.003 Mg kg^{-1}. Lead level in cocoyam corms were within tolerable limit. Tang et al (2015) showed more levels of pb in root and shoots of plant grown in organic waste amended soil. The results of this study agreed with those of Nnadi et al (2019) and Mbah and Njoku (2023) when the used organic wastes as soil amendments. However, the result differed from those of Augelova et al (2010) who reported lower levels of heavy metals in potato grown in organic waste amended soil relative to the control. The levels observed in pb does not constitute health problems in crops and human food.

CONCLUSION

The tillage practices amended with burnt rice husk dust improved soil chemical properties (Ca, Mg, K, Na, total N, OC, available P an pH). There is higher concentrations of carbohydrate determined as cold water soluble, hot water soluble and dilute acid soluble in burnt rice husk dust (BRHD) amended tillage practices. Higher nutrient (Ca, Mg, K, Na) content by cocoyam corm was observed in tillage practices amended with BRHD compared to tillage practices alone, Application of burnt rice husk dust on tillage practices increased heavy metal (Cu, Mg, Pb, Fe) uptake by cocoyam shoot to non-toxic level for humans. The amendment of tillage practices with burnt rice husk dust was recommended for improvement of fertility of degraded soils and increase in crop performance without problem of heavy metal toxicity in crops and humans.

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Integrated Effect of Azolla in Combination with Nitrogenous Fertilizer on Chemical Properties of Soil and Yield of Rice Grown under SRI

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Abstract: The study was conducted to assess the effect of azolla application in combination with nitrogen fertilizer on yield of rice and chemical properties of soil under system of rice intensification (SRI)at CSKHPKV, Palampur during *kharif,* in the year2016.Azollafirst produced and then collected. The collected azollawas evaluated for nitrogen (%), nitrogen fixation, carbon and nitrogen ratio (C: N), protein content, phosphorous, potassium, secondary elements (S, Ca and Mg) and micronutrient cations (Fe, Mn, Zn and Cu). Azollawas applied along with graded doses of inorganic N fertilizer. Maximum paddy grain yield of 5.13 t ha^{-1} was observed with application of125 kg N ha^{-1} + 8 tonnes of azolla followed by 100 kg N ha^{-1}+ 8 tonnes of azolla. However, lowest rice grain yield (0.83 t ha^{-1}) was in control with no application of azolla and fertilizer N. The highest straw yield was observed with 125 kg N ha^{-1} + 8 tonnes of azolla. The increase in pH (5.57) was also observed with combined application of azollaand fertilizer nitrogen. Organic carbon, CEC as well as available N, P and K were higher in 125 kg N ha^{-1} + 8 t azolla.

Keywords: Azolla, N fertilizer, SRI, paddy, Yield, Soil chemical properties

The primordial shift has taken place in agriculture research and food production. In the past, the principal driving force was to increase the yield potential of food crops and to maximize the productivity and now the drive is focusing on increasing the productivity along with sustainability. For farming systems to remain productive and to be sustainable in long-term it will be necessary to replenish the reserves of nutrients which are removed or lost from the soil. Rice (*Oryza sativa*) is the staple food for more than half of the world's population. About 90 per cent of total rice is grown and consumed in Asia. In India rice is cultivated on an area of 43.79 million hectare with the total production of 112.91 million tonnes with the average productivity of 25.8 q ha^{-1} (Anonymous 2019). Rice is also one of the main food crops grown during the *kharif* season in the state of Himachal Pradesh; where it occupies an area of 71.61 thousand hectares with a total production of 132.49 thousand tonnes and productivity of 1736 kg ha^{-1} (Anonymous 20118). At the current rate of population growth, India has to produce about 130 million tonnes of rice by 2025 to feed the growing population (Anonymous 2012). Meeting the targeted demand of food grains is a challenging task for the policy makers, researchers and all other stakeholders. The problem is still confounded as the targeted increase has to be met in the background of declining resource base (land, water, soil productivity, labour etc.) and increasing environmental and soil health concerns. To safeguard and sustain the food security in India, it is therefore, imperative to explore and evaluate such technologies which may increase the productivity of rice under situations of dwindling resource base particularly when there is little scope of horizontal or lateral expansion. Thus, the increase in production has to be vertical and should come from the same cultivated land by way of increased crop productivity. The System of Rice Intensification (SRI) is a method of rice cultivation developed in an unconventional way now known and being practiced in more than 40 countries. In agricultural systems N has been applied in the form of N-fertilizer, or be derived from atmospheric nitrogen through biological N_2 fixation (BNF). Although, BNF has long been a component of many farming systems throughout the world, its importance as a primary source of nitrogen for agriculture has diminished in recent decades as increasing amounts of nitrogen fertilizers are being used for the production of food and cash crops. However, international emphasis on environmentally sustainable development with the use of renewable resources is likely to focus attention on the potential role of BNF in supplying N for agriculture. Azolla is a free floating water fern which fixes atmospheric nitrogen in association with the cyanobacteria *Anabaena azollae*. The heterocyst of symbiont anabaena is a site of nitrogen fixation. Nitrogen fixation associated with high growth rate can enables azolla to accumulate more than 10 kg N $ha^{-1}day^{-1}$ under optimal growth conditions. In general, a single crop of azolla is known to provide 20-40 kg ha^{-1} N and also increases the availability of both macro and micro nutrients, but this is insufficient to meet the total nitrogen requirement of the target crop. Therefore, the use of azolla in combination with chemical nitrogen fertilizers affords a feasible alternative practice.

In addition to the use of azolla as nitrogen source for rice crop can be used for reclaiming saline soils, reducing evapotranspiration and to control weed infestations in rice crops. It can also be used to purify waste water as it can accumulate P and some heavy metals from water. However, there are some constraints on the production and use of azolla, like the availability and control of water supplies, P limitations in soils, predators of azolla, light intensity, photoperiod, salinity and its temperature sensitivity. Azolla is capable of tolerating a wide range of temperature from 5-45°C, so high-temperature-tolerant azolla species, *azolla microphylla*, can be used in tropical countries to overcome the problem of its sensitivity to high temperatures. This species can survive at temperatures of up to 38±1ºC and can fix nitrogen. Sufficient work has been done on the exploitation of azolla as a biofertilizer in rice in other states of country, however limited systematic studies so far has been conducted in Himachal Pradesh about the usefulness of azolla in rice production (Thakur 2013). Keeping this in view the present study has been done to evaluate the integrated effect of azolla application along with graded doses of inorganic N on rice yield and soil properties.

MATERIAL AND METHODS

Location and climate: The present study was conducted at CSK Himachal Pradesh Agriculture University, Palampur of Himachal Pradesh in the North-Western Himalayas. The experimental farm is situated at 32°6' N latitude and 76°03' E longitude at an altitude of about 1290 meters above mean sea level. The climate of the study area is characterized as wet temperate with mild summers (March–June) and cool winters. The average annual rainfall of the area ranges from 2500 to 3000 mm. In general, a major portion of the rainfall (about 80%) was received during monsoon period from June to September. The weekly maximum and minimum temperature ranged from 23.9 to 30.6 °C and 14.0 to 20.6°C, respectively. The mean relative humidity ranged from 55.6 to 98.3% and total of 2500 mm rainfall were received during the crop season. Soil of the study area was silt loam in texture and was classified as "*Typic Hapludalf*" as per the Taxonomic System of Soil Classification. At the initiation of the experiment the pH of the soil was 5.5. The contents of organic carbon, available nitrogen (N), phosphorus (P) and K were 8.7 g kg, 377.0 kg ha^{-1}, 17.8 kg ha^{-1} and 159 kg ha^{-1}, respectively (Table 1). The 12 treatments which includes azolla application along with fertilizer N (Table 3). The experiment was conducted in randomized block design (RBD) with three replications and the plot size was 10 m^2 (5 m X 2 m).

Nutrient management: Paddy (HPR-2143) was taken as the test crop and was fertilized with different grades of nitrogen fertilizers along with azolla. Azolla has been grown in nursery into three trenches of size 2 x 2 x 0.2 m and leveled uniformly. Water was maintained at a depth of 10 cm. Cattle dung (112.5 g) mixed with water (225 ml) was sprinkled. Azolla inoculum @ 100 g was introduced in each trench. Superphosphate @ 10g was applied in three splits at an interval of 4-days as top dressing. Azolla is a fast growing aquatic fern and doubles in 2 to 3.5 days. After fifteen days azolla was harvested and from one harvest 1.9 kg fresh azolla m^{-2} was obtained. The azolla produced was then collected, which was ready for application in fields. The collected azolla was evaluated for nitrogen (%), N fixation, carbon and nitrogen (C: N) ratio, protein content, phosphorous, potassium, secondary elements (S, Ca and Mg) and micronutrient cations (Fe, Mn, Zn and Cu). The manurial content of the azolla have been given under (Table 2).

Sampling and analysis: Soil samples from a depth of 0-0.15 m from each plot were collected after the harvest of crop and then were air dried and finely grounded to pass through 2 mm sieve and subsequently stored in polythene bags for further analysis. The processed soil samples were analyzed for pH, organic matter, cation exchange capacity, available N, P and K, microbial biomass carbon, urease activity and phytase enzyme following glass electrode method given by Jackson

Table 1. Soil properties before sowing of *kharif*, rice (2016)

Soil property	Value
Water holding capacity (%)	49.38
Bulk density (mg m^{-3})	1.46
Water stable aggregates (<0.1mm)	1.49
Permanent wilting point (%)	16.10
Field capacity (%)	25.81
pH (1: 2.5, soil : water)	5.50
Organic carbon (g kg^{-1})	8.70
Nitrogen (kg ha^{-1})	377.0
Phosphorus (kg ha^{-1})	17.8
Potassium (kg ha^{-1})	159.0
CEC [cmol (p+) kg^{-1}]	8.50
Microbial biomass carbon (µg g^{-1})	113.4
Urease activity (µg g-1 min^{-1})	4.1
Phytase activity (µg inorganic P solid g^{-1} ha^{-1})	0.32

Nursery of paddy (HPR-2143) was raised and further transplanted on 25th June, 2016 at a spacing of 25 cm X 15 cm

(1967) rapid titration method (Walkley and Black, 1934), alkaline permanganate method (Subbia and Asija, 1956), ammonium molybdate blue colour method (Olsen et al 1954), 1N neutral ammonium acetate method (Jackson 1973), ammonium acetate method (Black 1965), fumigation extraction method (Vance et al 1987), urea hydrolysis method (Tabatabai 1972) and Ames (1966) respectively.

RESULTS AND DISCUSSION

Integrated effect of azolla and N fertilizer on productivity of paddy: The maximum paddy grain yield (5.13 t ha^{-1}) was with application of 125 kg N ha^{-1} + 8 tonnes of azolla followed by 100 kg N ha^{-1} + 8 tonnes of azolla (5.10 t ha^{-1}) and 50 kg N ha^{-1} + 8 tonnes of azolla (5.00 t ha^{-1}). An increase of 0.59 per cent was observed with application of 100 kg N ha^{-1} + 8 tonnes of azolla over 125 kg N ha^{-1} + 8 tonnes of azolla (Table 3). The grain yield obtained in all the treatments was significantly higher than the control. However, minimum grain yield i.e. 0.83 t ha^{-1} was observed in control with no application of azolla and N fertilizer. The maximum straw yield of 7.55 t ha^{-1} was in 125 kg N ha^{-1} + 8 tonnes of azolla followed by 100 kg N ha^{-1} + 8 tonnes of azolla, 50 kg N ha^{-1} + 8 tonnes of azolla and 50 kg N ha^{-1} + 8 tonnes of azolla. The increase of 0.80 per cent was observed in 125 kg N ha^{-1} + 8 tonnes of azolla over 100 kg N ha^{-1} + 8 tonnes of azolla. There is an increase of 17.95 per cent in straw yield in 100 kg N ha^{-1} + 8 tonnes azolla over 100 kg N ha^{-1} + 4 tonnes of azolla. Similarly, 100 kg N ha^{-1} + 4 tonnes of azolla produced 21.18 per cent increased straw over 100 kg N ha^{-1}. The straw yield obtained from all the treatments was significantly higher than control. Kumar and Shahi (2016) also reported similar findings on yield of rice with integrated application of azolla and inorganic N fertilizer. The increase in grain and straw yield in all the treatments over control might be due to the continuous addition of N through the application of azolla and inorganic fertilizers, which had significantly increased the biological yield of paddy. Inorganic treatments alone produced higher yield as compared to organic alone because of inability of organic sources to release N at the time of higher requirements by the crop (Castro et al 2003).

Integrated effects of azolla and N fertilizers on soil properties: The pH of the soil samples varied between 5.51 and 5.71 (Table 4). There was an increase in pH of soil after the application of azolla. As azolla is a green manure, rise in pH may be resulted due to the decomposition of azolla that might have reduced Fe and Mn oxides causing the soil pH to rise and secondly mineralization of organic anions to CO_2 and H_2O, thereby removing H^+ ions. Similar results were reported by Singh et al (2006). Similarly, highest organic carbons were r in treatments where, azolla was added and were slightly higher than sole application of inorganic fertilizer. The lowest organic carbon was in control. The organic carbon content in soil is due to successive azolla cropping with rice plants. It has been observed that azolla completely decomposed within 30 days. Azolla biomass may persist in soils for a longer period, and possibly results in an increase in the organic matter content of soil at a faster rate. This is in agreement with (Cisse and Vlek 2003). The cation exchange capacity also increased with the azolla addition and varied in between 8.50 cmol (p+) kg^{-1} to 8.73 cmol (p+) kg^{-1}. The

Table 2. Manurial content of azolla

Parameters	Mean value
Moisture (%)	81.54
C (%)	35
N (%)	4.10
P (%)	1.11
K (%)	4.50
Ca (%)	0.20
Mg (%)	0.21
S (%)	0.49
Zn (mg kg^{-1})	38
Mn (mg kg^{-1})	39
Fe (mg kg^{-1})	7.62
Cu (mg kg^{-1})	16
C:N ratio	9.56
Protein content (%)	25.62
N fixation (n moles $C_2H_4 g^{-1}$ Dwt min^{-1})	13.94

Table 3. Effect of integrated application of azolla and inorganic N fertilizer on grain and straw yield of rice

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Control	0.83	1.05
50 kg N ha^{-1}	2.33	2.99
100 kg N ha^{-1}	4.03	5.24
125 kg N ha^{-1}	4.47	5.90
4 tonnes of azollaalone	2.67	3.57
50 kg N ha^{-1}+ 4 tonnes of azolla	3.67	4.99
100 kg N ha^{-1}+ 4 tonnes of azolla	4.60	6.35
125 kg N ha^{-1}+ 4 tonnes of azolla	4.87	6.81
8 tonnes of azolla alone	3.80	5.40
50 kg N ha^{-1}+ 8 tonnes of azolla	5.00	7.20
100 kg N ha^{-1} + 8 tonnes of azolla	5.10	7.49
125 kg N ha^{-1} + 8 tonnes of azolla	5.13	7.55
CD (P= 0.05)	0.70	0.97

Table 4. Effect of integrated application of azolla and inorganic fertilizer on soil chemical properties

Treatments	pH	Organic carbon ($g\ kg^{-1}$)	CEC [cmol (p+) kg^{-1}]	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	AvailableK ($kg\ ha^{-1}$)
Control	5.61	8.70	8.50	365.0	15.50	146.7
50 kg N ha^{-1}	5.61	8.80	8.60	387.3	17.87	162.3
100 kg N ha^{-1}	5.61	8.80	8.60	390.5	18.50	165.4
125 kg N ha^{-1}	5.61	8.80	8.70	395.7	18.70	166.2
4 tonnes of azollaalone	5.63	8.90	8.65	382.0	18.20	162.3
50 kg N ha^{-1} + 4 tonnes of azolla	5.71	8.90	8.70	387.8	18.30	163.4
100 kg N ha^{-1} + 4 tonnes of azolla	5.64	8.90	8.72	395.6	18.50	164.6
125 kg N ha^{-1} + 4 tonnes of azolla	5.51	8.90	8.72	398.4	18.70	167.4
8 tonnes of azolla alone	5.71	8.90	8.69	392.7	18.40	163.7
50 kg N ha^{-1}+ 8 tonnes of azolla	5.65	8.90	8.70	395.9	18.60	165.2
100 kg N ha^{-1} + 8 tonnes of azolla	5.53	8.90	8.71	399.2	18.80	167.8
125 kg N ha^{-1} + 8 tonnes of azolla	5.54	8.90	8.73	402.8	18.87	169.4
CD (P= 0.05)	NS	NS	0.12	13.26	1.61	6.58

highest was in 125 kg N ha^{-1} + 8 tonnes of azolla*,* whereas lowest was recorded in control. This might be due to the continuous release of cations with the decomposition of organic matter which would have increased the CEC of soil (Thakur 2013). Available nitrogen was found significantly higher in the treatment 125 kg N ha^{-1} + 8 tonnes of azolla over all the treatments. The lowest available N content was in control. These results indicate that higher dose of inorganic N along with azolla had increased the nitrogen content of soil. Increase in available N with azolla plus inorganic N application can be explained on the basis of nitrogen mineralized during the decomposition of azolla (Sudadi and Sumarno 2014). The release of nitrogen from azolla species was faster than from sesbania as the C: N of azolla is quite low in comparison to sesbania. Singh et al (2005) also reported the similar results. Available phosphorus and potassium did differ significantly among all the treatments. Numerically higher value was recorded in the treatment 125 kg N ha^{-1} + 8 tonnes of azolla, which was significantly higher than control, 50 kg N ha^{-1} and 4 tonnes of azolla alone, whereas it was significantly at par with the rest of the treatments. Lowest available K was recorded in control. Singh et al (2006) also reported that application of azolla in combination with urea showed higher available K in soil. Increase in available potassium over control with the addition of azolla might be due to reduction in potassium fixation and release of potassium due to interaction of organic matter with clay, besides the direct addition to the soil pool (Urkurkar et al 2010).

CONCLUSIONS

The highest grain and straw yield under paddy was with 125 kg N ha^{-1} + 8 tonnes of azolla followed by 100 kg N ha^{-1} along with 8 tonnes of azolla the treatment. Similarly, rise in pH over initial pH was observed in almost all the treatments with integrated application of inorganic fertilizers along with azolla. Similarly, other chemical properties of soil have also showed an increase over initial values, where integrated application of inorganic fertilizer and azolla has been done.

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Development of Soil Spectral Library and Fertility Mapping using Hyperspectral Remote Sensing in Pantnagar Region, Uttarakhand

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Abstract: Hyperspectral remote sensing is an advance technology that facilitates the implementation of field soil data into digital soil mapping. It provides easier and effective way in understanding of soil chemical, physical, mineralogical and biological characteristics. In the present study a soil spectral library and fertility maps were developed based on different soil series for the university farm of GBPUA&T, Pantnagar. Twenty-five soil samples were collected from the farm at regular intervals. The samples were analyzed for soil texture, available nitrogen, available phosphorus and available potassium. Various soil-related indices were calculated from Hyperion imagery, which included Brightness Index, Redness Index, Saturation Index, Coloration Index, Hue Index, Normalized Difference Vegetative Index and Ratio Vegetation Index and Carbon Difference Index. The soil spectra of soil series showed different reflectance intensity due to variability of organic matter, sand, silt and clay. Beni silty clay loam soil showed highest reflectance peak among all the soil series due to maximum silt content whereas Phoolbagh clay loam soil comprises highest organic matter that decreases the reflectance peak. Moreover, the multiple regression equation of available nitrogen and available phosphorus was found significant with R^2 of 0.66 and 0.61 respectively.

Keywords: Hyperion, Hyperspectral remote sensing, Soil Spectral library

Remote sensing technology plays an important role in agriculture and also introduces new opportunities for improving agricultural practices. It consists large varieties of data in both spatial and non-spatial domains over large and inaccessible areas even in areas where little geologic and/or cartographic information available. Thus, the technique is ideally suited for regional studies. Soil is a complex and heterogeneous system; the assessment of soil properties is not so easy by using conventional methods. Soil texture also significantly influences the reflectance pattern. Soil spectral library approach is highly suitable to facilitate the determination of soil characteristic with relatively low cost and effort. The shape of soil spectra holds information about mineral composition, organic matter, water (hydration, hygroscopic and its free pore water), iron form, salinity and particle size (Shepherd and Walsh 2002). Therefore, soil spectral signatures describe the appropriate use of soil in precision agriculture. With increasing demand of spatial and temporal resolution concerning soil properties in various precision agriculture applications, traditional laboratory methods are proving inadequate (Ehsani et al 1999). Hyperspectral remote sensing technology is used to create a spectral signature and fertility mapping associated with different soil properties. Such information is used to improve the prediction accuracy in transforming the hyperspectral signals into meaningful soil attributes. Some spectral libraries also exist in developed countries on the bases of regional soil. Recently, a global spectral library with 3768 soils was developed in which only 104 soils were from the whole of Asia (Brown et al 2006) whereas in India, only a fewer spectral libraries are existing with different soil properties (Srivastava et al 2004, Santra et al 2009, Gulfo et al 2012). Many studies also demonstrated the contribution of RS data in mapping soil properties based on reasonable correlations between soil properties and reflectance spectra (Ray et al 2004, Bajwa and Tian 2005, Ghosh et al 2012, Gautam et al 2016, Bisht and Nain 2016). Due to large variation in soil properties, there is a requirement for developing more extensive spectral libraries and fertility maps representing specific region. Therefore, this study was conducted to develop soil spectral library and fertility maps of Pantnagar region that can further support in the classification and characterization of soils.

MATERIAL AND METHODS

Study area: The study was carried at Agricultural farm of GBPUA&T, Pantnagar, U.S. Nagar (Uttarakhand), India which is located at 29°N latitude, 79.29°E longitude and with an altitude of 243.80m from the mean sea level in the *Tarai* belt (Fig. 1). The study area falls under sub-humid to sub-tropical climate with hot dry summers and cool winters.

Soil characteristic: The soils of Pantnagar belong to Mollisols order and having six soil series viz. Patharchatta sandy loam (Psl), Nagla loam (Nl), Haldi loam (Hl), Phoolbagh clay loam (Phcl), Khamia sandy loam (Khsl) and Benisilty clay loam (Bsicl) (Deshpandey et al 1971). Twenty-five soil samples (surface soil) were collected from the university farm at regular intervals. The field work was undertaken during the month of May on a clear sunny day. The samples were analyzed for soil texture, available N, available P and available K using hydrometer method, Alkaline Permanganate Extractable Method (Subbiah and Asija 1956), Sodium Bicarbonate Extractable Method, (Olsen et al 1954) and Ammonium Acetate Extractable Method, (Muhr et al 1965) respectively. The physical and chemical characteristics of different soil serious examined in the study region was presented in Table 1.

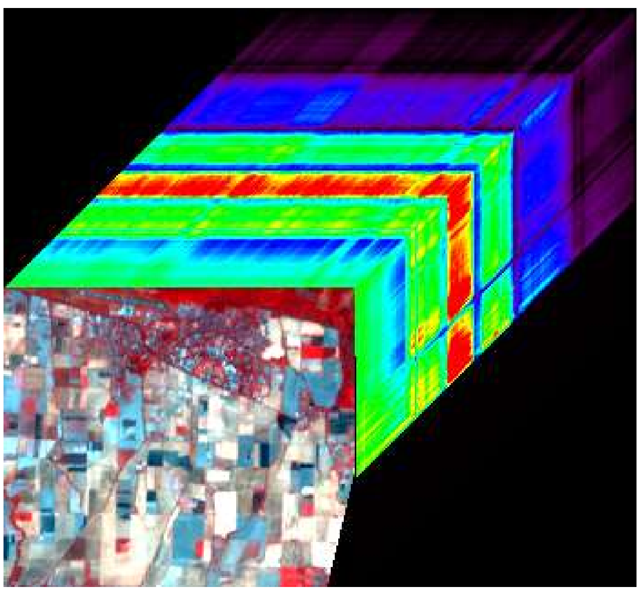

Fig. 1. Hyperion image of 2nd May, 2013 showing agriculture farm of GBPUA&T, Pantnagar

Remote sensing data acquisition: The Cloud free Hyperion imagery of May 2nd, 2013 was acquired from the United States Geological Survey (USGS) archive (http://earthexplorer.usgs.gov/). Hyperion has 242 spectral bands spanning a spectral range from 0.4 to 2.5 µm, with a sampling interval of 10nm

Pre-processing and atmospheric correction of hyperion image: In order to standardize L1GST hyperion image into ENVI format band, the original image was imported using Hyperion Tools 2.0 (White 2013) that contains wavelength, full width half maximum and bad band information. In this study, 147 bands were used finally used which are: bands 9 – 55, 86 – 119, 133 – 164, 183 – 184, 188 – 200, and 202 – 220. The image was atmospherically corrected into the surface reflectance using QUAC (Quick atmospheric correction technique).

Development of spectral library of different soil series: A ground survey of the study area has been made to precisely identify and collect soil samples of different soil series along with geographical coordinates. These geographical coordinates have been plotted on the Hyperion image of the study area and the spectral signature of each soil series have been extracted from the image by ENVI 4.8 software. Thereafter, a spectral library has been developed that comprising the six soil series of the study area.

Computation of spectral indices: Various soil-related spectral indices were computed from Hyperion data, after converting the digital numbers into radiance values. Those indices included soil related indices such as, Brightness Index (BI), Hue Index (HI), Saturation Index (SI), Coloration Index (CI), Redness index (RI) Normalized Difference Vegetative Index (NDVI) and Ratio Vegetation Index (RVI). The statistical models for estimating these indices are presented in Table 1.

Development of multivariate model: In the present study, stepwise multivariate statistical regression was carried out using SPSS package to model the relationship between spectral indices and soil organic carbon. The representative expression of multivariate model has been mentioned below:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots + b_nX_n$$

Table 1. The physical and chemical characteristics of soils of Pantnagar region

Soil series	Texture	OM (%)	Sand (%)	Silt (%)	Clay (%)
Phoolbagh clay loam (Phcl)	Clay loam	1.89	26.54	44.70	28.76
Benisilty clay loam (Bsicl)	Silty clay loam	1.90	9.61	62.74	27.65
Haldi loam (Hl)	Loam	1.41	34.11	49.06	16.83
Nagla loam (Nl)	Loam	1.37	38.47	39.93	21.6
Khamia sandy loam (Khsl)	Sandy loam	1.27	55.68	27.69	16.63
Patharchatta sandy loam (Psl)	Sandy loam	1.20	52.89	33.98	13.13

Where, Y= dependent variables, b_0= estimated constant, b_n= estimate coefficients, X_n= independent variables

Spectral indices mentioned in Table 1 together with different individual's bands were used as independent variables, while SOC has taken as dependent variable.

Correlation coefficient: The relationship was established between observed and estimated SOC to analyze the accuracy of multivariate model.

$$r = \frac{\sum_{n=1}^{N}(Rn - R')(Cn - C')}{\sqrt{\sum_{n=1}^{N}(Rn - R')^2 * (Cn - C')^2}}$$

Where, *r* is the correlation coefficient, *R* is the selected variables (spectral band values and indices, *N* is the number of soil samples, here N is 25, *Cn* is soil organic carbon content of sample *n* and R' as well as C' are the mean values.

Root mean square error (RMSE): The RMSE has been used as a criterion for model evaluations and has been computed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

Where X_{obs} is observed values and X_{model} is modelled values.

RESULTS AND DISCUSSION

Spectral library of different soils: The spectral signature of the individual soil series has been collected and plotted on the Hyperion image for Pantnagar. The spectral library of soil series namely Patharchatta sandy loam (Blue), Nagla loam (green), Haldi loam (sea green), Phoolbagh clay loam (red), Khamia sandy loam (brown) and Benisilty clay loam (purple) of Pantnagar region has been represented in figure 2 and reflectance value of each soil series corresponding to different hyperion bands was compiled in Table 3. Results showed that the reflectance curves for all six soil series increased continuously in visible bands (426.18nm, 436.99nm, 487.86nm, 538.74nm, 569.26nm, 681.19nm) while corresponding to wavelength 894.87nm, soil reflectance represented less fluctuation as compare to red band (681.19nm). Although spectral curve in SWIR (short-wave infrared) region for different soil series showed almost similar kind of response and maximum reflectance (55.35%) reached at 2052.44 nm. Consequently, the general reflectance of bare soil was increased as wavelength increased (Nagler et al 2000). However, soil series affected the spectral reflectance due to its influence on water holding capacity and the size of soil particles in different soil series. As organic matter content decreases, soil reflectance increases throughout from 0.4 to 2.5µm wavelength. Since the sand content and organic matter content in Khamia sandy loam was 55.68 and 1.27%, respectively and in Patharchatta sandy loam soils are 52.89 and 1.20%, respectively. The reflectance values were high for Khamia sandy loam and Patharchatta sandy loam due to high sand content and relatively low organic matter content. Phoolbagh soil showed lowest reflectance among all six soil series. This soil has high proportion of clay and organic matter *i.e.* 28.76 and 1.89%, respectively that causes a decrease in reflectance. Studies showed that soil organic matter increases the absorbance of the soil(Chen *et al.* 2000). However, silt content of soil is considered as major controlling factor for spectral reflectance. Haldi soil has more silt content (49.06%) than Nagla soil, thus reflectance of Haldi soil is more as compared to Nagla soil whereas Beni soil possesses highest proportion of silt content and showed maximum reflectance peak among all the soil series. Similarly, Saxena *et al.* (2003) also reported the spectral reflectance characteristics of some dominant soils occurring on different altitudinal zones in Uttarakhand Himalayas.

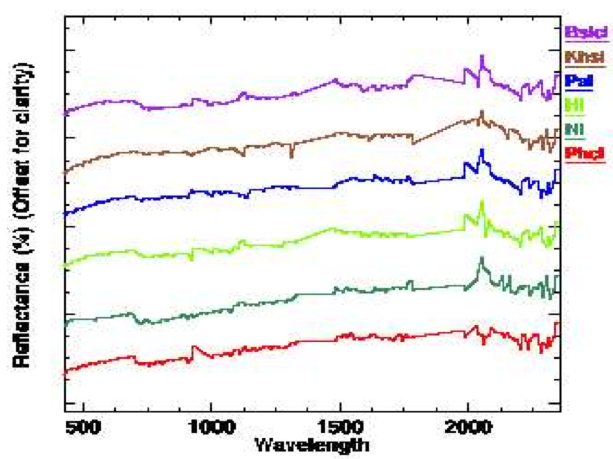

Fig. 2. Comparison of soil spectral library for different soil series of Pantnagar

Table 2. Spectral indices calculation using hyperion image

Index	Formula Index	References
BI	$\{(B^2+G^2+R^2)/3\}^{1/2}$	(Mathieu and Pouget 1998)
RI	$R^2/(B*G^3)$	(Mathieu and Pouget 1998)
SI	(R-B)/(R+B)	(Mathieu and Pouget 1998)
CI	(R-G)/(R+G)	(Mathieu and Pouget 1998)
HI	(2*R-G-B)/(G-B)	(Mathieu and Pouget 1998)
RVI	NIR/R	(Jordan 1969)
NDVI	(NIR-R)/(NIR+R)	(Rouse et al 1974)

CDI (Carbon difference index) was developed by taking the difference between band 199 and band 184

Where, R, G, B and NIR are red, green, blue and near infrared bands respectively

Where R = 681.19 nm, G = 569.27 nm, B = 487.87 nm, NIR= 894.88 nm

Statistical characteristics of soil parameters: The chemical analysis of 25 soil samples showed high spatial variability in available N, available P, and available K content among the different soil sampling sites. This may be due to natural or by human activity (Olorunlana 2015). The statistical summary of all soil samples of different locations shows the mean, median, standard deviation and coefficient of variation (CV) (Table 4). Mean of available N content for surface soils (0–15 cm) was 90.86 kg/ha, available P was 27.41 kg/ha and available K was 156.8 kg/ha. These values show that overall the soil has low available N, high available P and high available K.

Soil properties showed large variability, with lowest CV being observed for available P (18.67%), whereas available N and available K have moderate CV of 24.69 and 26.95%, respectively. These result revealed that the variability of the soil properties is mainly due to textural characteristics, chemical properties and organic matter.

Pearson correlation between spectral parameters and soil properties: The correlation between soil properties and different spectral indices was performed by using SPSS software package. Table 5 showed the relationship between soil properties (available N, available P and available K) and spectral reflectance. Available N has significant negative correlations with red band (-0.55**), green band (-0.46*), band 97 (-0.44*), band 143 (-0.44*) and HI (-0.41*). All spectral bands and indices except CDI (-0.40) had negative correlation with available nitrogen. The significant correlation of available N was not observed with CI, RI, RVI, NDVI and blue band. However, available P showed negative correlation with spectral bands and indices except NDVI and RVI. It showed highly significant negative correlation with BI (-0.41*) and RI (-0.43*), whereas significant correlation of available K

Table 4. Statistical characteristics of soil samples

Parameters	Mean	Median	SD	CV (%)
Available N (kg/ha)	90.86	87.80	22.44	24.69
Available P (kg/ha)	27.41	27.81	5.12	18.67
Available K (kg/ha)	156.8	184.8	42.26	26.95

Table 3. Reflectance of six soil series of Pantnagar corresponding to different Hyperion bands

Bands		Reflectance (%)					
Bands No.	Wavelength (nm)	(Phcl)	(Bsicl)	(Hl)	(Nl)	(Khsl)	(Psl)
8	426.18	14.04	21.60	17.36	16.20	18.36	18.24
9	436.99	15.28	22.20	20.11	15.87	20.11	17.99
14	487.86	18.75	25.17	20.32	19.64	24.11	21.43
19	538.74	21.29	28.06	23.66	22.56	27.21	23.91
22	569.26	21.49	28.93	25.62	22.66	28.10	26.79
33	681.19	22.96	29.25	27.89	23.45	28.95	28.27
54	894.87	20.48	27.82	25.59	22.25	27.10	28.93
79	932.63	30.59	30.59	28.55	20.40	29.87	30.59
89	1033.49	22.91	27.910	26.91	23.92	27.87	30.90
99	1134.38	30.77	34.19	30.77	27.87	34.19	27.35
110	1245.36	27.84	31.57	30.14	28.70	30.87	30.22
118	1326.05	31.96	34.42	31.96	31.96	33.33	34.42
134	1487.53	33.92	42.40	38.16	38.16	42.20	33.92
137	1517.82	37.33	37.33	37.33	33.84	42.30	37.33
149	1638.80	37.94	37.94	37.94	37.94	36.65	36.15
164	1790.18	35.57	44.17	35.57	35.57	35.57	35.57
184	1991.95	35.76	47.68	47.68	35.76	47.68	47.68
190	2052.44	36.90	55.35	55.35	55.35	55.35	55.35
201	2163.43	35.75	35.75	35.75	44.69	44.69	35.75
205	2203.82	29.41	29.41	29.41	39.22	39.22	29.41
216	2314.81	35.94	35.94	35.94	35.94	35.94	35.94
219	2345.10	43.58	43.58	43.58	43.58	43.58	43.58
220	2355.20	45.12	45.12	45.12	45.12	45.12	45.12

was not observed with spectral bands and indices but maximum negative correlation was recorded as -0.37 with band 219 followed by -0.23 with band 214.

Multivariate statistical regression models for soil properties: The Different multivariate models were generated between soil properties viz. available N, available P and available K and spectral parameters using stepwise regression technique (Table 6). The empirical relation between available N and spectral indices was highly significant with $R^2 = 0.66$ while available P showed significant with R^2 of 0.61. However, available K, though individually had no significant correlation with spectral parameters and also did not form a significant multiple regression equation (R^2=0.51).

A scatter plot (Fig. 3) was prepared between measured and predicted value of available N, available P and available K. Results showed a good agreement between the predicted values and the measured values of available N, available P and available K with R^2=0.64, 0.55 and 0.50 respectively and RMSE has been observed as 16, 12 and 18% respectively. Similar types of studies were conducted by Zheng (2008), Kadupitiya et al (2010) and Ghosh et al (2012).

Variability map generation: The multivariate model of for available N, available P and available K were also applied to the hyperion image data to develop soil fertility variability maps (Fig. 4) over the study area. Available N content varied from 86.4 Kg/ha to 172.9 Kg/ha over agricultural farm of Pantnagar. Available N map was classified into four class average values of 37.5, 75.0, 112.5 and 173 kg/ha, represented from dark to light tones. The results showed that the available N over Pantnagar farm region was relatively low. Available P map was classified into three class values of 13.3, 26.7 and 40 kg/ha, represented from dark to light colors. The yellowish color in this image corresponds to higher amounts of P in surface soil. Most of the regions come under the range of high available P content. It was also observed from Figure 4(c) that most of the study areas come under high available K. Available K map was classified into three class values of 83.3, 166.7 and 250 kg/ha, represented from dark to light colors. The light shade in the figure corresponds to

Table 5. Correlation study of spectral parameters derived from hyperion image and soil properties

Spectral parameters	Soil properties		
	N	P	K
BI	-0.36	-0.41*	0.09
CI	-0.25	-0.01	0.07
HI	-0.41*	-0.05	0.31
RI	-0.32	-0.43*	0.11
SI	-0.38	-0.08	0.19
RVI	-0.10	0.02	0.10
NDVI	-0.12	0.01	0.20
CDI	0.40*	-0.02	0.17
Blue (487.86)	-0.31	-0.31	-0.01
Green (569.27)	-0.46*	-0.36	0.13
Red (681.19)	-0.55**	-0.36	0.13
BAND 97 (1114.2)	-0.44*	-0.18	0.27
BAND 143 (1578.3)	-0.44*	-0.28	0.11
BAND 201 (2163.43)	-0.16	-0.18	-0.13
BAND 215 (2304.7)	-0.16	-0.25	-0.23
BAND 216 (2314.8)	-0.26	0.12	-0.08
BAND 219 (2345.1)	-0.20	-0.22	-0.37

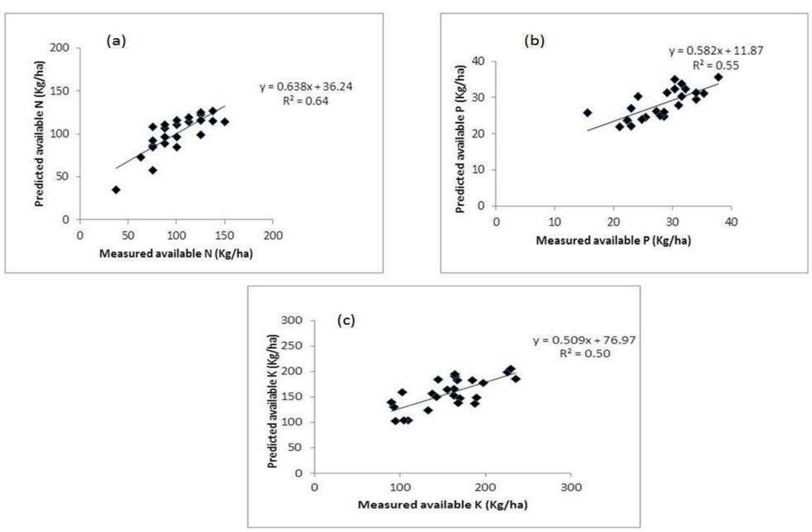

Fig 3. Comparison of measured and predicted (a) Available N, (b) Available P and (c) Available K

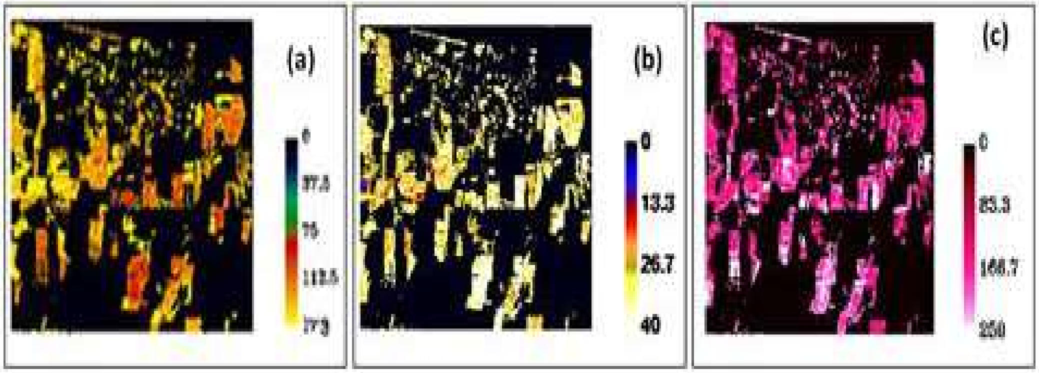

Fig. 4. Spatial distribution of (a) Available N, (b) Available P and (c) Available K

Table 6. Empirical equations between soil properties and spectral parameters derived using stepwise regression technique

Regression model	R^2
Available N (kg/ha)=128.09+253.52*NDVI-47.69*RVI-337.88* RI+309.33*Band 14-286.89*BI+41.03*Band 219	0.66
Available P (kg/ha)= 20.13-1391.35*RI-3.92*CDI-22.66*Band 219+38.06*Band216+161.49*BI-37.87*Band215-47.43*Band14-24.04*Band97	0.61
Available K (kg/ha)= 177.24-226.32* Band 219+765.62*Band 143+26.42* CDI+0.23* HI-676.66*Band97-316.77*Band215+390.49*BI+199.86*CI	0.51

Where, Band 14= 487.9nm, Band 97= 1114.2nm, Band 143= 1578.3nm, Band 215= 2304.7nm, Band 216= 2314.8nmand Band 219= 2345.1nm

higher amounts of K in surface soil. These variability maps can be used for site-specific soil fertility management.

CONCLUSION

The soil spectral library was able to support the characterization of six soil series of Pantnagar region. The soil reflectance intensity was influenced by the proportion sand, clay, silt and organic matter. Organic matter promoted the reduction of reflectance intensity and softening curve of reflectance in Phoolbagh clay loam, Nagla loam and Haldi loam whereas the decrease level of organic matter in Pattarchatta soil series promoted an increase in the reflectance. Benisilty clay loam having high proportion of silt content showed spectral curve with highest reflectance intensity. Therefore, the study showed that hyperspectral remote sensing is feasible, fast and advance technique in soil property assessment.

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Conservation Agriculture in Cotton-Wheat System: Effect on Physico-Chemical Properties of Sandy Loam Soil in North-Western IGP

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Abstract: For sustainable of the system, it is vital to know how soil properties change when agricultural management systems change. Conservation agriculture based cotton (*Gossypium hirsutum* L.)-wheat (*Triticum aestivum* L.) crop rotations with intensification of mungbean are advocated as alternate to conventional cotton-wheat (CW) system in South Asia due to better strategies for tackling the issues of soil health deterioration, plant nutrients status and over exploitation of underground water resources, particularly in conventional tillage based intensive crop rotations. Two-years field experiment was conducted at Borlaug Institute for South Asia (BISA), Ladhowal in Punjab, India to evaluate the impacts of promising RCTs such as permanent broad beds (PBB), relay planting of wheat in cotton and integrating mungbean in cotton under PBBc+MB was 28 and 17.8 % higher SOC compared to CT in CW system under 0–15 cm and 15–30 cm layer, respectively. BD was significantly higher 9.4–10.6 and 4.3–7.4 at 0–15 and 15–30 cm layer compared to CT. Similarly, hydraulic conductivity was higher by 1.19 and 1.10 times and 1.17 and 1.31 times higher under PBB & ZT at 0–10 cm and 10–20 cm layer over CT, respectively. Steady state infiltration rate was significantly higher under conservation tillage and crop establishment techniques than CT and was about 1.41 times higher under beds compared furrow. Soil aggregates was 44.8, 74.2 and 25.1% higher under PPBc+MB with WSA, macro-aggregates and micro-aggregates in 0-15 cm layer compared CT, respectively. Electrical conductivity and pH of soil were improved due to RCTs practices compared CT. PBBc+MB was significantly higher under N, P & K available status in 0–15 and 15–30 cm layer compared CT, respectively.

Keywords: Chemical and physical properties, Conservation agriculture, Permanent beds, Zero tillage

Cotton (*Gossypium hirsutum* L.) - wheat (*Triticum aestivum* L.) system is a well-established crop production system in South Asia (SA) occupying 4.5 Mha with approximately 2.6 Mha in India (Das et al 2014). The crop residues are not incorporated in the field. The sticks of cotton are pulled out, removed from the field and used as fuel. In wheat crop following cotton, the same tillage operations as in cotton are repeated, but the straw of wheat is either removed from the fields or is burnt due to shortage of time between harvesting of wheat crop (mid-April) and sowing of cotton crop (end of April to mid of May) that causes loss of carbon and other nutrients (Jalota et al 2008). Deterioration of land quality due to different forms of soil degradation and excess residue burning are other pervasive problems in the region (Das et al 2013). Tillage is an important management practice involving physical manipulation of soil for crop establishment. Optimization of tillage practices lead to improvement in soil health. Soil health is a dynamic and complex system, and its functions are mainly mediated by agricultural management practices (Congreves et al 2015). Intensive agricultural practices often leads to changes in soil health governing properties like, soil structure, aggregation, porosity, strength, hydraulic conductivity, infiltration, bulk density, soil moisture content, soil carbon content, microbial biomass and their activities (Parihar et al 2016). Sandy loam (Typic Haplustept) soil is the most dominant soil texture of Indo Gangetic Plains. Cotton-wheat system integrating with mungbean (MB) on permanent broad beds (PBB) enhanced system productivity by 37% and sustained the productivity of current CWS in NW India (Choudhary et al 2016).

Crop management practices (tillage systems or cropping sequences) can affect soil health (FAO 2011). Conservation agriculture based management practices have potential to promote conjunctive use of organics (avoids residue burning), improve soil health and promote timely planting of crops to address issues of terminal heat stress to wheat in the region and increased water infiltration leading to groundwater recharge, improved soil quality, reduced methane emissions and short-term carbon sequestration in soil due to retention of crop residues instead of burning (Jat et al 2011). Hydraulic conductivity and infiltration can be improved and evaporation can be decreased by no-tillage and crop residue cover (Li et al 2011). Therefore, long term study (>5 years) on effect of tillage practices for maintaining or enhancing soil physical, chemical and biological characteristics of sandy loam (Typic Haplustept) soil are needed (Singh et al 2016). Bed planting generally saves irrigation water (Gathala et al 2011).

Mungbean (*Vigna radiata* L.) being a leguminous crop has the capacity to fix atmospheric nitrogen through symbiotic nitrogen fixation, and as short duration crop, it also fits well in various multiple and intercropping systems. Similarly, diversification in crop rotations can also affects soil health by affecting carbon contents, due to the difference in chemical composition of different crop residues that are added to soil (Srinivasarao et al 2013). However, precise information on the long term effects of different tillage practices and intensified mungbean based crop rotations on soil health in the IGP region of South Asia is lacking. In this backdrop, the objectives of present study were to determine the effects of different tillage practices and conservation tillage based sustainable intensification of cotton-wheat sequence on soil physico-chemical properties, carbon sustainability index of a sandy loam soil and plant nutrients use efficiency in north-western Indo-Gangetic Plains.

MATERIAL AND METHODS

Experimental site, soil and climate characteristics: Field experiment on CW system was conducted for two consecutive years (2013-14 and 2014-15) at CIMMYT's Borlaug Institute for South Asia (BISA), Ladhowal (30.99°N latitude, 75.44°E longitude, Punjab located in Trans-Gangetic alluvial plains of India. The soil of the experimental site was sandy (Typic Haplustept) loam in texture with alkaline in reaction, poor in organic carbon content, Olsen P and 1M NH_4OAc-extractable K. The initial soil characteristics of the experimental field are presented in Table 1. Experimental site represented the sub-tropical climate with hot and dry (May-June) to wet summers (July-November) during the mungbean/cotton growing season and cool dry winters (December-April) during wheat growing season with average annual pan evaporation was about 850 mm. May and June were the hottest month (40-44.8°C), while January was the coldest month (as low as 1.6°C). Total rainfall received during the growing periods of wheat, cotton and mungbean was 220.4, 1033.7 and 376.4 mm during 2013-14 and 202.2, 490.9 and 114.8 mm during 2014-15, respectively (Fig. 1).

Treatments and experimental design: Seven combinations of CA-based tillage and crop establishment (planting method and crop geometry) were described in Table 2. In bed planting, crops were grown on the raised beds alternated by furrows. The experiment was laid out in a completely randomized block design with three replications.

Figure 2 shows the configuration of cotton, wheat and mungbean crops under different treatments. The plot size for each treatment was 450 m^2. The field experiment was laid out in the previous wheat season of 2012-13 after conventional tillage and the fresh beds were prepared using bed maker. The beds were maintained by reshaping once a year after wheat harvest. The reshaping included use of relay seeder attached to high clearance tractor after adjusting the tynes for reshaping of beds using shapers.

Crop establishment and management: Cotton after harvest of uniform crop of wheat in mid-April of 2013, Bt cotton hybrid (MRC 7017) was planted in the end of May

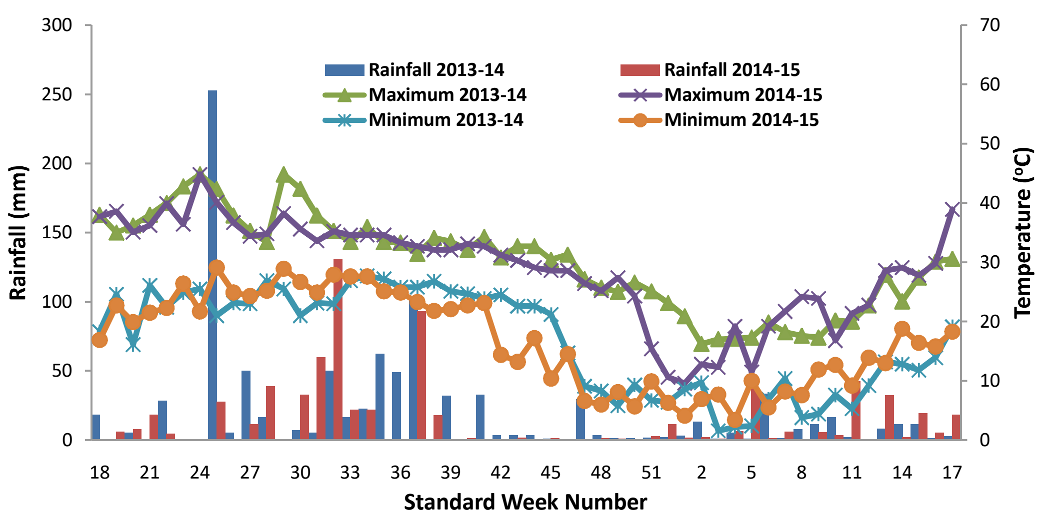

Fig. 1. Monthly rainfall, temperature (Maximum and minimum) during the crop season in 2013-14 and 2014-15

under two geometries (67.5 cm row by 75 cm plant spacing and 102 cm row by 50 cm plant spacing). Seed drill having inclined plate seed-metering system was used for planting cotton with a seed rate of 3 kg ha^{-1}. Recommended doses of 150 kg N, 30 kg P and 25 kg K ha^{-1} were applied as urea, di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively, in both the years. While whole of the P and K was applied at the time of seeding, balance of fertilizer N (total minus added through DAP) was applied in two equal splits (50% at thinning or 35 days after seeding (DAS) and 50% at flowering stage or 80 DAS) coincided with irrigation events. Mungbean (var. SML 668) was sown in last week of April in both years using high clearance tractor with a seed rate of 20 kg ha^{-1}. Three rows of mungbean were planted in PBBc + MB treatment on alternate side of beds. Mungbean seeds were treated with cultures of *Rhizobium* and phosphate solubilizing bacteria before seeding. The basal dose of 100 kg ha^{-1} of DAP (18% N and 46 % P_2O_5) was applied at the time of sowing. Wheat var. HD 2967 was sown with a seed rate of 100 kg ha^{-1} in second week of November. Seed was treated with chlorpyrifos (20 EC, 400 ml 100 kg seed^{-1} mixed in 5 liters of water) to control termite attack. High clearance 4-wheel tractor-mounted two types of relay seeders with 12 and 15 rows were used for relay seeding of wheat into 67.5 and 102 cm wide rows of cotton. A uniform fertilizer dose of 120 kg N, as urea 26 kg P as DAP and 33 kg K as MOP kg ha^{-1} was applied to wheat on all plots. One-third of N and whole of P and K fertilizers were drilled below the seed at the time of sowing, and the remaining N was applied in two equal splits at first irrigation (25-30 days after sowing) and at 2nd irrigation (50-55 days after sowing). Tank mix solution of total (sulfosulfuron + metsulfuron) at 16 g ha^{-1} was applied to control *Phalaris minor* weed at 25-30 days after sowing. For managing weeds, herbicide glyphosate was sprayed @ 1.0 kg ha^{-1} in the ZT and PB plots about two days before sowing of each crop.

Residue management: The entire cotton sticks were removed from the field, which are used as fuel in the region. About 75% of the wheat straw after combine harvesting is generally collected from the fields for use as animal fodder and the remaining portion is burnt in-situ. In study, wheat from experimental plots was manually harvested at ~25-30 cm height from the ground to simulate combine harvesting. After removing grains, the straw was removed and the anchored stubbles were retained in all plots. Cotton residue left after removing sticks included the leaves and tender twigs. In case of mungbean all the residues after removing pulse grains were retained under PBBc+MB plots. The amounts of wheat, cotton and mungbean residues retained in the plots averaged (for the two years) were about 2 .0, 0.6, and 3.0 Mg ha^{-1}, respectively.

Soil sampling and processing: The soil was sampled in

Table 1. Initial status (Prior to wet season, 2013) of soil properties at the experimental site

A. Soil Physical properties

Soil properties	Depth (cm)		
	0-15	15-30	30-60
BD (Mg m^{-3})	1.48	1.48	1.59
HC (mm hr^{-1})	13.04	11.39	
Infiltration (mm ha^{-1})	On Top	Furrow	
	22.20	16.65	

B. Soil aggregation

Depth (cm)	Total WSA%	% Of micro aggregate (<0.25 mm)	% Of micro aggregate (>0.25 mm)	MWD (mm)	GMD (mm)	Particle size distribution			Soil texture
						Sand (%)	Silt (%)	Clay (%)	
1-15	58.81	33.89	24.91	0.79	0.56	62.0	30.9	7.1	SL
15-30	51.35	30.10	21.25	0.68	0.53	65.5	25.2	9.2	SL
30-60	47.73	28.64	19.09	0.60	0.52	66.1	25.5	8.4	SL

C. Soil chemical properties

Depth (cm)	pH	EC (dS/m)	SOC (g kg^{-1} of soil)	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)
0-15	8.2	0.27	4.6	127.4	10.56	149.4
15-30	8.3	0.22	3.1	72.61	7.10	110.1
30-60	8.3	0.18	1.5	43.13	5.1	90.0

HC= Hydraulic conductivity; BD= Bulk density; SL= Sandy loam; Water stable aggregates; SOC= Soil organic content; MWD= Mean weight diameter; GMD= Geometric mean diameter; WSA= Water stable aggregates

2013-14 (prior to establishing the experiment) and 2014-15 (after harvest of *Rabi* season crop) from fixed plots. Soil physical and chemical parameters were recorded at end of the research experiments. The soil samples for bulk density, pH, EC, available nutrient NP&K and total organic carbon of soil profile (0-15, 15-30 and 30-60 cm) were collected in triplicate from each experimental unit by a core sampler with core of 5 cm height and 5 cm diameter. Soil samples from 0-15, 15-30 and 30-60 cm layers were collected using hand shovel for aggregate analysis. After drying in shade, they were broken by giving gentle stroke in a wooden hammer and only aggregates of 4-8 mm size were used for aggregate analysis.

Soil physical properties: Physical properties of soil such as bulk density, hydraulic conductivity, infiltration rate, soil aggregation and soil moisture were calculated by adopting the following methodologies. The procedure for determining bulk density was followed as described by Chopra and Kanwar (1991). The soil collected for bulk density with the core sampler (0-10 and 10-20 cm depth) was used for determining the hydraulic conductivity using constant head method (Mishra and Ahamed 1987). Direct moisture infiltration was measured by double ring infiltrometer (Bouwer 1986). Infiltration rate measured on top (Without tractor wheel passed with included plant row line) and furrow (Tractor wheel passed with excluded plant row line). Two infiltrometer rings were set across uniform and well levelled plots to a depth of 15 cm after dry field preparation at the beginning and termination of experiment. The infiltration rate was expressed as mm hr^{-1}. Soil water stable aggregates (WSA) >0.053 were determined by wet sieving procedure (Cambardella and Elliot 1993). The aggregate size distribution of soil was determined by wet sieving method using Yodders apparatus (Yodder 1936). Mean weight diameter (MWD) of aggregates was estimated (Kemper and Rosenau, 1986) using the formula of Eq.

$$\mathrm{MWD(mm)} = \sum_{i=1}^{i=n} (\mathrm{XiWi}) \sum_{i=1}^{i=n} (\mathrm{Wi})$$

Where, Wi, is the proportion of aggregates retained on each sieves in relation to the whole, Xi is the mean diameter of the sieve (mm). The geometric mean diameter (GMD) was determined by using the following formula of Eq.

$$\mathrm{GMD\ (mm)} = \exp\left(\left(\sum_{i=1}^{i=n} \mathrm{Wi} \log \mathrm{Xi} \Big/ \sum_{i=1}^{i=n} \mathrm{Wi}\right)\right)$$

Soil chemical properties: The samples were air-dried and organic carbon content in soil samples were determined by Walkley and Black (1934) method. Soil pH of surface and profile soil samples were measured (1:2 soil: water suspension) using pH meter fitted with calomel glass electrode. Electrical conductivity of 1:2 soil: water

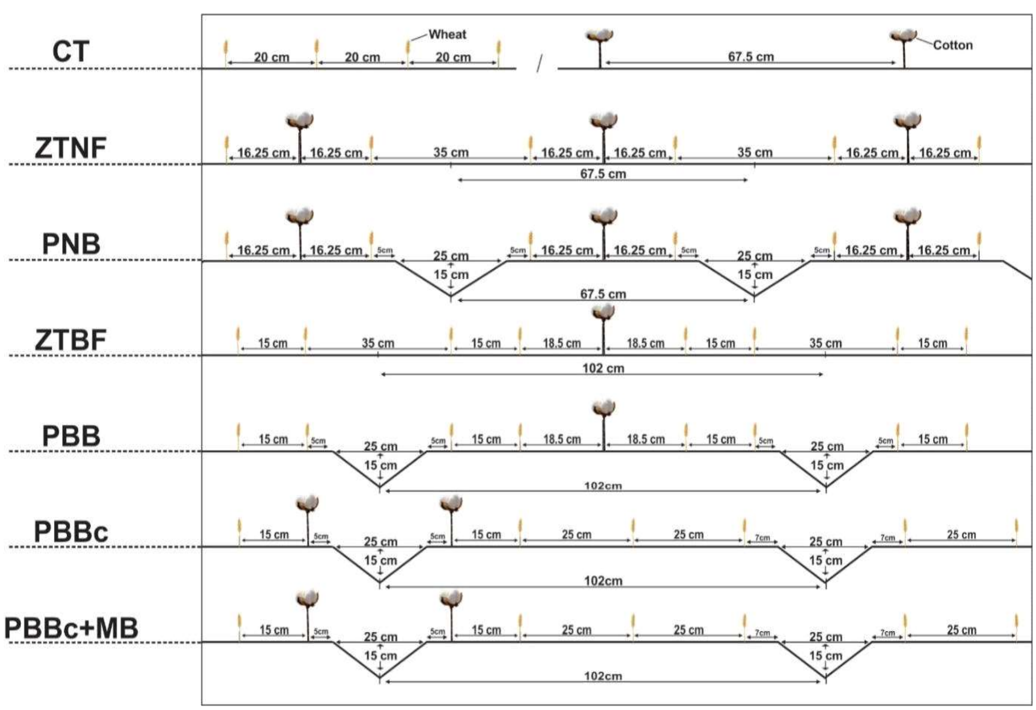

Fig. 2. Configuration of cotton, wheat and mungbean crops under different treatments in cotton-wheat system. For treatment descriptions refer to Table 1

supernatant (kept overnight) was estimated using solubridge (Richards et al 1954). The available N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in kg ha^{-1}. The available P content in soil was estimated by Olsen's method (Olsen et al 1954). Available K was determined using neutral normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) and expressed in kg ha^{-1}.

Statistical analysis: The data recorded for different parameters were analyzed with the help SAS 9.1 software (SAS Institute, Cary, NC). Tukey procedure was used to study treatments.

RESULTS AND DISCUSSION

South Asia faces the issues of soil health deterioration and over exploitation of underground water resources; particularly in conventional tillage based intensive crop rotations. The Conservation agriculture (CA) based tillage and crop establishment practices such as zero tillage (ZT) and permanent raised beds (PB) with residue hold potential to improves soil physico-chemical properties, carbon sustainability index and plant nutrients use efficiency of cotton-wheat system compared to conventional tillage systems with a wide variety of soils and agro-ecological conditions.

Effect on soil physical properties: CA-based management practices showed significant effect on soil physical properties in cotton-wheat sequence after two years studies.

Bulk density: The bulk density under conservation based management practices (PB-N, ZT-N, PBB-A, ZT-B, PBB and PBBc+MB) was significantly lowered by 9.4-10.6% in 0-15cm and 4.3-7.4% in 15-30cm soil profile than CT practices (Table 3). The decrease in BD under CA could be due to higher SOC content, better aggregation and increased root growth. Elsewhere, the similar findings reported by Salem et al (2015). PBBc+MB was significantly minimum BD due to intensification of mungbean crop. The similar findings of lower BD due to pulses inclusion were also reported by Verhulst et al (2011). Permanent bed planting techniques (PBBc+MB, PBBc, PBB and PNB) of crop establishment resulted significantly lower values of the BD over flat planting (ZTNF and ZTBF) in upper layers of the soil profile under respective tillage practices. The maximum BD was under CT (1.60 Mg m^{-3}) at 0-15 cm. While, lowest BD was recorded with PBBc+MB (1.43 g cm^{-3}) in 0-15 cm soil depth (Table 3). The BD was recorded higher in lower layers of the soil profile due to absence of residue and low organic matter content than upper layers under all the treatments. The similar results were also reported by Obalum and Obi (2010).

Table 2. Description of the treatments

Treatment abbreviation	Cotton	Wheat
CT	Residues of previous wheat removed. Conventional tillage (CT) for cotton included two ploughings with disc harrow and one with cultivator followed by planking. Cotton planted at 67.5 cm row spacing with seed cum-fertiliser drill.	Stalks of previous cotton removed. Conventional tillage for wheat included two ploughings with disc harrow and one with cultivator followed by planking. Wheat planted with seed cum fertiliser drill
ZTNF	ZT narrow (67.5 cm) flat. Cotton planted in the middle of each bed. Same as above	Same as in PNB treatment.
PNB	Permanent narrow raised bed (PNB). The PNB system consisted of permanent raised beds of 67.5 cm (42.5 wide from top and separated by furrow of about 25 cm wide, and 15 cm deep). Permanent beds involved no ploughing, but minor reshaped and cotton planted in a single operation using a high clearance tractor operated relay seeder. One row of cotton planted in the middle of 67.5 cm wide raised beds.	Permanent beds involved no ploughing, but minor reshaped and relay seeded in single operation (2 rows/ bed on either side of cotton row) with 4-wheel high clearance tractor using double ZT disc opener relay seeder.
ZTBF	ZT broad (102 cm) beds flat. Cotton planted at 102 cm row spacing in the centre of flat beds.	Relay sowing (4 rows/bed; two paired wheat rows on either side of cotton row)
PBB	Permanent broad (102 cm) raised bed (PBB) prepared by making adjustments in normal bed planter using narrow wheel tractor. The PBB system consisted of broad beds of 102 cm wide, with 77cm from top of beds separated by furrow of about 25cm wide and 15 cm deep. Cotton planted in the centre of 102 cm wide beds.	Same as above.
PBBc	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed.	Relay sowing (3 rows/bed) on the opposite side of the cotton row on the bed).
PBBc+MB	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed. Mungbean (3 rows/bed) planted after wheat harvest in the same rows.	Relay sowing (3 rows/bed) of wheat on the opposite side of cotton row on each bed.

Hydraulic conductivity: The average saturated hydraulic conductivity (HC) of soil was influenced significantly due to conservation practices and crop establishment techniques in the surface (0-10 cm soil depth) as well as sub surface (10-20 cm soil depth) soil layers (Table 4). Moreover, hydraulic conductivity was higher 11.9 % at 0-10 cm soil depth compare to 10-20 cm soil depth. The increase in HC under conservation agriculture practices (PB and ZT) was mainly attributed to decrease in bulk density and increase in effective pore volume because of better soil aggregation in these practices. Similar findings have also been reported Li et al (2011). The maximum values of hydraulic conductivity was measured under PBBc+MB (15.67 and 14.66 mm hr^{-1}) in 0-10 and 10-20 cm soil depth, respectively; in the former depth (0-10 cm) it was significantly greater than rest of the treatments, but at par with PBBc. Saturated hydraulic conductivity of PBBC+MB was 25% and 41% higher than for CT in both the layers, respectively (Table 4). While in the later depth (10–20 cm) it was significantly higher as same trend in depth of 0-10cm. Permanent broad bed planting resulted significantly 8.9% and 12.4% higher rate of the HC compared flat planting in both the soil layers in respective tillage practices. Bed system was also probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers. ZTNF, PNB and PBB were significantly higher than CT and ZTBF and it was significantly greater than CT in both the layers. Residue application also significantly improved the hydraulic conductivity due to addition of the organic matter in the soil which improves the soil macro-aggregates that might facilitate easy movement of water in the soil over no-residue application under CT in both the layers in respective planting systems. The similar results were also reported by Blanco-Canqui and Lal (2007).

Infiltration rate: The mean initial infiltration rate (initial infiltration rate after 5 min) was significantly higher under CT

Table 3. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on soil organic carbon content and bulk density in different soil layers

Treatments†	Organic carbon content (g kg^{-1})			Bulk density (Mg m^{-3})		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
CT	3.72c‡	2.70b	1.42a	1.60a	1.63a	1.65a
ZTNF	4.85a	3.15a	1.40a	1.44b	1.52b	1.56a
PNB	4.70ab	3.10a	1.80a	1.44b	1.53b	1.56a
ZTBF	4.82a	3.12a	1.30a	1.45b	1.56b	1.62a
PBB	4.72ab	3.40a	1.42a	1.43c	1.53b	1.59a
PBBc	4.60b	2.90ab	1.80a	1.44b	1.51b	1.58a
PBBc +MB	4.90a	3.42a	1.70a	1.43c	1.52b	1.59a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05

Table 4. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on hydraulic conductivity and infiltration rate

Treatments†	Hydraulic conductivity (mm hr^{-1})		Infiltration rate (mm hr^{-1})		
	0-10 cm	10-20 cm	Initial$	Steady state	
				On top #	Furrow ¥
CT	12.54d‡	10.40d	135.8a	20.72c	14.62c
ZTNF	14.45b	12.78b	98.7c	30.57b	21.62b
PNB	14.37b	12.64b	103.3b	34.50ab	22.51ab
ZTBF	13.15c	11.62c	95.3c	31.67b	21.71b
PBB	14.51b	12.94b	105.3b	34.67ab	23.39a
PBBc	15.59a	14.63a	103.7b	34.89ab	22.16ab
PBBc +MB	15.67a	14.66a	110.0b	36.72a	23.77a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05; $Indicate initial infiltration rate after 5 min, #steady state infiltration rate on top (Without tractor wheel passed with included plant row line) and ¥furrow (Tractor wheel passed with excluded plant row line), respectively

plots than all rest of treatment plots, but in case of steady state infiltration rate under conservation practices (PB&ZT) were influenced significantly due to conservation tillage and crop establishment techniques compared CT. The mean initial infiltration rate (initial infiltration rate after 5 min) was significantly 23.45–42.6 % higher under CT plots than all rest of treatment plots (Table 4), but in case of steady state infiltration rate under conservation practices (PB&ZT) were influenced significantly due to conservation tillage and crop establishment techniques compared CT. The increase of hydraulic conductivity and infiltration rate by tillage and bed system was also probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers. The Steady state infiltration rate on top was about 1.49 times compared on furrow (Table 4). Steady state infiltration rate on top was significantly higher under conservation tillage and crop establishment techniques than CT with 47.5-52.8 and 66.5-77.2% under ZT and PB, respectively (Table 4). Similarly, steady state infiltration on furrow (Tractor wheel passed with excluded plant row line) rate was significantly higher 62.58 % in PB compared to CT. Tillage and residue management also influenced steady-state infiltration (Verhulst, et al 2011).

Soil aggregation: Effect of tillage and crop establishment techniques were significantly higher WSA %, macro-aggregates, micro-aggregates, MWD and GMD in different soil layers but except 30-60cm layer (Table 5 & 6). The WSA% was significantly (71.4%) highest under PBBc+MB compared all remain treatments and followed by PNB, PBB & PBBc were significantly higher than CT, ZTNF and ZTBF at 0–15 cm soil layer. CT was significantly inferior compared all the rest of treatments. At 0-15cm layer of soil was recorded 44.8, 74.2 and 25.1% higher under PPBc+MB with water stable aggregates (WSA), macro-aggregates and micro-aggregates, respectively compared CT after harvest the last rabi crop (wheat). The highest WSA, macro-aggregates and micro-aggregates under ZTNF with 35.5, 58.7 and 18.6 % higher compared CT at 15-30 cm layer, respectively (Table 5). In minimum tillage systems, new aggregates were formed due to incorporation of crop residues in the soil and storage of excess organic matter in biochemically degraded fraction especially in the surface soil (Chaudhary et al 2015).

Table 5. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on soil aggregates in different soil layers (cm)

Treatments†	WSA %			Aggregate (>0.25)			Aggregate (<0.25)		
	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
CT	49.3d‡	47.0c	53.4a	19.8d	20.1c	25.3a	29.5d	26.9c	28.1a
ZTNF	61.2c	63.7a	55.4a	30.2c	31.9ab	25.9a	31.0c	31.9a	29.4a
PNB	67.5b	58.1ab	52.3a	32.8b	28.5ab	24.7a	34.7b	29.7ab	27.6a
ZTBF	61.6c	62.4a	53.8a	30.4c	31.4ab	25.4a	31.2c	31.0a	28.4a
PBB	67.5b	58.5ab	52.1a	32.8b	28.6ab	24.5a	34.7b	29.9ab	27.6a
PBBc	65.2b	55.9b	53.9a	31.3b	27.3b	25.0a	33.9b	28.5b	28.9a
PBBc +MB	71.4a	59.7ab	52.3a	34.5a	29.3ab	24.97a	36.9a	30.4ab	27.4a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

Table 6. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on mean weight diameter (MWD) and grand mean diameter (GMD) of soil aggregates in different soil layers

Treatments†	MWD			GMD		
	0-15	15-30	30-60	0-15	15-30	30-60
CT	0.76c‡	0.66c	0.65a	0.57b	0.53b	0.56a
ZTNF	1.13b	0.91a	0.67a	0.63a	0.63a	0.56a
PNB	1.24a	0.81b	0.66a	0.63a	0.58a	0.55a
ZTBF	1.14b	0.89a	0.70a	0.62a	0.63a	0.57a
PBB	1.24a	0.81b	0.65a	0.63a	0.58a	0.55a
PBBc	1.19a	0.77b	0.65a	0.63a	0.58a	0.54a
PBBc +MB	1.28a	0.85ab	0.67a	0.63a	0.61a	0.56a

†Refer table 2 for treatment description
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05

The MWD was significantly (1.28) highest under PBBc+MB compared CT, ZTNF and ZTBF but it was statistically ($P < 0.05$) at par with PNB, PBB & PBBc in 0-15 cm layer (Table 6). PBBc+MB was 68.42 % higher at 0-15cm layer than CT. ZTNF was significantly highest (0.91) MWD than all the treatment, only except ZTBF and PBBc+MB at 15–30 cm layer. At 30-60cm layer of soil MWD was recorded non-significant. In case of GMD, all conservation tillage practices (all treatments) were significantly (8-10%) higher than CT at 0-15 and 15-30 cm layer. GMD was recorded non-significant in all treatments at 30-60 cm layer. This might be due to non-disturbance of the soil with tillage and addition of residues might have contributed for increased MWD and GMD (Meena and Behera 2008).

Effect on soil chemical properties: CA-based management practices showed significant effect on soil chemical properties (except pH) in cotton-wheat sequence after two years' studies.

Soil organic carbon: Total soil organic carbon content (SOC) under PBBc+MB was significant higher (28 % or 4.90 g kg^{-1}) SOC in 0-15 cm layer compared CT but it was statistically similar with all remain treatments only except PBBc. All conservation tillage treatments (ZT&PB) were significantly 0.9-1.18 g kg^{-1} higher compared CT at surface layer. Crop residues application significantly ($P>0.05$) increased the SOC under PBBc+MB, ZTNF, ZTBF, PBB and PNB by 31.7, 30.3, 29.6, 26.9 and 26.3 % over CT, respectively in 0-15 cm layer of soil. Permanent raised beds with full residue retention with mungbean intensification increased soil organic C 1.28 times more over the conventional tilled at 0–15 cm layer and 1.17 times more at 15–30 cm layer (Table 3) Similar findings were also reported by Sarkar and Kar (2011). In case of 15-30 cm layer of soil, SOC was significantly (0.90 g kg^{-1}) higher than CT but it was statistically at par with all remain treatments only except PBBc. SOC was non-significant in all treatments at 30-60 cm layer of soil. Total soil organic carbon content (SOC) was affected significantly due to conservation tillage, permanent beds with residue management and diversified crop rotations on total soil organic carbon in soil (Kaiser et al 2014).

Soil pH and electrical conductivity: The pH of soil was not influenced significantly due to different continuous tillage, crop establishment techniques and diversified crop rotations (Table 7). The maximum value of pH was recorded under CT (8.25) followed by ZTBF (8.22), while least was recorded under PBBc+MB (8.10) at 0-15 cm layer of soil depth. It was similar trend at 15-30 and 30-60cm layer. Electrical conductivity was influenced significantly highest (0.26 dS/m) under PNB due conservation tillage, permanent beds with residue management and diversified crop rotations compared CT but it was statistically at par with all remain treatment (conservation tillage) in 0-15 cm layer of soil (Table 7). It was recorded non-significantly under all the treatment at 15-30 and 30-60 cm layer of soil depth. The similar results were also reported by Verhulst et al (2011). Opposite to pH, EC values were slightly decreased under residue applied treatments over no-residue (CT) applied treatments. Tillage and straw management usually had little or no effect on soil pH in any soil layer (Malhi et al 2011).

Available N, P & K: Available nitrogen (N) status in soil under PBBc+MB was influenced significantly (144.50 kg ha^{-1}) highest than all the remains treatments, but it was statistically at par PBB. PBBc was significantly higher N compared CT but, it was similar ZTBF and PNB. However, Available P and K status in soil were found similar trend as well as N status in 0-15cm layer of soil (Table 8). PBBc+MB was reported 38.22, 48.23 and 23.8 % higher under N, P & K available status in 0-15cm layer compared CT, respectively. In case of 15-30cm

Table 7. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on electrical conductivity and pH in different soil layers

Treatments[†]	pH			EC (dS/m)		
	After study			After study		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
CT	8.25a	8.34a	8.42a	0.22b‡	0.19a	0.15a
ZTNF	8.18a	8.25a	8.28a	0.24a	0.24a	0.18a
PNB	8.11a	8.21a	8.25a	0.26a	0.23a	0.20a
ZTBF	8.22a	8.30a	8.30a	0.24a	0.18a	0.16a
PBB	8.12a	8.22a	8.30a	0.24a	0.18a	0.16a
PBBc	8.15a	8.27a	8.28a	0.24a	0.22a	0.18a
PBBc +MB	8.10a	8.20a	8.30a	0.25a	0.20a	0.16a

[†]Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

Table 8. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on available nitrogen, phosphorus and potassium (kg ha^{-1}) content of soil in different soil layers

Treatments†	0-15 cm			15-30 cm			30-60 cm		
	N	P	K	N	P	K	N	P	K
CT	104.54c	8.77c‡	128.20c	70.27b	6.67a	109.31b	42.73a	4.92a	89.90a
ZTNF	140.27a	12.20a	156.61a	73.55a	7.83a	113.75a	43.44a	5.37a	92.89a
PNB	131.71b	10.73b	154.52b	72.74a	7.53a	112.58a	43.20a	5.13a	92.36a
ZTBF	131.07b	10.50b	153.17b	73.59a	7.33a	114.84a	43.86a	4.33a	92.29a
PBB	140.69a	12.83a	158.55a	71.97a	7.33a	111.66a	43.86a	5.42a	94.38a
PBBc	134.28b	12.00b	155.94b	71.46a	6.33a	114.65a	42.19a	4.86a	95.87a
PBBc +MB	144.50a	13.00a	158.77a	74.69a	7.34a	115.21a	42.61a	5.42a	89.90a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

layer, available N and K status in soil were influenced significantly due to different continuous tillage, crop establishment techniques and with residue management compared CT, but available P was non-significant in 15-0cm layer (Table 8). PBBc+MB was recorded 6, 5.4 and 5.4 % higher with available N, P and K status in 15-30cm layer compared CT, respectably. However, Available N, P and K status were non-significantly in 30-60 cm layer of soil. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increases nutrient availability (Marahatta et al 2014).

CONCLUSIONS

The major aim of this study was to evaluate the impacts of promising RCTs on soil physico-chemical properties in cotton–wheat system in the western IGP. Our study showed that RCTs such as permanent broad beds (PBB), relay planting of wheat in cotton and integrating mungbean in cotton under PBBc+MB was recorded 28 and 17.8 % higher SOC compared to CT in CW system under 0-15 cm and 15-30 cm layer, respectively. BD was significantly higher (9.4-10.6 and 4.3-7.4) in 0-15 and 15-30cm layer compared CT. Similarly, hydraulic conductivity was increased 1.19 & 1.10 time more under PBB (PBBc+MB) and ZT practices at 0-10 cm layer compared CT. The Steady state infiltration rate was about 1.41 times higher under PB practices (PBBc+MB) compared on furrow. Soil aggregates was recorded 44.8, 74.24 and 25.1% higher under PPBc+MB with WSA, macro-aggregates and micro-aggregates in 0-15cm layer compared CT, respectively. The pH and Electrical conductivity of soil was improved due to RCTs practices compared CT. PBBc+MB was significantly 38.22, 48.23 and 23.8 % higher under N, P & K available status in 0-15cm layer compared CT, respectively. Thus, these results are of tremendous importance in terms of identification of a suitable sustainable management practice under a non-rice based cotton-wheat system, and are very novel in the South Asia. Thus, the said PBBc + MB package of practice has a wide scope for adoption in the cotton-wheat system of this region and other countries with similar agro-ecologies, where intensive tillage is practiced.

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Selection of Significant Raster Images for Digital Soil Mapping Using Data Reduction Technique

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Abstract: The study was conducted to select the significant environmental covariates for mapping the soil through the computer-assisted soil mapping method. A total of 340 soil profile information was intersected against the environmental covariates to reduce the dimension of the data by which the quality of the spatial soil predictions can be improved. Robust PCA is known for its supremacy in handling image drive data as it can even process the data extracted from raster image series, which are high in outliers. The selection of significant covariates for digital soil mapping was done through robust Principal Component Analysis (PCA) and conventional PCA. The scree plot indicates that four principal components are to be considered from both methods. The selected principal components of robust PCA cumulatively contribute 63.17% of the total information to the original dataset, whereas conventional PCA contributes 52.46% only. Contribution charts were employed for extracting the significant environmental covariates in which 26 out of 33 covariates are obtained from the selected principal components of robust PCA. Soil mapping would be efficient if the covariates are selected through this process and employed for the mapping process.

Keywords: Data reduction technique, Digital soil mapping, Environmental covariates, Principal component analysis, Robust

Soil is a life support component that is vital to the Earth's ecosystem. All living organisms depend on soil directly or indirectly, where plants are predominant. Therefore, information regarding its nature, types, properties, spatial distribution, and extent is important for efficiently utilizing and managing (Afshar et al 2018) the resources. Over a decade, the distribution, pattern, and type of soil vary due to biotic and abiotic factors from place to place and time to time. Hence, it is necessary to identify and classify the soil forms in different areas. Mapping of soils helps to locate and classify the existing soil types (Semy and Singh, 2021). In addition, it collects information regarding their location, nature, and properties. Generally, traditional soil mapping is done based on the information gathered from soil samples at regular intervals throughout the landscape. The maps are primarily in hard copy and are gradually converted to digital form after the Geographical Information System (GIS) advent. But they are time-consuming, expensive, laborious, and untrustworthy in producing spatial variability of soil maps (Abdel-Kader et al 2011). The possibility of human error is high and unavoidable in conventional cases.

Digital soil mapping (DSM) is a predictive soil mapping that collects the geographically referenced soil databases created on quantitative relationships between spatially related environmental data (Kumaraperumal et al 2022). It is a quantitative technique of surveying, mapping, and analyzing the associations between soil properties and environmental variables (Polisgowdar et al 2022, Wani et al 2022). It involves the generation of initial soil survey maps, refining, or updating the soil survey information, making specific soil interpretations, and measuring the risk (Zhang et al 2017). DSM is employed using the soil profile information as dependent and environmental covariates as independent variables. These data are collected once in a particular period, and the soil maps are predicted for the future using probability statistics or artificial intelligence methods. The choice of the independent variable for effective mapping remains a challenging one. Out of available covariates, effective mapping can be generated only if the significant covariates are identified and used in the mapping process. Environmental covariates are available in shape files and were converted into a raster format for mapping purposes in which the outliers are common. The common cause of outliers is faulty pixels like noise, occlusion, or alignment errors. It makes the conventional principal component analysis fail. So, robustness is the better option for handling these outlier datasets which paved the path for using robust principal component analysis in selecting the significant variable. These powerful dimensionality reduction techniques handle the outlier efficiently and analyze image data in a better way.

The modern glitches of estimation, optimization, image recognition, and signal processing are part of analyzing huge dimensional data. In computer vision applications, outliers naturally occur within a sample image which demands the need for structuring low-dimension approximations for the large-scale dataset. This versatile technique can be used even when the assumptions are violated which readily deals with pixels, raster images, facial recognition, image compression, and remote sensing data, etc. (Pinto da Costa and Cabral 2022). Robust PCA is insensitive to outliers and produces the same result as the conventional method without outliers (Sapra 2010). However, they leave the residuals associated with the outlier and help in identifying the influential points. So, the study attempts to use robust principal component analysis to discover the significant covariates. This study gives insight in selecting the important environmental covariates that DSM can use for future purposes.

MATERIAL AND METHODS

Study area: The Coimbatore district is located in the western Agro-climatic Zone of Southern India which is 411 meters above the mean sea level and geographically extended from 11°24'23" to 10°13'12" N latitude and 76°39'20" to 77°18'00" E longitude covering an area of about 4721.28 sq. km. The average annual rainfall is about 642.2mm with the mean maximum and minimum temperatures of the district being 32.7°C and 21.5°C, respectively. Sugarcane, cotton, turmeric, and oilseeds were the different crops cultivated in the study area. The area map and the corresponding soil profile sites, along with their elevation and physiographical information are given in Figure 1.

Data: The soil class information containing 340 soil profile samples i.e., a subgroup was collected with the help of the Department of Remote Sensing and GIS and the Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore in 2022. Further, thirty-three different environmental covariates (Table 1) depicting the Climate, Organisms, Relief, and Parent were developed from the DEM (Digital Elevation Model) and other remote sensing variables. The continuous spatial information on the climatic parameters was downloaded from WorldClim 2.1 including the temporal range of 1970-2000 interval at 30 arc seconds. The qualitative nature of the Agro-Climatic, Agro-Ecological zones, and the Western Ghats were rasterized to enable stacking with other covariates. Satellite data products (Landsat 8) along with their transformed NDVI images were utilized to impart the influence of the organisms on soil formation (NRSC 2012). The cloud-free Landsat 8 data product was downloaded from USGS earth explorer during March to May period to enhance the delineation of the soil attributes.

The relief parameters were primarily derived from Shuttle Radar Topography Mission (SRTM) DEM product by utilizing the hydro geomorphometric indexes of the SAGA GIS software. Existing soil information on the Geology, Geomorphology, and Land use and Land cover products obtained from the National Remote Sensing Centre (NRSC) at 1:50,000 map interval was rasterized (NRSC, 2016) using the raster tool feature available in ArcGIS 10.6 software and were implemented as covariates. The rasterized covariates

Table 1. Parameters of environmental covariates

Covariate	Parameter	Scale
Climate	Maximum annual temperature	ºC / 30 seconds
	Minimum annual temperature	ºC / 30 seconds
	Mean annual rainfall	mm/ 30 seconds
	Agro-Climatic Zone	30m
	Agro-Ecological Zone	30m
Organisms	Land Use & land cover map	1:50,000 scale
	Landsat 8 – Band 2 (Blue)	30m
	Landsat 8 – Band 3 (Green)	30m
	Landsat 8 – Band 4 (Red)	30m
	Landsat 8 – Band 5 (NIR)	30m
Relief	Elevation (SRTM DEM)	30m
	Hill shading	30m
	Aspect	30m
	Convergence index	30m
	General curvature	30m
	Longitudinal curvature	30m
	Slope length steepness (LS) factor	30m
	Maximum curvature	30m
	Mid slope position	30m
	Minimum curvature	30m
	Plan curvature	30m
	Profile curvature	30m
	Slope gradient	30m
	Tangential curvature	30m
	Terrain ruggedness index	30m
	Topographic wetness index	30m
	Total catchment area	30m
	Total curvature	30m
	Valley depth	30m
	Western ghats	30m
	Physiography	1:50,000 scale
Parent material	Geomorphology	1:50,000 scale
	Rock outcrop difference ratio	1:50,000 scale

are then resampled and reprojected to the common projection system. The covariate parameters are then stacked and intersected with the soil profile information in the R spatial environment. The extracted data is subjected to data reduction techniques from which the significant environmental parameters are sorted.

Variable screening: Dimensionality reduction techniques are the multivariate approaches used when the variables are highly correlated or when the number of variables is more than the number of observations. It is also used to identify the variable which significantly contributes to the results. Data processing with a low dimensional significant variable makes the analysis easier and more effective (Gowsar et al 2019).

Principal component analysis: Principal Component Analysis (PCA) is one of the dimensionality reduction techniques used to reduce the dimension of the datasets by removing the nsignificant variables without any information loss and for forming predictive models (Dinesh et al 2022). It helps in screening the significant environmental covariates, thus reducing the dimension of original variables and extracting a small number of latent factors, *i.e.,* Principal Components (PC). Principal components are a linear combination of p random variables explaining the variation produced by original data. The linear combination the of p variable is given by,

$$PCv = ev_1Y_1 + ev_2Y_{2+} \ldots + ev_pY_p \quad (1)$$

PCA computes the covariance matrix or correlation matrix for the given datasets, followed by calculating the eigenvectors and the eigenvalues for the covariance matrix.

$$\det(\lambda I - A) = 0 \text{ and } (\lambda I - A)\, v = 0I \quad (2)$$

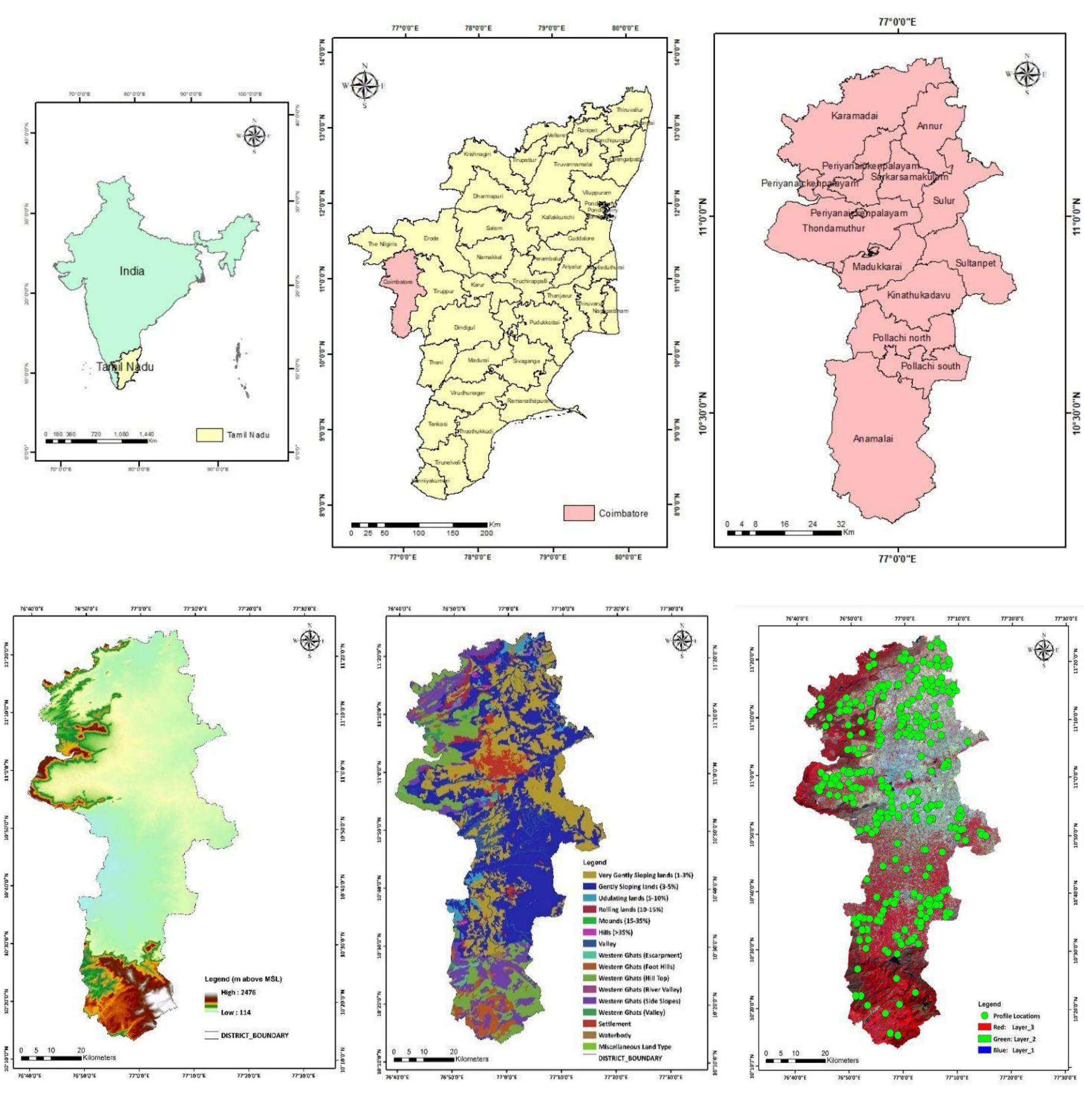

Fig. 1. Study area map

Where λ is an eigenvalue, *v* is an eigenvector, *A* is a square matrix, and *det* is the determinant of the matrix. However, the conventional PCA technique is not recommended for the study data, as they are susceptible to outliers and poorly handle the data extracted from raster images (Jolliffe and Cadima 2016).

Robust principal component analysis: Outliers are the observations that fluctuate significantly from actual observations. Outliers in data affect the conventional PCA analysis in terms of the correlation matrix, covariance estimations, and proportions of the total variance (Zahariah and Midi 2022). To overcome these problems, robust principal component analysis is replaced in place of the conventional method. Robust PCA helps reduce the dimensionality problem of explanatory variables and deals with multi-collinearity like the traditional way, but all these in the presence of outliers in data (Lu et al 2023). It recovers the low-rank matrix and principal components with high probability, avoiding the choice of the tuning parameter. Rousseeuw used the Minimum covariance determinant (MCD) method in robust principal component analysis (Kalina and Tichavský 2022). It reduces the number of iterations and analysis time for limited to low-dimensional data. It uses the intra-sample outlier process to account for pixel outliers. The Minimum Covariance Determinant (MCD) is also referred to as modified robust PCA. It is one of the popular and fastest methods in showing a high degree of robustness against outliers. In robust PCA, the location and scale parameters of conventional PCA are replaced and produced with high breakdown using MCD (Piccini et al 2019). Parameters μ and Σ are replaced with robust estimates μ (median) and Σ (MAD - Median Absolute Deviation) for calculating scale and location parameters. Initially, the data is split into groups, parameters are found using the MCD method, and finally, they are joined, which is the main modification in this procedure.

Let *h* represent the dimension of sub-clusters datasets containing n observations. The *h*-value determines the robustness of the estimator, and a minimum [((n + p + 1)) / 2] value should be taken as a lower bound. The MCD estimator attempts to find the minimum covariance determinant of the optimal h-subset containing these sub-clusters, and the distance between them is calculated by

$$d_i = \sqrt{(x-\hat{\mu}_0)^t \hat{\Sigma}_0^{-1}(x-\hat{\mu}_0)} \qquad (3)$$

The mean of the optimal h-subset gives the estimate of location parameter μMCD as

$$\hat{\mu}_{MCD} = \frac{\Sigma_{i=1}^{n} W(d_i^2)x_i}{\Sigma_{i=1}^{n} W(d_i^2)} \qquad (4)$$

The covariance matrix provides the estimate of scale parameter ΣMCD as

$$\hat{\Sigma}_{MCD} = C_1 \frac{1}{n} \Sigma_{i=1}^{n} W(d_i^2)(x_i \hat{\mu}_{MCD})(x_i - \hat{\mu}_{MCD})^t \qquad (5)$$

The breakdown point value of the MCD estimator is (n – h + 1)/n. Weighted estimators (Bulut and Zaman 2022) will be used to increase the estimator's efficiency.

RESULTS AND DISCUSSION

The respective profile information of each covariate, concerning the sample points is extracted using ArcGIS software. The data values obtained from stacked environmental covariates are used for the study. Even though all the parameters are expected to contribute some information to the map generation process, sorting out the important parameters with appropriate data reduction techniques is necessary (Samuel-Rosa et al 2015). Soil maps of the study area generated from the significant environmental covariates are highly efficient and informative compared to the map generated using all the covariates (Bhat et al 2020). Therefore, the environmental covariate layers, which significantly contribute to the map generation (Shafeeva et al 2022) process by providing necessary information, were sorted out using robust PCA techniques. Conventional PCA is worked for the data to show the effectiveness of robust PCA. The initial step of PCA starts with dimensioning the principal components using extracted data points. Each principal components contribute some percent of variation to the original data. The first few principal components account for a high percentage of variability, and the percentage of variation decreases as we move down. The next step is to select the minimum number of principal components which contribute a high percentage of the variation, i.e., cumulatively contributing to the original data set. The number of principal components is decided based on the knee point observed in the scree plot. Finally, the analysis is performed using R software.

Scree plot directs to pick four principal components as the knee point break at the fourth principal component (Greenacre et al 2022) (Table 2a, Fig. 2a). Those four principal components cumulatively contribute about 52.46% to the original dataset. Similarly, robust PCA is applied to the data. Figure 2b shows the scree plot formed using the eigenvalues of robust principal components. The selected four PCs cumulatively contribute about 63.17% variation to the total variation of original data. The percentage of variation contributed by PC1 is 30.84 which is the highest among PCs. It is followed by PC2, PC3, and PC4. These four principal components have eigenvalues greater than 1. Thus, the selected principal components are uncorrelated and free from multi-collinearity (Shankar et al 2019). Since robust PCA contributes more information with fewer principal components than the conventional method, the selected four principal components of the robust technique are taken for further analysis (Parra-González and Rodriguez-Valenzuela 2017). Generally, the selected four principal components are used for further computing purposes. But as this study aimed to determine the environmental parameters for mapping, the high contributing parameter of each principal component is found.

Table 2a. Results of conventional PCA

Principal components	Eigen value	Percentage of variance	Cumulative percentage of variance	Principal components	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	9.05	22.78	22.78	PC 18	0.24	1.32	96.04
PC2	6.18	15.01	37.79	PC 19	0.21	1.28	97.32
PC3	4.07	8.91	46.70	PC 20	0.20	0.77	98.09
PC4	2.13	5.76	52.46	PC 21	0.10	0.67	98.76
PC5	2.11	4.90	57.36	PC 22	0.06	0.54	99.30
PC6	1.34	4.74	62.10	PC 23	0.03	0.44	99.74
PC7	1.33	4.67	66.77	PC 24	0.02	0.23	99.97
PC8	1.01	4.56	71.33	PC 25	0.02	0.03	100.00
PC9	0.70	3.76	75.09	PC 26	0.00	0.00	100.00
PC10	0.73	3.56	78.65	PC 27	0.00	0.00	100.00
PC11	0.70	3.45	82.10	PC 28	0.00	0.00	100.00
PC12	0.61	3.33	85.43	PC 29	0.00	0.00	100.00
PC13	0.58	2.78	88.21	PC 30	0.00	0.00	100.00
PC14	0.51	2.01	90.22	PC 31	0.00	0.00	100.00
PC15	0.44	1.58	91.80	PC 32	0.00	0.00	100.00
PC 16	0.32	1.51	93.31	PC 33	0.00	0.00	100.00
PC 17	0.31	1.41	94.72				

Table 2b. Results of Robust PCA

Principal components	Eigen value	Percentage of variance	Cumulative percentage of variance	Principal components	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	6.90	30.84	30.84	PC 18	0.51	0.24	95.71
PC2	5.01	15.37	46.21	PC 19	0.41	0.98	96.69
PC3	3.01	10.47	56.68	PC 20	0.38	0.93	97.62
PC4	2.41	6.49	63.17	PC 21	0.30	0.74	98.36
PC5	1.53	5.47	68.64	PC 22	0.26	0.63	98.99
PC6	1.37	4.04	72.68	PC 23	0.25	0.61	99.60
PC7	1.30	3.82	76.50	PC 24	0.12	0.29	99.89
PC8	1.27	3.35	79.85	PC 25	0.07	0.10	99.99
PC9	0.99	2.95	82.80	PC 26	0.04	0.01	100.00
PC10	0.97	2.83	85.63	PC 27	0.03	0.00	100.00
PC11	0.96	2.69	88.32	PC 28	0.02	0.00	100.00
PC12	0.95	1.92	90.24	PC 29	0.01	0.00	100.00
PC13	0.91	1.85	92.09	PC 30	0.00	0.00	100.00
PC14	0.88	1.20	93.29	PC 31	0.00	0.00	100.00
PC15	0.77	0.89	94.18	PC 32	0.00	0.00	100.00
PC 16	0.73	0.75	94.93	PC 33	0.00	0.00	100.00
PC 17	0.64	0.54	95.47				

The significant parameter of selected principal components is screened using contributing chart developed from principal components. Contribution charts were produced between PC1-PC2 and PC3-PC4 and can be formed for two principal components simultaneously, containing bars and cut-off lines (Fig. 3a, 3b). The bars in the charts represent the contribution of each parameter. The cut-off line in the graph indicates that the bars above the line contribute highly, whereas the bars below the line contribute

Table 3. Major contributing covariates of four principal components

Contributing covariates of principal components PC1, PC2, PC3 and PC4 (26 variables)	
Satellite data- Blue	Longitudinal curvature
Satellite data- Green	LS factor
Satellite data- Red	Maximum curvature
Satellite data- NIR	Minimum curvature
Agro Climatic Zone	Physiography
Agro-Ecological Zone	Plan curvature
Western Ghats	Slope
Maximum Temperature	Tangential curvature
Minimum Temperature	Terrain Ruggedness Index
Rainfall	Topographic Wetness Index
Analytical Hill shading	Total curvature
Elevation	Valley depth
General curvature	Lithology

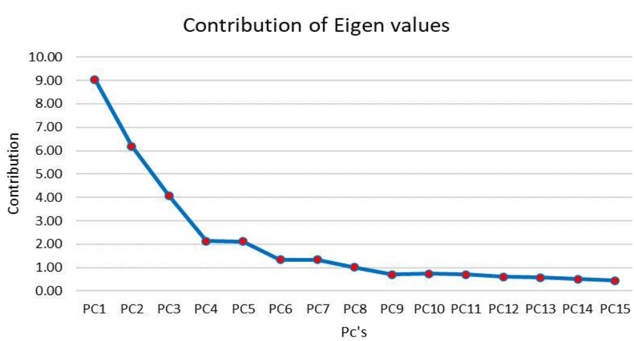

Fig. 2a. Scree plot of conventional PCA

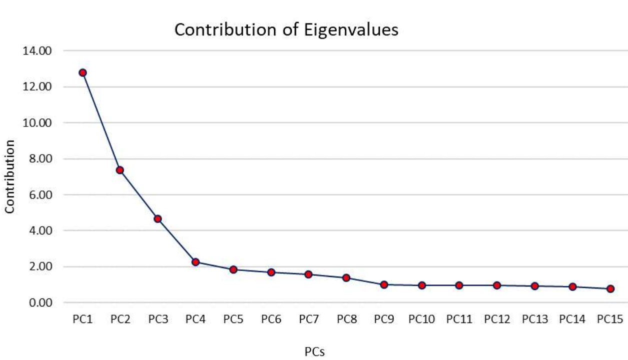

Fig. 2b. Scree plot of robust PCA

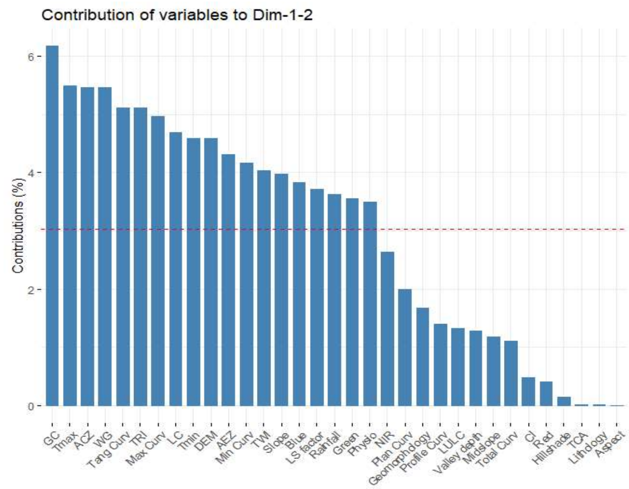

Fig. 3a. Contribution chart of PC1 and PC2

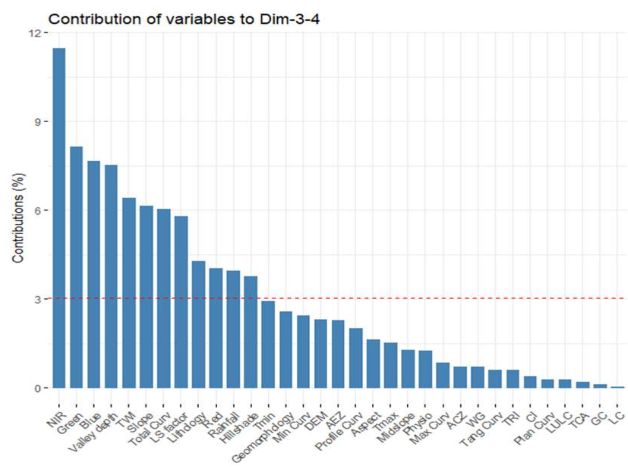

Fig. 3b. Contribution chart of PC3 and PC4

less (Luo et al 2022). If there are N parameters, then the expected average contribution of a PC is 1/N= n%. The cut-off line will fall on the n%, and the contributing layers of only two PCs can be determined. Selecting the contributing variables from two principal components, namely PC1 and PC2, given by

(n× eigenvalue of PC1) + (n× eigenvalue of PC2) (6)

The contribution chart of PC1-PC2 (Fig. 3a) shows that nineteen out of thirty-three layers have a high percentage and fall above the cut-off line. Similarly, the PC3-PC4 contribution chart (Fig. 3b) reveals those twelve out of thirty-three layers with a high contribution percentage. The two-contribution chart are combined and found that twenty-six layers out of thirty-three were highly contributing covariates of selected PCs. Table 3 gives the selected environmental covariates as the study's final independent variables and can be used for future mapping (Cavazzi et al 2013).

CONCLUSION

Robust PCA effectively reduces dimensionality when the datasets are derived from image or raster forms. They are extensions of the conventional method in terms of robustness and are effective in the presence of outliers. The robust PCA selects four principal components, cumulatively contributing to the variation of about 63.17%, whereas conventional PCA contributes only 52.46%. The scree plot aided the selection of appropriate principal components in both methods, and it was four principal components. Each principal component is composed of all environmental covariates, and the significant covariates in each principal component were found using contribution charts. Contribution charts were developed for PC1-PC2 and PC3-PC4. The cut-off line in the charts indicated the significantly contributing covariates. Environmental covariates like Agro Climatic Zone, Agro-Ecological Zone, Western Ghats, Maximum Temperature, Minimum Temperature, Rainfall, Analytical Hill shading, Elevation, General curvature, Longitudinal curvature, LS factor, Maximum curvature, minimum curvature, physiography, plan curvature, slope, tangential curvature, terrain ruggedness index, topographic wetness index, total curvature, valley depth, lithology, and green, red, blue, NIR wavelength are found to important participants of selected four principal components. Therefore, in the process of digital soil mapping, effective map generation can be achieved when the environmental covariates used as independent variables are chosen in the suggested way.

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Influence of Forest Canopy Gaps on Soil Properties and Richness of Understory Vascular Plants in 2-hectare Long-Term Ecological Research (LTER) Site in Mt. Musuan in Bukidnon, Southern Philippines

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***Abstract*:** Several studies have reported on the influence of forest canopy gaps on understory plant growth and species richness. In this study, soil properties and the richness of understory vascular plants under forest canopy gaps of varying sizes in a permanent Long-Term Ecological Research (LTER) plot in Mt. Musuan were determined. Based on the results, the light and photosynthetically active radiation varied among canopy gaps. There was an observed variation in the mean pH, percent organic matter content, extractable P and exchangeable K among forest canopy gap classes but the variations were not statistically significant. Large gaps had higher species richness of trees, shrubs and vines. Mean species abundance was also higher in large gaps (81) in comparison with small (60) and medium gaps (76). Although there are many species of trees present, there are only very few numbers of individuals. *Donax canniformis* (G.frost) K.Schum., *Orania palindan* (Blanco) Merr. and *Calamus sp.* were the most abundant species. The abundance of *D. canniformis* increased with canopy gap size which may indicate that it can easily spread in open sites. This could be indicative of the potential harm that the species can pose to tree regenerates if its spread is not controlled.

Keywords: Canopy gaps, Understory, Vascular plants, Soil properties, Mt. Musuan

The gap dynamics theory postulates that at any given time within any closed forest stands, disturbances may spontaneously happen to cause the death or injury of one or more canopy trees leading to gaps creation. Disturbance is a phenomenal forest activity which paves the way for the creation of canopy openings called canopy gaps (Hammond and Pokorny 2020). Disturbances that open gaps provide specific microenvironmental conditions in light, soil moisture, and temperature regimes, which often initiate regeneration processes and development (Muscolo et al 2014). Forest canopy gaps have an important forest ecological role (Schliemann and Bockheim 2011). Gaps in the canopy bring about significant effects on the structure and dynamics of most temperate and tropical forests. Death and fall of trees due to wind, disease or over-maturity can lead to the creation of forest gaps (Amolikondori et al 2021). Environmental changes particularly light intensity that reaches the understory can accompany gap creation. The formation of canopy gaps decreases canopy interception of precipitation and increases rain flushing and solar radiation in the understory. These impact the temperature, humidity, physical-chemical properties, and microbial community structure and function of soils, in addition to altering the forest environment (Xu et al 2016). This in turn can have an influence on plant diversity (Richards and Hart 2011) and soil nutrient cycling (Schliemann and Bockheim 2014).

Several studies indicated the effect of forest canopy gaps on understory plant growth and diversity. Tree growth is largely dependent on light capture (Fichtner et al 2013). Pedersen and Howard (2004) reported higher stem radial growth rates for overstory trees at gap edges compared to trees which were not positioned at canopy gap edges in a mature mixed forest. Seedling establishment, survival, and growth exclusively depend on light (Diaci et al 2008). Gap size is a strong predictor of species composition in forest gaps (Čater et al 2014). The importance of the effect of gap size on plant species diversity and composition in different forest types in tropical (regions has been validated (Schnitzer et al 2008, Marra et al 2014). The size of canopy gaps also relates to the amount of different light conditions that reach the forest floor and the type of light condition species exploit in gaps (Nagel et al 2010). Shade-tolerant tree species grow well in small gaps, while shade-intolerant species survive better in large gaps (Nagel et al 2010). Small gaps with low direct light levels supported shade- tolerant fir regeneration in mixed Dinaric forests (Čater et al 2014). For instance, large gaps are generally beneficial to the regeneration of light-adapted species (Čater 2017, Hammond and Pokorný 2020).

Previous studies on forest canopy gaps were mostly done on forest plantations and in temperate setting. Although several studies have been conducted in natural forests, only few were done in the Philippines. To gain an understanding on the dynamics of understory species richness and soil properties under natural forest canopy gaps, a study was conducted in a 2-hectare permanent plot inside a tropical forest. This study hypothesizes that plant diversity and the abundance of some plants increase with gap size. Soil physicochemical property values decline with increasing gap size. This study aimed to generate meaningful insights on the dynamics of soil and richness and abundance of understory vascular plants under various canopy gaps, with emphasis on forest regeneration and management.

MATERIAL AND METHODS

Study area: The study was conducted within the 2 ha. LTER permanent plots established in the natural forest of Mt. Musuan from March-May 2023. The LTER plot is approximately located at geographic coordinates 7.882361 North & 125.065694 East. In general, Mt. Musuan is 2005, the mean annual rainfall was about 1935 mm. June to October are also the wettest months on record, while the driest months were January to April with less than 100mm. The ecosystems in Mt. Musuan fall onto 4 general types; natural forest, plantation forest, grass-shrubland, and agro-ecosystem (Paquit et al 2023).

Characterization of canopy gaps: A reconnaissance survey was conducted to assess the presence of forest canopy gaps. Data on the location and estimated size (m^2) of the gaps were also collected. Three classes of gaps, namely small gaps (SG) (no central opening), medium gaps (MG) (100-200 m^2) and large gaps (LG) (>200 m^2) (modified from Hammond et al 2020) were characterized. Three replicates of NG, SG, and LG for a total nine forest canopy gaps were sampled. The geographic coordinates, elevation and the number of downed trees were also recorded.

Establishment of transect and sampling plots: Four transect lines oriented on a north-south and east-west directions were established (Fig. 2). The length of each

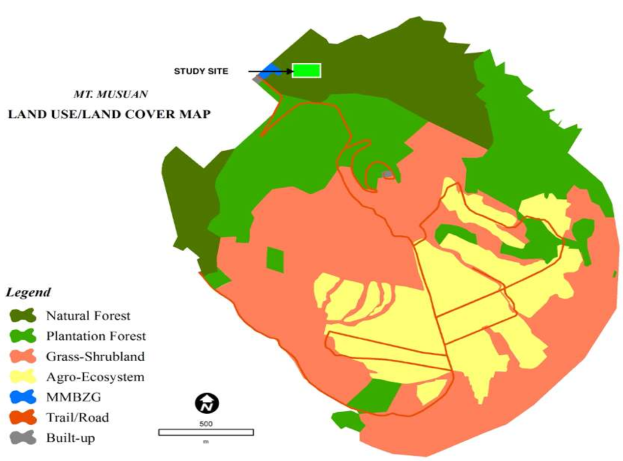

Fig. 1. Location of the study (Map from Paquit et al 2023)

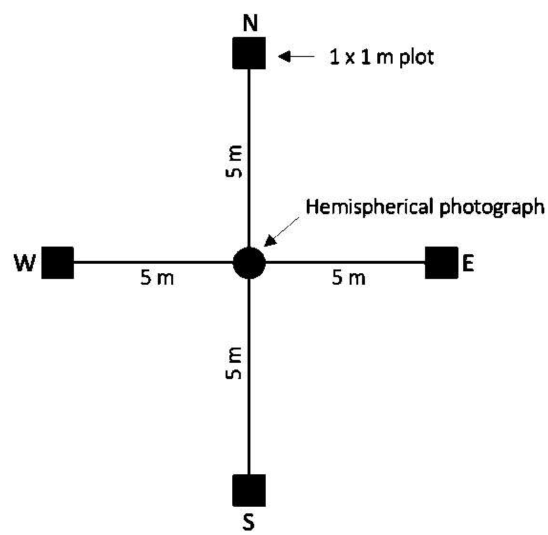

Fig. 2. Layout of transect and sampling plots (Modified from: Hammond et al 2020)

Table 1. Geographic location and tree fall characteristics of canopy gaps

Canopy gap class	Latitude	Longitude	Elevation (masl)	GPS accuracy (m)	No. of tree fall
SG1	7.88173	125.06609	433	12	0
SG2	7.88187	125.06626	412	10	0
SG3	7.88192	125.06591	422	7	0
MG1	7.88249	125.06668	409	7	1
MG2	7.88179	125.06571	409	5	1
MG3	7.88256	125.06692	408	8	1
LG1	7.88244	125.06588	382	7	4
LG2	7.88198	125.06594	427	7	3
LG3	7.88209	125.06557	400	6	2

transect line was 5 meters starting from the center of cardinal plane. 1x1 meter plots were then laid out at the ends of each transects line for the sampling plots of understory vegetation and soils. This set-up was replicated in other forest canopy gap classes.

Collection of canopy photographs: Hemispherical photographs were used to quantify the light environment below the canopy gaps. The photographs were taken during overcast skies using a digital camera (Nikon D3100) with a fish-eye lens. The camera system was set up at 1.37 m above ground, with the lens leveled and positioned vertically, and the top of the resulting image orientated to the north. The set up was laid at the intersection of the N-S and E-W transect lines (Fig. 2). Calculation of percent light transmission (% light) and photosynthetically active radiation (PAR) from the hemispherical photographs was accomplished using the software package Gap Light Analyzer (GLA version 2; Frazer et al 1999).

Vegetation and soil sampling*:* All vascular plants within each 1 m^2 plot were sampled. The taxonomic identification and number of individuals of plants were recorded. Aside from tree fall, trees adjacent to the plot were also noted. Soil samples from A horizon (30-cm depth) were taken using soil auger and other available tools. Thirty-six samples were collected from the field, airdried and then sieved to remove extraneous materials such as leaves, roots and others. Four soils samples from each gap class were grouped together for form nine composite samples. These nine samples were then brought to the laboratory for chemical analysis that included pH, percent organic matter (OM) content, extractable P, and exchangeable K.

Data analysis*:* Data from each 1 m^2 plot was pooled. Differences in species richness and abundance was analyzed using Microsoft excel. Soil properties of each gap category was in Microsoft Excel. Descriptive statistics such as means and percentages was also applied as deemed appropriate.

RESULTS AND DISCUSSION

Percent light and PAR in canopy gaps: Large gaps obtained a higher mean % light (22.25%) and mean PAR (9.13 Mol s^{-2} d^{-1}) as compared with small gaps (% light = 8.42, PAR =3.51) and medium gaps (% light = 12.27, PAR = 5.11). These are expected variations since more light can penetrate the canopy as the opening from gaps increase. PAR is strongly attenuated by foliage and canopy structure, but canopy opening in gaps can greatly increase the amount of PAR that reaches the forest floor. Kobe (1999) also found that canopy gaps had much higher levels of PAR than understory microsites due to the direct penetration of sunlight through the gap.

As depicted in the canopy photographs (Fig. 3), numerous gaps can be seen even in the small gap class. With the area classified as secondary forest (Marin and Casas 2017), it was observed that canopy gaps frequently occur in the 2-hectare permanent plot established under the Long-term Ecological Research project implemented by the Center of Biodiversity Research and Extension in Mindanao (CEBREM) of Central Mindanao University. A completely closed canopy with no small gaps or openings appear to be absent in the area. In large gaps, an average number of three fallen trees per gap was documented indicating that there was a total of nine fallen trees recorded in large gaps. This is

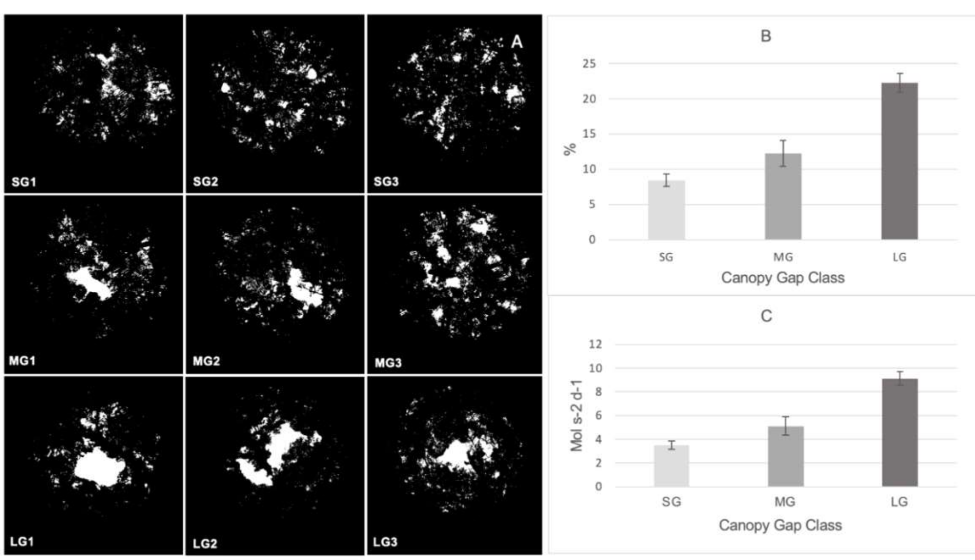

Fig. 3. Canopy gaps (A) and their variation in % light (B) and PAR (C)

higher than in medium gaps wherein only a single fallen tree was recorded per gap. The diameter of fallen trees observed in medium and large gaps ranged from 26-55 cm. It also appeared that trees downed by wind, a natural phenomenon (Amolikondori et al 2021) had led to the creation of those mentioned gaps. Gaps in the canopy bring about significant effects on the structure and dynamics of most temperate and tropical forests. Environmental changes particularly light intensity that reaches the understory can accompany gap creation (Xu et al 2016). This in turn can have an influence on plant diversity (Richards and Hart 2011) and soil nutrient cycling (Schliemann and Bockheim 2014). However, a few logs cut down using axe and saw have been observed outside the studied gaps. These were medium sized logs which may have been illegally felled. Further observations should be done to observe activities that could potentially cause disturbance in the area.

Variation in soil properties among canopy gaps: There was an observed variation in the mean pH, percent OM content, extractable P and exchangeable K among forest canopy gap classes (Fig. 4). However, the variations were not statistically significant. The mean pH was closely comparable but was highest in Small Gap (Fig. 4). Soil pH tend to increase in closed forest canopy (Tang et al 2019). Zhang & Zhao (2007) observed that soil pH under closed canopy was also higher but was not significantly different than in canopy gaps. Levia and Frost (2003) also found lower soil pH in larger canopy gaps. Soils under larger canopy gaps are more exposed to rainfall which can hasten the leaching of cations (Levia and Frost 2003). However, the relationship between canopy gap size and soil pH can be complex. Other factors including the age of the gap, the surrounding vegetation and the level of soil disturbance could also influence soil pH (Levia and Frost 2003).

Meanwhile, percent OM content was lower in small gap as compared with medium and large ap. Previous studies have suggested that soil organic matter content tend to decrease with increasing canopy gap size (Potvin and Gotelli 2008). In the same manner that it affects soil pH, exposure of the soil surface to solar radiation and rainfall hastens soil organic matter decomposition. Minerals are eventually absorbed by the growing vegetation including the understory.

Table 2. *p* values of the different soil properties

Soil properties	p value	Remarks
pH	0.94	Not significant
% OM	0.31	Not significant
Extractable P (ppm)	0.49	Not significant
Exchangeable K (ppm)	0.51	Not significant

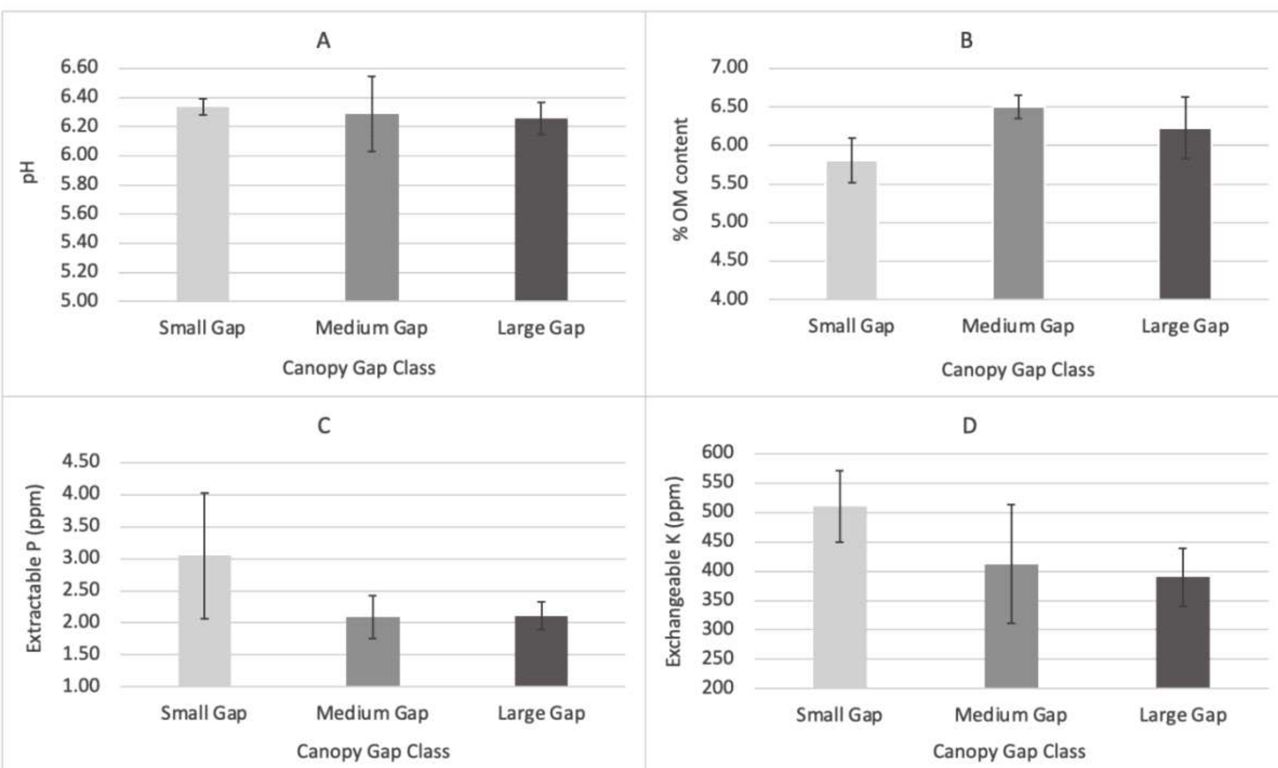

Fig. 4. Variation in mean pH (A), % OM (B), Extractable P (C), and Exchangeable K (D) among canopy gap classes

In forest ecosystems, gaps that are created by natural disturbances such as tree fall and windthrow may possibly increase soil organic matter content. Understory vegetation growing in microhabitats under canopy gaps can contribute to the accumulation of organic matter in the soil

Higher Extractable P was observed in soil under small gaps. Kaspari et al (2008) found higher soil phosphorus availability in gaps than in closed understory microsites. Chen et al (1995) also observed higher soil phosphorus availability in canopy gaps than under closed canopy. Meanwhile, there was a higher exchangeable K in small gaps than in medium and large gaps. Soil potassium availability can be influenced by canopy gaps, with gaps having higher potassium availability than in closed canopy areas (Clark et al 2001). Higher P and K in gaps could be attributed to an increased litter decomposition and nutrient cycling (Kaspari et al 2008). The previous studies suggest that phosphorus and potassium stocks increased with forest gaps, this phenomenon can also depend on other factors. The effect of gap size on P and K stocks may also depend on forest composition, with gaps having more deciduous species that contribute to litter production likely to have higher soil P and K (Clark et al 2001). This study was not able to include completely closed canopy gaps as these are absent because the study area is a disturbed secondary forest.

Species richness and abundance of understory vascular plants: Large gaps had higher species richness of trees, shrubs and vines (Fig. 5a). On average, 23 different species of vascular plants was recorded under large gaps wherein 12 are tree species. This is higher than in small and medium gaps wherein only 7 and 10 tree species were recorded respectively. The mean total number of species is also lower in small and medium gaps, only 14 and 17 respectively. Čater et al (2014) observed that gap size is a strong predictor of species composition in forest gaps. Several studies have also reported that canopy gaps can influence species diversity in forest ecosystems. Lertzman et al (2002) observed that in a temperate rainforest, gaps created by windthrow increased plant diversity and biomass.

The, mean species abundance was also higher in large gaps (81) in comparison with small (60) and medium gaps (76). Moreover, the abundance of trees, shrubs and vines increased with canopy gap size. In contrast, the abundance of palms decreased as the canopy gap size increased. Canopy gaps can also have an influence on seedling abundance in forest ecosystems. Busing and Brokaw (2002) found that seedling abundance was higher in canopy gaps than in closed canopy in a tropical rainforest in Puerto Rico. Canham and Thomas (2010) also had the similar observation on their study in a temperate deciduous forest in the northeastern United States. The enhanced light condition in gaps is exploited by different species especially the light demanding (Nagel et al 2010). Changes in light, temperature and moisture conditions caused by the creation of gaps could have affected the germination, growth and survival of tree seedlings associated with gaps.

Implications for conservation and management: Although there are more species of trees, only very few individuals are present. The top three most abundant species under different canopy gaps are *Donax canniformis* (G. frost) K. Schum., *Orania palindan* (Blanco) Merr. and *Calamus sp* (Fig. 6). These species dominate the understory in the study sites regardless of the size of the canopy gaps. The mean abundance of *O. palindan and Calamus sp.* drops as the canopy gap size increase. The mean abundance of *Calamus sp.* decreased from 18 to 15 from small to large gaps respectively. The mean abundance of *O. palindan* had a stepper drop from 21 in small gaps to only 4 in large gaps. Meanwhile, an increase in the abundance of *D. canniformis* was positively correlated with the increase in gap size.

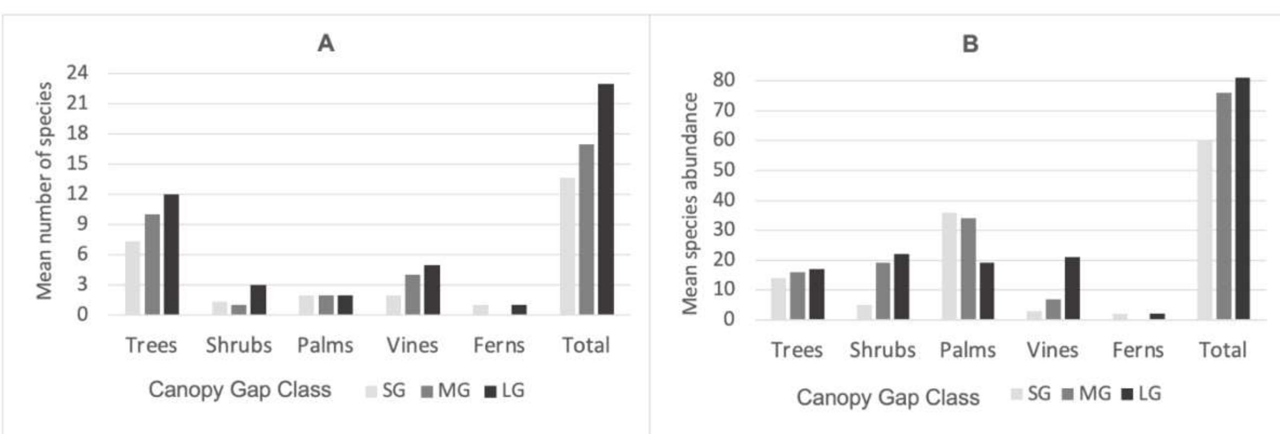

Fig. 5. Mean number of species (A) and mean species abundance (B) among canopy gap classes

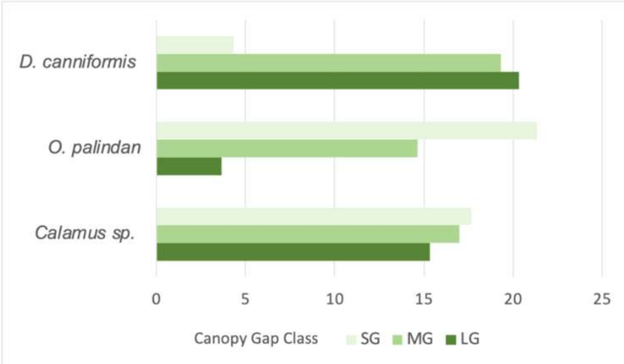

Fig. 6. Top 3 most abundant species in canopy gaps

Ardiyani et al (2010) observed that *D. canniformis* is common especially in open and disturbed places. It is common in low and medium elevation secondary forest in the Philippines and is common throughout South East Asia. This explains its observed greater abundance under canopy gaps.

D. canniformis is classified as native species. However, as observed, the species had become the dominant understory plant species in the open sites of the study area. As seen in this study, larger openings in the canopy can promote the spread of this species in other parts of the forest. The species can potentially outcompete tree regenerants for light, space and nutrients and may impact plant diversity. Natural disturbances such as windthrow can promote canopy openings. Anthropogenic activities such as timber poaching can also pose disturbance. The uncontrolled spread of some species such as *D. canniformis* may be averted by silvicultural intervention such as manual removal of individuals. Various authors have written about *D. canniformis* being used in novelty items such as placemats, baskets, and flowerpot holders (Agduma et al 2011). The stem is made into a wide range of handicrafts including hats, baskets, magazine rack and bookshelves (Teo 2003). The leaves also contain saponins, phenolics, and tannins (Hidayatullah et al 2017). These are some of the potential uses of the species to control its population.

CONCLUSIONS

This study observed the presence of canopy gaps of different sizes in the study area. % light and PAR differed among canopy gaps. There was an observed variation in soil properties, however, their differences were not statistically significant. In general, species richness increased with canopy gaps. The abundance of species, except for palms, were also greater as the gap size increased. However, three species namely; *D. canniformis*, *O. palindan*, and *Calamus sp.* dominate the understory of the canopy gaps. In particular, the mean abundance of *D. canniformis* had a steep increase from small to large gaps. This could be indicative of the potential harm that the species can pose to tree regenerates if its spread is not controlled. The findings of this study can have implications in the management of the area. Apart from strict forest protection from timber poachers, silvicultural interventions could be explored to control the population of *D. canniformis*, *O. palindan*, and *Calamus sp.* This is to allow trees and other plant species to grow and survive in the area.

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Effect of Tigris Water Irrigation on Heavy Metal Contamination in Soil and Plant

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Abstract: The study was conducted to observe the effect of Tigris River water irrigation on heavy metal (Cu, Ni, Cd, Pb) contamination in soil and plant within the boundaries of the city of Baghdad. Four sites were chosen to take water samples: Al Rashidiya, Al Dora power station, the confluence of the Diyala River with the Tigris River (Al Tuwaitha) and Salman Pak from May to December 2019. Soil and plant samples (*Medicago sativa* L) were collected from fields adjacent to the riverbed selected sites. Results indicated significant changes in the water quality parameters like electrical conductivity (1.31 dSm^{-1}), pH (8.05), total dissolved solids (TDS; 692.95), residual sodium carbonate (RSC; 49.81), exchanged sodium percentage (ESP; 1.11) and sodium adsorption ratio (SAR; 1.60 mg l^{-1}). Chemical oxygen requirement (COD), organic carbon concentration (TOC) and turbidity at Al-Tuwaitha site increased to 20.23, 35.58, 39.27 mg l^{-1} respectively. In addition to high concentration of dissolved cations and anions at the same site. River water was classified as C_2S_1 according to American Salinity Laboratory system. Lead and cadmium concentrations were 0.69 and 0.04 mg L^{-1}, at Al-Dora and Al-Tuwaitha electricity sites, respectively and exceeded the internationally permissible limits, while concentrations of copper and nickel were within permissible limits. Cadmium contamination of soil was also observed and concentrations ranged between 14.45-2.25 mg kg^{-1}. The soils of Al Dora power station and Tuwaitha sites were contaminated with lead with concentrations of 55.4 0and 61.75 mg kg^{-1}, respectively. The concentrations of copper and nickel were within the limits allowed internationally. Concentrations of lead in plant ranged between 1.85-1.01 and cadmium between 0.45-0.24 mg kg^{-1}dry matter, exceeding the permissible limits internationally, while the concentrations of copper and nickel were between 1.05-0.78 and 0.38-0.24 mg kg^{-1}dry matter and were within permissible limits.

Keywords: Tigris River, Irrigation, Soil pollution, Heavy metals

Water resources are most important input in agricultural production as development and expansion requires the provision of sufficient quantities of water needed to achieve food security. Many developing countries discharge city waste water without any treatment into rivers, causing pollution (Tail and Barhawi 2000). The process of discharging waste water directly to the Tigris River is a serious breach of the natural balance resulting changes in water chemical and physical properties and causing threat to plant life in the long run. Water quality in terms of salt concentration and ionic composition affects different soil characteristics through sedimentation and dissolution. As the use of water with high concentrations of a particular ion leads to the dominance of that ion over exchange complex in soil and upset the nutritional balance in soil. Heavy metals are considered dangerous environmental pollutants due to their cumulative properties in bodies of living organisms (Mohsen and Mohsen 2008). High concentrations of these elements in polluted water leads to pollution of agricultural soil. High concentrations of these elements in plants growing in polluted soils beyond the permissible limits endanger the consumer's life (WHO 2003). The cause of soil pollution is due to excessive use of chemical fertilizers and agricultural pesticides, most of the time it is result of irrigation with water contaminated with factory and household wastes in addition to sewage waste (Azita and Seid 2008). Mhaimeed et al (2014) showed that salinity of Tigris water falls within the quality of water C_1S_1 - C_4S_2 (low salinity, low in sodium to very high salinity, medium soda), and salinity of water ranges from 0.44-3.00 dSm^{-1}. Diyala River is one of the tributaries of Tigris River, and suffers from a major change in its physical and chemical properties due to contamination with sewage water of the Rustumiya station for treating sewage, laboratory wastes and sewage water that is discharged into it. Our research aimed to study the concentration of some heavy metals (Cu, Ni, Cd, Pb) in waters of Tigris River and their effect on soil and plants irrigated with it.

MATERIAL AND METHODS

Four sites namely the Rashidiya site, the Dora power station, and at the meeting of the Diyala River with Tigris River (Tuwaitha) and Salman Pak were selected on Tigris River within the boundaries of Baghdad city, to observed of heavy metals in river water (lead, cadmium, nickel and copper) and effect on soil and plant in agricultural areas adjacent to river. Water samples were collected for chemical and physical analyses and placed in one-liter plastic bottles made of polyethylene after washing it thoroughly with distilled water, then with river water several times, after which was filled with river water. Drops of Tulane were added to it to prevent bacterial growth, and was kept in refrigerator until required analyses were carried out. Chemical and physical properties of water were estimated according to the methods of Richards (1954), Black et al (1965) and APHA (2012).

The concentrations of available and total heavy metals in soil and plants were measured by the Atomic Absorption Spectrophotometer (AAS) according to APHA (2012). The available heavy metals were extracted from soil by chelating compound ATPA (diethylene tri amine penta acetic acid) according to Lindsay and Norvell (1978). Soil samples were digested by a mixture of sulfuric and perchloric acids. The vegetative portion of alfalfa plant grown in all sites was taken and dry, milled, and screened plant samples were digested using a mixture of nitric and perchloric (Mohsen and Mohsen 2008). The river water was classified according to the American Salinity Laboratory system and International Food and Agriculture Organization (FAO 1995).

RESULTS AND DISCUSSION

The changes in chemical, physical and biological characteristics of Tigris River water, depend on amount of discharge to river from neighboring industrial establishments (Table 1A & B, 2). Highest significant electrical conductivity (EC) of river's water was at meeting sites of Tigris River with Diyala River (Tuwaitha region) and Dora power station (1.31 and 1.15 dSm^{-1}). This may be attributed to the contamination of Diyala River's water with sewage water loaded with salts and other dissolved materials as a result of the discharge of Al-Rustamiya heavy water plant in it, which finally enter into Tigris River. Jumaa et al (2010) also observed that sewage water discharge in rivers increases concentrations of dissolved ions, while increased electrical conductivity at Dora power plant is attributed to dissolved materials and salts that is used cooling to river basin. Muftin et al (2019) observed that the amount of dissolved solids in water of power station increased greatly and reached 540 mg L^{-1}, which led to an increase in electrical conductivity of water.

The pH values, were neutral to light basic with highest of 8.05 in Tuwaitha due to higher pollution of Diyala River water with sewage residues. The depending on this, TDS values increased significantly, residuals- sodium carbonate (RSC), sodium exchanged percentage (ESP), and sodium adsorption ratio (SAR) were 692.95, 49.81, 1.11 and 1.60 mg L^{-1}, respectively (Table 1A&B). Water temperature differed significantly, highest was in Dora power station (24-25°C) and is due to hot water used in cooling the station's facilities, which is released to river's water. Muftin (2019) pointed out, that the temperature of water near Dora power station reached 38.3°C in September.

There was significant increase in values of chemical oxygen demand (COD), organic carbon concentration (TOC) and turbidity (Tur.) at Tuwaitha site being 35.58, 39.27 and 20.23 mg L^{-1}, respectively (Table 2). This may be due to organic waste present in Diyala River polluted with sewage water, which flows into Tigris River at this site and increased decomposition of organic matter in river due to the influence of slightly higher temperatures and the release of more carbon ions into the river's water.

Table 1A. Physical characteristics of Tigris River water at different locations

Location	EC (dSm^{-1})	pH	TDS (mg l^{-1})	RSC	ESP	Temperature (°C)
Alrashidia	0.85	7.69	548.80	-4.00	0.78	18.62
Dora power station	1.15	6.86	603.10	-4.09	0.60	24.25
Altawayitha	1.31	8.05	692.95	49.81	1.11	18.63
Salman bak	0.96		571.77	-3.53	1.08	18.61
LSD (p=0.05)	0.01	7.88	3.93	1.39	0.22	0.05

Table 1B. Chemical and characteristics of Tigris River wa

Location	COD (mg l^{-1})	TOC (mg l^{-1})	TUR (NTU)	SAR (mg l^{-1})	Adj-SAR (mg l^{-1})	T.H (mg l^{-1})	Water class
Alrashidia	88.05	20.85	15.30	1.58	3.35	302.13	C2S1
Dora power station	88.18	25.30	16.14	1.26	3.20	338.66	C2S1)
Altawayitha	139.27	35.58	20.23	1.60	4.05	376.01	C2S1
Salman bak	88.05	20.86	15.31	1.58	3.93	301.95	C2S1
LSD (p=0.05)	2.12	0.68	0.32	0.04	0.97	2.83	

Falih and Rasheed (2016) showed that concentration of organic carbon ranged between 70-1120 mg L^{-1} in water of the Tigris River within the city limits of Baghdad city. Total hardness values (TH) ranged from 302.13 at the Rashidiya site to 376.01 mg L^{-1} at Tuwaitha site, Al-Ani et al (2019) also showed that amount of dissolved solids in Tigris River water ranged between 362-711 mg L^{-1}, which was reflected in total hardness values. Falih and Rasheed (2016) indicated that total hardness values of Tigris River water ranged between 310-500 mg L^{-1}.

The concentrations of cations and anions of river water at the different sites significantly increased in concentrations of sodium, calcium, magnesium, sulfate and bicarbonate ions at the Tuwaitha site, (108.28,203.90, 29.46, 101.21, 70.26 mg L^{-1}) as compared with rest of sites (Table 3). This is due to the large amount of pollution in river's water at this site due to the various wastes, materials and salts poured into river from the Al-Rustumiya station. Salwan et al (2019) indicated that an increase in concentrations of the above elements in river waters, a significant increase in concentration of both potassium and carbonate at Salman Pak site which (0.74 and 0.62 mg L^{-1}). Chloride ion was with containing of chloride-containing materials. Salwan et al (2019) observed that the concentration of chloride in water of Tigris ranged between 31-103 mg L^{-1}.

Shukri et al (2011) observed carbonate concentration ranging from 1.3-1.9 mmol L^{-1} in Tigris water. There were significant differences in boron concentration for the different study sites, highest concentration (0.38 mg L^{-1}) was at Al-Tuwaitha site, which may be attributed to drainage of Al-Rustumiya station for heavy water purification into river, as the wastewater contains high concentrations of Boron which may reach 0.86 mg L^{-1}. In addition, drainage water of agricultural soils on both sides of river contains high concentrations of boron resulting from addition of various boron fertilizers to soil. Issa (2018) recorded the boron concentrations ranging from 0.26-0.15 mg L^{-1} in Tigris water.

Classifying river water according to American salinity laboratory system, water falls within the class C_2S_1, indicating it as medium salty water with low in soda ash, but on the basis of severity of boron, water falls within the first concentration range, which is safe for crops sensitive to Boron. Classifying river water according to the International Food and Agriculture Organization (FAO) system, all sites fall into second category (increase in the problem).

There were significant differences in lead ion concentration, with highest (0.69 mg L^{-1}) at Dora power station site, exceeding the permissible limits according to Iraqi specifications (1996) of 0.1 mg L^{-1} whereas it does not exceed the permissible limits (5.0 mg L^{-1}) for irrigation water according to the World Health Organization WHO (2003). Earlier Al-Obaidy et al (2014) have reported lead concentration of 0.36 mg L^{-1} in Tigris River water. Cadmium concentrations ranged between 0.02-0.04 mg L^{-1} and significantly highest was at Tuwaitha site exceeding the permissible limits of Iraqi specifications (0.1 mg L^{-1}) and World Health Organization WHO (2003) of 0.01 mg L^{-1}. Juma and Al-Anbari (2010.) reported cadmium concentrations of 0.021 mg L^{1} in Tigris water within the boundaries of Baghdad. Copper and nickel concentrations did not exceed the permissible limits for irrigation water according to Iraqi specifications (1999) and World Health Organization WHO (2003) *i.e.* 1.0 and 0.2 mg L^{-1}, respectively.

Physico-chemical properties of soil: Physico-chemical

Table 2. Concentration of some cations and heavy dissolved elements (mg l^{-1}) in Tigris River water for different sites

Location	Cl	SO_4	HCO_3	CO_3	B
Alrashidia	123.10	131.57	157.17	0.92	0.18
Dora power station	80.62	182.10	166.00	0.02	0.22
Altawayitha	105.71	203.90	180.28	0.33	0.38
Salman bak	117.21	165.81	158.68	0.62	0.20
LSD (p=0.05)	1.55	4.49	1.75	0.20	0.011

Table 3. Concentration of some dissolved anions elements in Tigris River water for different sites (mg l^{-1})

Location	Na	K	Ca	Mg	Ni	cd	Pb
Alrashidia	57.12	0.91	86.46	27.22	0.01	0.02	0.02
Dora power station	53.40	0.67	90.63	27.51	0.03	0.02	0.69
Altawayitha	70.267	0.61	101.21	29.46	0.02	0.04	0.04
Salman bak	69.80	0.74	90.27	24.23	0.01	0.02	0.03
LSD (p=0.05)	1.13	0.20	0.93	0.52	0.0004	0.001	0.001

characteristics of agricultural soils adjacent to Tigris River, change in degree of soil reaction ranged between 7.46-8.12, highest values were in Tuwaitha soils than in other soils that were less contained (Table 4). The highest electrical conductivity (35.00 dSm^{-1}) was in Tuwaitha soil, which may be attributed to increased electrical conductivity of Tigris water in Tuwaitha area, which reached 1.04 dSm^{-1} compared to other regions. The increase in irrigation water led to accumulation of salts in soil. The total dissolved solids in soil of Tuwaitha amounted to 3430 mg L^{-1} which was highest compared to other sites. This corresponds to increased soil electrical conductivity in the region. Concentrations of soluble cations and anions was also highest in Tuwaitha soils. The concentrations of potassium, sodium, calcium and magnesium recorded as 49.10, 84.01, 81.30, 2.41 mmol L^{-1}, respectively, and 6.41, 1.74, 210.03, 65.11 mg L^{-1} for ions of sulfate, chloride, carbonate and bicarbonate, respectively. Higher concentrations of cations and anions in Tuwaitha soil compared to other sites may be attributed to higher concentrations of these ions in river water due to discharge of sewage water loaded with salts and other dissolved materials present in water of Diyala River as a result of Rustumiya heavy water station which finally flows into Tigris River and is carried with irrigation water to agricultural soil. Jumaa et al (2010) also observed that drainage of sewage water from river increases concentrations of dissolved ions.

There were variations in concentrations of available heavy metals in soil for different sites (Table 4). Highest concentration of available lead (6.70 mg kg^{-1}) in soil was in Dora site followed by Tuwaitha (5.52), Salman Pak (3.51) and Rashidiya (3.23 mg kg^{-1}). The concentration of available cadmium in Al-Dawra soil was 1.66, followed by Al-Tuwaitha

Table 4. Physical and chemical characteristics of soil

Characters	Unit	Salman bak	Altawayitha	Dora power station	Alrashidia
pH	-------	7.46	8.12	7.71	7.53
EC	dS m^{-1}	4.45	35.00	5.00	5.36
TDS	mg l^{-1}	2810	21215	3155	3430
O.M	%	1.19	1.25	1.19	1.23
Gypsum	Gm kg^{-1}	0.78	0.25	1.19	0.56
Carbonate	Gm kg^{-1}	259.00	335.00	274.00	296.00
Clay	%	39.00	37.00	41.00	44.00
Silt	%	40.00	45.00	49.00	42.00
Sand	%	21.00	18.00	10.00	14.00
Texture	-----	CL L	SiC L	Si CL	Si CL
CEC	C.mole+kg^{-1}	18.5	17.90	19.40	20.10
Dissolved ions	mmole l^{-1}				
Ca	mmole l^{-1}	10.17	84.01	10.70	11.21
Mg	mmole l^{-1}	8.10	49.10	7.50	8.35
Na	mmole l^{-1}	7.61	81.30	14.11	15.20
K	mmole l^{-1}	0.84	2.41	0.78	0.94
Cl	mmole l^{-1}	24.50	210.03	26.81	28.10
$SO_4^{=}$	mmole l^{-1}	8.20	65.11	9.12	10.41
$HCO_3^{=}$	mmole l^{-1}	3.19	6.41	3.40	4.20
$CO_3^{=}$	mmole l^{-1}	0.72	1.74	0.86	1.16
Available Pb^{2+}	mg kg^{-1}	3.51	0.52	6.70	٣.23
Available Ni^{2+}	mg kg^{-1}	2.55	2.80	2.90	2.٤5
Available Cd^{2+}	mg kg^{-1}	0.68	1.48	1.66	0.87
Available Cu^{2+}	mg kg^{-1}	1.56	1.89	1.79	1.48
Total Pb^{2+}	mg kg^{-1}	24.45	55.40	61.75	22.18
Total Ni^{2+}	mg kg^{-1}	29.75	41.28	38.81	10.50
Total Cd^{2+}	mg kg^{-1}	2.25	13.75	14.45	3.65
Total Cu^{2+}	mg kg^{-1}	12.40	13.26	11.35	8.41

1.48, Al-Rashidiya 0.87 and Salman Pak 0.68 mg kg^{-1}. The concentrations for lead and cadmium did not exceed the permissible limits of WHO (30-50 and 1- 3 mg kg^{-1}, respectively).

The highest concentration of copper was in Al-Tuwaitha (1.89 mg kg^{-1}) and nickel was higher in Dora soil (2.90 mg kg^{-1}). These elements did not exceed permissible limits of WHO (2003) *i.e.* 40- 50 and 75-530 $mgkg^{-1}$, respectively (Table 4). The highest soil lead concentration was in Al-Dora followed by Tuwaitha, Salman Pak and Rashidiya soil (61.75, 55.40, 24.45, 22.18 mg kg^{-1}, respectively). All soils were contaminated with lead exceeded critical limits of 30-50 mg kg^{-1} (WHO 2003). Muftin et al (2019) observed that total lead concentration in soils of Al-Dora site ranged between 12.8-136.0 mg kg^{-1}. Total soil cadmium concentration increased as a result of irrigation with Tigris water. Highest value was in Al-Dora soil followed by, Al-Tuwaitha and, Al-Rashidiya and Salman Pak (14.45, 13.75, 3.65, 2.25 mg kg^{-1}, respectively). All values exceeded the permissible limits of WHO (2003) *i.e.* 1-3 mg kg^{-1}. Highest soil concentration copper was in Tuwaitha followed by Al-Dora, Salman Pak and Rashidiya soi1 (3.26, 11.35, 12.40, l 8. 41 mg kg^{-1}, respectively). These values fall within the permissible limits *i.e.* 50-140 mg kg^{-1} (WHO 2003). Highest soil nickel concentration (41.28 mg kg^{-1}) was in Tuwaitha followed Dora and Rashidiya. These were within the permissible limits (75- 530 mg kg^{-1}) of WHO (2003). The higher concentration of heavy metals in Tuwaitha and Dora sites compared to rest of the sites may be attributed to increased pollutants in water of Tigris River in this area and that of Dora, may be due to increased precipitation of heavy metals from the Dora refinery specifically element of lead through the gaseous emissions, which fall on river water and soil. In addition, the wastes and residues that contain heavy metals from Dora power station to riverbed.

Heavy metals in plants: Results on heavy metals in vegetative part of alfalfa plant, grown in soils of different sites, indicated highest concentration of lead in Tuwaitha area (1.85 mg kg-1) followed by Dora, Rashidiya, and Salman Pak (1.70, ١،١٥, 1.01 mg kg^{-1} dry matter, respectively). These values are within the permissible limits (5.0 mg Kg^{-1} dry matter) of WHO (2007). Highest concentration of cadmium in plants of the Tuwaitha site was 0.45 mg kg^{-1}, followed by Dora, Rashidiya, Salman Pak (0.30 ,0.25, 0.24 $mgkg^{-1}$ dry matter, respectively). All these values exceeded the permissible limits (0.2 mg kg^{-1} dry matter) of WHO (2007). Copper concentrations ranged from 0.78- 1.05 mg kg^{-1} dry matter and nickel from 0.24-0.38 mg kg^{-1} dry matter. The copper and nickel, concentrations were within the permissible limits (*i.e.* 40.0 and 67.90 mg kg^{-1} dry matter for copper and nickel, respectively) of WHO (2007).

CONCLUSION

There were significant changes in the quality of water due to the impact of the river, including the dumping of city waste, industrial waste and sewage, pollution of river water with lead and cadmium at Al-Dora and Al-Tuwaitha electricity sites. Cadmium contamination of soil was also observed. Soils of Al Dora power station and Tuwaitha sites were contaminated with lead and exceeded the internationally permissible limits.

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Interactive Effects of Different Nitrogen Doses and spacing on Growth and Yield Parameters in Coriander (*Coriandrum sativum* L.)

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***Abstract*:** Coriander (*Coriandrum sativum* L.) is one of the most important spice crops worldwide, possessing varied medicinal impacts. The present study explores the effect of various nitrogen doses and spacing on coriander under field conditions. Among all the treatments, S_1N_3 (20×15; N@75 kg/ha) was best for plant height, S_3N_1 (40×15; N@0 kg/ha) for days to 50% flowering, S_1N_1 (20×15; N@0 kg/ha) for minimum maturing, and S_3N_3 (40×15; N@75 kg/ha) for number of umbellets per umbel, number of seeds per umbellets, number of seeds per umbel, seed yield per plant, primary branches. Based on this study, the aforementioned treatments can be exploited for sustainable coriander production.

***Keywords*:** Nitrogen, Spacing, *Coriandrum sativum,* Coriander

Coriander (*Coriandrum sativum* Linn.), a member of *Apiaceae* family grown as an annual herb and is originated from the Mediterranean region, however, extensively cultivated in Central Europe North Africa, and Asia as a medicinal as well as a culinary herb. The crop was grown over an area of 629 thousand hectares with a production of 756 thousand MT in India during 2019-20 (Anonymous 2019). In India, it is primarily grown in the *Rabi* season specifically for its leaves and seeds. Besides various culinary applications, possess a range of medicinal properties (Prachayasittikul et al 2018) owing to its broad phytochemical profile and a variety of chemical compounds present in every plant part (root, fruits, leaves, and seeds) (Mandal and Mandal 2015). There are several documented health benefits of coriander in literature (Maroufi et al 2010, Singh and Kaur 2022). In the coriander cultivation, nitrogen fertilization is considered a major production factor that imparts a direct effect on the quality, composition, and yield of coriander. As per previous documentation, the application of nitrogen fertilizer has improved seed yield and biomass of coriander by 43-68% and 25-42% (Ali et al 2015). Besides, maintaining the optimum plant population is also a beneficial, non-monetary agronomical practice of crop production. Maintaining the optimum density of plants results in reduced nutrient competition within the plant population. Various studies have reported that optimum plant density increased the growth and yield of coriander significantly (Katiyar et al 2014). However, wider or too close spacing beyond the optimum can negatively affect the yield of a crop. (Kaium et al 2015). Therefore, the present investigation was undertaken to demonstrate the effect of various nitrogen and spacing effects on coriander under field conditions.

MATERIAL AND METHODS

Experimental site: The field trial was conducted at Chaudhary Charan Singh Haryana Agricultural University, Hisar (India) (29^{0} 10' N, 75^{0}46' E, Elevation 215.2 m) in the *Rabi* season of 2019-20. The temperature varies from 40°C to 48°C during summer to as low as to freezing point accompanied by chilling frost in winter. The approximate average rainfall was 450 mm.

Soil properties: The soil of the experimental field was analyzed for mechanical and chemical properties and cropping history (Table 1).

Experimental details: The coriander variety DH 220 was chosen for the experiment. The seeds were sown in a plot size of 3.0×2.4 m^2 with Randomized Block Design with three replications. A total of twelve treatments were formulated and raised with the standard agronomic practices (Table 2). Half of the nitrogen was applied at the sowing time and the rest of the dose was applied after 6 weeks of the first dose. The five plants were selected randomly and tagged for data collection

Evaluation of Physical Parameters

Plant height: The height of the tagged plants from each plot was measured from the base of the plant to the tip of the main shoot at 45, 60 and 90 DAS and harvest.

Number of primary branches: The branches that emerged from the main shoot of selected plants from each plot were counted at 45, 60, 90 DAS, and at harvest.

Days to 50% flowering: The number of days taken from the date of sowing to 50% flowering was calculated and expressed as days taken for 50% flowering.

Days to maturity: When the lower leaves of the plants were almost shed, the seed color changed from green to brownish and the seeds get hardened; days were counted from sowing to maturity.

Number of umbels per plant: The total number of umbels that emerged from five tagged plants in each treatment was counted at the time of harvesting and averaged.

Number of umbellets per umbel: Five umbels were selected randomly from the tagged plants at harvest and total umbellets were counted. Then the average umbellets per umbel were worked out.

Number of seeds per umbel: Total seeds from five selected umbels of the tagged plants in each plot at harvesting time were counted.

Number of seeds per umbellet: The seeds from five selected umbellets of primary umbels of tagged plants of each plot were counted.

Seed yield per plant: All the umbels from five selected plants of each treatment were harvested, dried under shade, and threshed. The average weight of cleaned seeds was recorded as seed yield per plant in grams.

Statistical aanalysis: The data was statistically analyzed in Randomized Block Design using SPSS software (IBM, SPSS Inc., USA).

RESULTS AND DISCUSSION

Plant height: Plant height was maximum in spacing 20×15 cm which decreases significantly with an increase in spacing (Table 2). It might be due to the shading effect of the dense population which forces the plant to compete for light. Additionally, lower internodes might have elongated due to reduced light intensity at the base of the plant stem resulting in increased plant height. Although the plant continues to elongate at a faster rate due to mutual shading up to a certain height, after that internode elongation is checked because the availability of photosynthates is reduced (Katar et al 2016; Sharma et al 2016). Plant height was maximum at nitrogen dose 75 kg ha^{-1}. Nitrogen is a major nutrient of biological significance, it is mainly required in the synthesis of protein, chlorophyll, and other organic compounds. Therefore, with increased availability of nitrogen in the soil medium and thereafter, effective absorption and translocation in various parts of plants impart active cell division and elongation which results in greater plant height (Javiya 2017).

Primary branches: The maximum number of primary branches was in spacing 40×15 cm and at nitrogen dose of 75 kg ha^{-1}. The greater nitrogen inputs under wider spacing lead to vigorous branching which forces larger canopy development and delayed reproductive stage (Table 3). The

Table 1. Mechanical, chemical properties of the soil and cropping history

Sr. No.	Soil parameters	Methods and reference
Mechanical analysis of the soil		
1	Sand (%)	International pipette method (Piper 1945)
2	Silt (%)	
3	Clay (%)	
4	Soil texture	
Chemical analysis of the soil		
1	pH	Potentiometric method (Jackson 1973)
2	EC (ds/m) at 25^{0}C	Conductometric method (Jackson 1973)
3	Organic Carbon (%)	Wet oxidation method (Walkley and Black 1934)
4	Available nitrogen (kg/ha)	Kjeldhal- distillation method (Subbaiah and Asija 1956)
5	Available phosphorus (kg/ha)	$NaHCO_3$ extraction and colorimetry method (Olsen et al 1954)
6	Available potassium (kg/ha)	Flame photometry method (Jackson 1973)
Cropping history of the experimental field		
Year	*Kharif*	*Rabi*
2017-18	*Okra*	*Potato*
2018-19	*Okra*	*Fennel*
2019-20	Bottle gourd	Coriander

Table 2. Interactive effect of nitrogen levels under different spacing on plant height on coriander (*Coriandrum sativum* L.) days after sowing

Nitrogen (Kg/ha)	S_1 (20×15cm)	S_2 (30×15cm)	S_3 (40×15cm)	Mean N
45 days				
Control	11.46	11.07	9.93	10.82
25 kg	12.67	10.67	10.27	11.20
50 kg	12.93	11.53	10.80	11.76
75 kg	14.20	12.40	11.73	12.78
Mean S	12.82	11.42	10.68	
CD (p=0.05)	N= 0.79	S= 0.68	N × S= NS	
90 days				
Control	78.47	78.00	76.27	77.58
25 kg	82.33	81.40	80.53	81.42
50 kg	90.33	88.13	83.87	87.44
75 kg	95.13	92.57	84.87	90.86
Mean S	86.57	85.03	81.38	
CD (p=0.05)	N= 1.34	S= 1.16	N × S= 2.32	
Harvest				
Control	121.87	109.27	101.87	111.00
25 kg	129.40	125.13	125.47	126.67
50 kg	135.07	133.07	131.07	133.07
75 kg	142.33	137.47	136.47	138.76
Mean S	132.17	126.23	123.72	
CD (p=0.05)	N= 3.32	S= 2.87	N × S= 5.74	

Table 3. Effect of nitrogen under different spacing on primary branches of coriander (*Coriandrum sativum* L.) days after sowing

Nitrogen (Kg/ha)	S_1 (20×15cm)	S_2 (30×15cm)	S_3 (40×15cm)	Mean N
45 days				
Control	4.50	4.53	4.53	4.52
25 kg	4.57	4.60	4.63	4.60
50 kg	4.67	4.73	4.77	4.72
75 kg	4.70	4.80	4.83	4.78
Mean S	4.61	4.67	4.69	
CD (p=0.05)	N= 0.10	S= NS	N × S= NS	
90 days				
Control	5.79	5.86	5.91	5.85
25 kg	6.01	6.07	6.13	6.07
50 kg	6.18	6.25	6.34	6.25
75 kg	6.44	6.50	6.63	6.52
Mean S	6.10	6.17	6.25	
CD (p=0.05)	N= 0.05	S= 0.04	N × S= NS	
Harvest				
Control	6.74	6.79	6.89	6.81
25 kg	7.00	7.15	7.29	7.15
50 kg	7.42	7.53	7.57	7.50
75 kg	7.68	7.72	7.97	7.79
Mean S	7.21	7.30	7.43	
CD (p=0.05)	N= 0.10	S= 0.08	N × S= NS	

larger canopy development associated with profuse branching had increased interception, absorption, and utilization of solar energy resulting in the formation of higher photosynthates and subsequently, higher dry matter per plant (Sharma et al 2016).

Days to 50% flowering and days to maturity: Minimum days to 50% flowering were in control with a spacing of 40×15 cm which is due to the application of nitrogen which affects the physiological and biochemical process in the plant, which thoroughly enhanced 50 % flowering in plants (Singh and Singh 2019). The minimum days to maturity were in control with a spacing of 20×15 cm (Table 4). The days taken to flowering are decided by C:N ratio. The plants are likely to flower earlier with a higher C:N ratio as higher levels of nitrogen boosts the vegetative growth and hinders the reproductive stage (Singh and Kaur 2022).

Number of umbellets per umbel: The number of umbellets per umbel was recorded maximum at 75 kg N ha^{-1} with a spacing of 40×15 cm and significantly lower values were observed in control (Table 5). Javiya (2017) also observed the maximum number of umbellets per umbel with 60 kg N ha^{-1}. Nitrogen is considered an important plant nutrient. In addition to its character in the building of proteins, nitrogen is an important part of chlorophyll which is the prime extractor of light energy needed for photosynthesis and is a component of certain organic compounds of physiological importance. Additionally, it might be due to the availability of more nutrients to the plant so that it could develop more branches, due to which the maximum number of umbels were produced on the plant (Patel et al 2013) Ghawade et al (2019) have observed maximum number of umbellets per umbel at 45×45 cm and stated that the vigorous vegetative growth and early flowering in the adequately spaced plant seem to be directed toward a suitable supply of metabolites resulting in the greater biomass production, which might lead to the maximum number of umbellets per umbel in coriander (Katar et al 2016, Singh and Kaur 2022).

Number of seeds per umbellet: The number of seeds per umbellet was maximum at 75 kg N ha^{-1}. Javiya (2017) also determined the maximum number of seeds per umbellet @ 60 kg N ha^{-1}. The number of seeds per umbellet was maximum with a spacing of 40×15 cm and minimum seeds per umbel was with a spacing of 20×15 cm (Table 5). It might be due to the vigorous vegetative growth and timely flowering due to the adequate spacing of plants which may lead to an optimum supply of metabolites that increase the biomass per plant and maximize the yield contributing characters in coriander (Ghawade et al 2019, Singh and Kaur 2022).

Number of seeds per umbel: The maximum number of seeds per umbel was at 75 kg N ha^{-1} (Table 5) and is due to better availability of nutrients in the root zone coupled with increased metabolic activity at the cellular levels which increases the number of seeds per umbel (Yadav 2017). The maximum number of seeds per umbel was recorded with a spacing of 40×15 cm and may be due to the vigorous vegetative growth and timely flowering in the adequate spacing of plants which may lead to an optimum supply of metabolites that increase the biomass per plant and get

Table 4. Interaction effect of nitrogen levels under different spacing on 50% flowering and maturity on coriander (*Coriandrum sativum* L.) days after sowing

Nitrogen (Kg/ha)	S_1 (20×15cm)	S_2 (30×15cm)	S_3 (40×15cm)	Mean N
Days to 50 % flowering				
Control	73.33	74.33	72.00	73.22
25 kg	74.00	73.33	74.00	73.78
50 kg	74.33	76.33	74.33	75.00
75 kg	77.33	73.67	76.33	75.78
Mean S	74.75	74.42	74.17	
CD (p=0.05)	N= NS	S= NS	N × S= NS	
Days to maturity				
Control	103.33	104.67	103.33	103.78
25 kg	103.67	104.00	104.67	104.11
50 kg	104.33	106.33	104.67	105.11
75 kg	106. 67	104.67	105.67	105.67
Mean S	104.50	104.92	104.58	
CD (p=0.05)	N= NS	S= NS	N × S= NS	

Table 5. Effect of nitrogen levels under different spacing on yield attributes on coriander (*Coriandrum sativum* L.)

Treatments	Umbellets per umbel	Umbel per plant	Seeds per umbellet	Seeds per umbel
N_0S_1	5.3	49.3	4.7	26.4
N_0S_2	5.4	56.2	5.0	29.0
N_0S_3	5.5	64.4	5.1	30.5
N_1S_1	5.7	69.4	5.2	32.9
N_1S_2	5.9	76.7	5.3	35.6
N_1S_3	6.1	77.3	5.4	39.3
N_2S_1	6.4	78.5	5.5	42.3
N_2S_2	6.7	85.0	5.8	45.7
N_2S_3	6.8	85.4	5.9	47.4
N_3S_1	6.6	82.2	5.7	43.5
N_3S_2	6.9	85.8	6.0	49.6
N_3S_3	7.1	86.8	6.1	53.3
CD (p=0.05)	NS	4.2	NS	NS

maximum yield contributing characters in coriander (Ghawade et al 2019).

Seed yield per plant: Maximum seed yield per plant was recorded at 75 kg N ha^{-1} (Table 5). It might be due to the higher absorption of N and P during seed formation that increased the seed yield per plant (Javiya 2017, Yadav 2017). Seed yield per plant was observed maximum with 40×15 cm spacing. This might be due to the availability of lavish space to the plant so that the plant canopy gets more opportunity to spreads resulting in more umbels per plant which ultimately increases the seed yield per plant (Katiyar et al 2014).

CONCLUSION

The study on the interactive effects of different nitrogen doses and spacing in coriander has provided valuable insights into the optimal conditions for growing this important herb. Both nitrogen dose and spacing have a significant impact on the growth, yield, and quality of coriander.

AUTHOR CONTRIBUTION

MB, RKG: conceptualization, methodology, investigation, writing original draft preparation. AK, CV: reviewing and editing. B, MK, AK: reviewing the final draft and editing. All authors contributed to the article and approved the submitted version.

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Life Form Spectrum of Zanübu Mountain Ecosystem of Phek District, Nagaland, India

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***Abstract*:** Study was carried out to understand the life forms and biological spectrum of plants in Zanübu mountain ecosystem of Phek district of Nagaland. A total of 118 plant species belonging to 60 families and 95 genera were recorded. The life forms in order of importance were phanerophytes chamaephytes cryptophytes, hemicryptophytes and therophytes with 79, 12, 11, 10 and 6 species. The dominant two groups i.e., phanerophytes and chamaephytes constituted 77.12 % of the total plants' life, and thus exhibited a "Phanero-chamaephytic" phytoclimate. The climate is ideal for sustaining the forest trees, which in turn influence many ecosystem processes. The study revealed that hemicryptophytes and cryptophytes showed an increasing trend towards high altitude while therophytes and chamaephytes showed a decreasing trend. This indicates that some anthropogenic activities are operating in the lower altitude.

Keywords: Life form, Biological spectrum, Phytoclimate, Zanübu mountain ecosystem, Nagaland

The study of plant life forms is essential, because it provides the basic structural composition of vegetation and describes vegetation structure of a region. Plants provide many ecosystem services, and thus obtaining the floristic data is imperative to determine the plant wealth of a region (Wagay et al 2015). The floristic list of any area leads to the proper identification of plant species and thereby helps in conservation in a scientific and systematic way (Manan et al 2022). A life-form is the sum of all the plants' adaptation to certain ecological conditions (Devi and Devi 2020). The system of Raunkiaer's (1934) is the most widely accepted system for the description and classification of plant life forms, and is based upon the principle of position and degree of protection of the buds during the adverse climatic conditions. It consists of five main classes: phanerophytes, chamaephytes, hemicrytophytes, cryptophytes and therophytes. Plants with a similar life-form are likely to exhibit similar responses on the dominant ecosystem processes (Pausas and Austin 2001). Hence, the understanding of life form is an important aspect in ecological studies and vegetation description. The biological spectrum is the percent representation of the number of species belonging to each life-form in a given flora (Gazal and Raina 2015), and is a mirror reflection of the phytoclimate and floristic composition of the site (Sharma and Sharma 2018). The occurrence of similar biological spectra in different regions indicates similar climatic conditions. Differences in the life-form distribution between the normal spectrum and a biological spectrum would point out which life-form characterizes the phytoclimate or the vegetation understudy (Reddy et al 2001). In northeast India, Devi et al (2014) reported "Phanero-therophytic" type of phytoclimate in hill forest of Manipur; Usharani et al (2015) reported "Phanero-chamaephytic" phytoclimate in the sacred grove of Manipur; Arila and Gupta (2016) reported "Phanero-therophytic" phytoclimate in lower elevation and "Phanero-cryptophytic" phytoclimate in higher elevation in Montane Forests of Senapati district of Manipur.

Study of floristic composition and life form is important to find out phytoclimate zones of a particular area (Sidanand and Kotresha 2012). Biological spectrum may be changed due to introduction of therophytes like annual weeds, biotic influences like grazing, deforestation and trampling, etc (Jadhav 2020). The biological spectrum may set the guidelines for eco-restoration and optimization of a community (Gazal and Raina 2015). The Zanübu Mountain is the highest mountain peak of Phek district, Nagaland. However, due to lack of investigation on the life forms and floristic composition, an attempt was made to study the life form and biological spectrum and floristic composition so as to compare the widely separated plant communities. This will also help in conservation of important plant species occurring in the area.

MATERIAL AND METHODS

Study area: The present study was conducted in Zanübu mountain ecosystem of Phek district, Nagaland. Mount Zanübu is the highest point at 2426 m above mean sea level. Two study sites were selected. Site I occurs at lower elevation (1600-2000m amsl) and the forests range from subtropical to montane wet temperate forest, and lies between N25^{0}39 712' to N25^0 38 530' latitude and E94^0 22 051' to E94^0 21 753' longitude. Site II occurs at higher elevation (2001-2426m amsl) consisting of montane wet temperate forest and lies between N25^0 40 420' to N25^{0}39 794' latitude and E94^0 20 608'to E94^0 21 980' longitude. Phek district has temperate to subtropical climate. It enjoys moderately warm summer with average temperature of 27^{0}C and 32^{0}C as maximum temperature. Winters are cold and the temperature drops to 0^{0}C in the coldest months of January and February. It receives average annual rainfall of 1527mm. The soils are acidic in reaction with pH ranging from 4.15 to 5.74 (Poji et al 2017). The upper forests of Zanübu mountain ecosystem are conserved by seven surrounding Chakhesang villages. Activities such as logging and hunting are banned in these forests, and fines are imposed on the defaulters. However, some disturbances like seasonal hunting and trekking activities are still observed. The lower elevation forests are prone to anthropogenic activities like logging, hunting, shifting cultivation, grazing, collection of wild edible resources and commercial plantations. Plant samples were collected from January 2020- March 2022 using random sampling method.

Sampling and analysis: To study the life form of the plant community, six quadrats each measuring 50mx50m were laid in each study site. Within each of these quadrats, 10 random quadrats, each measuring 10mx10m for trees, 5mx5m for shrubs and 1mx1m for herbs were laid. Quadrats for shrubs and herbs were nested within the quadrat for trees (trees >10cm dbh, and herbs less than 1 m height). So 60 quadrats each for trees, shrubs and herbs were laid in each study sites. Hence, altogether 120 quadrats each for trees, shrubs and herbs were laid. The specimens of all the species occurring within the sampling plot were collected and herbarium was prepared (Jain and Rao 1977) and deposited in the Department of Botany, Nagaland University. The specimens were identified with the help of floras (Kanjilal et al 1934, 36, 38, 40) and herbaria of the department of Botany, Nagaland University, besides consulting some taxonomic experts. The nature of perennating buds of plant species was observed and the life form classes were worked out according to the life-forms system of Raunkiaer (1934). The biological spectrum of the area was constructed by calculating the percentage distribution of these species in different life forms. The percentage life-form was calculated as follows and were then compared with the normal spectrum given by Raunkiaer (1934)

$$\text{Percent life form} = \frac{\text{Number of species in a given life form}}{\text{Total number of species of all life forms}} \times 100$$

RESULTS AND DISCUSSION

The present study recorded a total of 118 species belonging to 61 families and 95 genera. The plant species recorded were assigned different life form classes based on the Raunkiaer' s system of classification (Table 1). These include 3 pteridophytes and 115 angiosperms with 100 dicots and 15 monocots. In terms of habit, trees were the most dominant with 45 species, followed by herbs with 39 species, shrubs 16 species, shrub to small trees 8 species, climber 8 species and shrub to vine 2 species. The most dominant families were Lauraceae with 12 species, followed by Asteraceae, Rosaceae and Urticaceae with 6 species each, Araliaceae with 5 species and Euphorbiaceae and Fagaceae with 4 species each. The most dominant genera were *Lindera* with 5 species followed by *Lithocarpus, Litsea, Prunus* and *Elatostema* with 3 species each. The genus *Betula, Brassiopsis*, *Cinnamomum*, *Hedychium, Impatiens, Macaranga, Magnolia, Persicaria, Phoebe, Rubus* and *Zanthoxylum* consist of 2 species each, while the rest of the genera had 1 species each. Site I recorded a total of 70 species representing 39 families and 62 genera, while a total of 73 species belonging to 40 families and 63 genera were recorded from Site II. In Site I, families with maximum species were Urticaceae and Rosaceae, while that in Site II were Lauraceae, Fagaceae and Urticaceae.

In the biological spectrum, the percentage representation of life-forms recorded in the study area reveals that phanerophytes were the most abundant life-forms with 79 species constituting 66.95 % of the total flora, followed by Chamaephytes (12 species, 10.17%), Cryptophytes (11 species, 9.32%), Hemicryptophytes (10 species, 8.47%), and lastly Therophytes (6 species, 5.09%). The number and percentage of species belonging to each life-form category relative to the total number of species in each site is presented in Figs. 1 and 2. The dominant life forms in biological spectrum of a region indicate the phytoclimate of that region (Sharma et al 2014, Thakur 2015, Bhattacharjya and Sarma 2016, Nasir et al 2016, Al-Hawshabi et al 2017). The dominant two groups (phanerophytes and chamaephytes) constituted 77.12 % of the total plants' life, and thus exhibit a "Phanero-chamaephytic" phytoclimate. The climate is ideal for sustaining the forest trees. The dominance of phanerophytes helps to improve the micro-climate, control regeneration, establish herbaceous plants and maintain biodiversity, which are of vital importance in

Table 1. Plant species recorded and their life forms in Zanübu mountain ecosystem

Name of the species	Vascular plant	D/M	Family	Habit	Life form	Below 2000 m	Above 2000 m
Achyranthes aspera L.	A	D	Amaranthaceae	Herb	Th	+	+
Actinidia callosa Lindl.	A	D	Actinidiaceae	Shrub/Vine	Ph	-	+
Schefflera sp.	A	D	Araliaceae	Tree	Ph	+	+
Ageratina adenophora (spreng.) R. M. King & H. Rob.	A	D	Asteraceae	Herb	Ch	+	-
Ageratum conyzoides L.	A	D	Asteraceae	Herb	Th	+	-
Alnus nepalensis D.Don	A	D	Betulaceae	Tree	Ph	+	-
Anaphalis margaritacea (L.) Benth. & Hook.f.	A	D	Asteraceae	Herb	H	-	+
Arisaema consanguineum Schott	A	D	Araceae	Herb	Cr	+	-
Artemisia nilagirica (C.B. Clarke) Pamp.	A	D	Asteraceae	Herb	H	-	+
Asparagus racemosus Willd.	A	M	Asparagaceae	Herb	Cr	-	+
Athyrium sp.	P		Athyriaceae	Herb	Ch	+	-
Baliospermum calycinum Müll. Arg.	A	D	Euphorbiaceae	Shrub	Ph	-	+
Betula alnoides Buch.-Ham.ex D. Don	A	D	Betulaceae	Tree	Ph	+	+
Betula utilis D.Don	A	D	Betulaceae	Tree	Ph	-	+
Boehmeria macrophylla Hornem	A	D	Urticaceae	Shrub	Ch	+	+
Bidens pilosa L.	A	D	Asteraceae	Herb	Th	+	-
Brassaiopsis glomerulata (Blume) Regel	A	D	Araliaceae	Tree	Ph	+	-
Brassaiopsis hainla (Buch. - Ham.) Seem.	A	D	Araliaceae	Tree	Ph	+	+
Calanthe triplicata (Willemet) Ames	A	M	Orchidaceae	Herb	Cr	-	+
Campylendra wattii C.B. Clarke	A	M	Asparagaceae	Herb	H	-	+
Canarium sp.	A	D	Burseraceae	Tree	Ph	-	+
Carex baccans Nees	A	M	Cyperaceae	Herb	H	+	-
Celastrus sp.	A	D	Celastraceae	Shrub/ Vine	Ph	-	+
Cephalostachyum capitatum Munro	A	M	Poaceae	Shrub	Ph	+	+
Cinnamomum camphora (L.) J. Presl	A	D	Lauraceae	Tree	Ph	-	+
Cinnamomum verum J.S. Presl.	A	D	Lauraceae	Tree	Ph	-	+
Clematis sp.	A	D	Ranunculaceae	Climber	Ph	+	+
Commelina maculata Edgew.	A	D	Commelinaceae	Herb	Th	+	-
Cornus capitata Wall.	A	D	Cornaceae	Tree	Ph	-	+
Cyathea gigantea (Wall.ex Hook.) Holttum	P		Cyatheaceae	Tree	Ph	+	-
Cyperus rotundus L.	A	M	Cyperaceae	Herb	Cr	+	-
Cyphostemma auriculatum (Roxb.) P.Singh & B.V.Shetty	A	D	Vitaceae	Climber	Ph	+	-
Debregeasia longifolia (Burm.f.) Wedd.	A	D	Urticaceae	Shrub/ Small tree	Ph	+	-
Dichroa febrifuga Lour.	A	D	Hydrangeaceae	Shrub	Ph	-	+
Didymocarpus pulcher C.B.Clarke	A	D	Gesneriaceae	Herb	Cr	-	+
Diospyros sp.	A	D	Ebenaceae	Small tree/ Shrub	Ph	+	-
Disporum cantoniense (Lour.) Merr.	A	D	Colchicaceae	Herb	Cr	+	+
Dobinea vulgaris Buch.-Ham.ex D. Don	A	D	Anacardiaceae	Shrub	Ph	+	-
Drymaria cordata (L.) Willd. ex Schult.	A	D	Caryophyllaceae	Herb	Th	+	-
Elatostema acuminatum (Poir.) Brongn.	A	D	Urticaceae	Herb	Ch	+	+
Elatostema lineolatum Wight.	A	D	Urticaceae	Herb	Ch	+	+
Elatostema platyphyllum Wedd.	A	D	Urticaceae	Herb	Ch	+	+

Cont...

Table 1. Plant species recorded and their life forms in Zanübu mountain ecosystem

Name of the species	Vascular plant	D/M	Family	Habit	Life form	Below 2000 m	Above 2000 m
Engelhardia spicata Lesch. ex Blume	A	D	Juglandaceae	Tree	Ph	+	-
Eurya acuminata DC.	A	D	Theaceae	Shrub/ Tree	Ph	+	+
Exbucklandia populnea (R.Br. ex Griff.)R.W. Brown	A	D	Hamamelidaceae	Tree	Ph	-	+
Fagopyrum cymosum (Trevir.) Meisn.	A	D	Polygonaceae	Herb	Th	+	-
Hedera nepalensis K. Koch	A	D	Araliaceae	Climber	Ph	-	+
Hedychium densiflorum Wall.	A	M	Zingiberaceae	Herb	Cr	+	-
Hedychium spicatum Sm.	A	M	Zingiberaceae	Herb	Cr	-	+
Hovenia dulcis Thunb.	A	D	Rhamnaceae	Tree	Ph	+	-
Hydrocotyle javanica Thunb.	A	D	Apiaceae	Herb	H	-	+
Impatiens arguta Hook. f. & Thomson	A	D	Balsaminaceae	Herb	Ch	+	+
Impatiens pallida Nutt.	A	D	Balsaminaceae	Herb	Ch	+	+
Jasminum sp.	A	D	Oleaceae	Climber	Ph	-	+
Juglans regia L.	A	D	Juglandaceae	Tree	Ph	+	-
Leucosceptrum canum Sm.	A	D	Lamiaceae	Shrub	Ph	+	-
Lindera caudata (Nees) Hook.f.	A	D	Lauraceae	Shrub/ Small tree	Ph	-	+
Lindera pulcherrima (Nees) Benth	A	D	Lauraceae	Tree	Ph	-	+
Lindera supracostata Lecomte	A	D	Lauraceae	Shrub/ Small tree	Ph	-	+
Lindera sp. A	A	D	Lauraceae	Tree	Ph	+	+
Lindera sp. B	A	D	Lauraceae	Tree	Ph	-	+
Lithocarpus elegans (Blume) Hatus. ex Soepadmo	A	D	Fagaceae	Tree	Ph	-	+
Lithocarpus pachyphyllus (Kurz) Rehder	A	D	Fagaceae	Tree	Ph	-	+
Lithocarpus sp.	A	D	Fagaceae	Tree	Ph	-	+
Litsea cubeba (Lour.) Pers.	A	D	Lauraceae	Tree/Shrub	Ph	+	-
Litsea sp. A	A	D	Lauraceae	Tree	Ph	-	+
Litsea sp. B	A	D	Lauraceae	Tree	Ph	-	+
Lyonia ovalifolia (Wall.) Drude	A	D	Ericaceae	Tree	Ph	+	+
Macaranga indica Wight	A	D	Euphorbiaceae	Tree	Ph	+	-
Macaranga pustulata King ex Hook.f.	A	D	Euphorbiaceae	Tree	Ph	+	-
Macropanax dispermus (Blume) Kuntze	A	D	Araliaceae	Tree	Ph	+	-
Magnolia doltsopa (Buch. - Ham.ex DC.) Figlar	A	D	Magnoliaceae	Tree	Ph	-	+
Magnolia sp.	A	D	Magnoliaceae	Tree	Ph	-	+
Mahonia napaulensis DC.	A	D	Berberidaceae	Shrub	Ph	-	+
Malaxis sp.	A	M	Orchidaceae	Herb	Cr	-	+
Mallotus nepalensis Müll. Arg.	A	D	Euphorbiaceae	Tree	Ph	+	-
Melia azedarach L.	A	D	Meliaceae	Tree	Ph	+	-
Mimosa pudica L.	A	D	Fabaceae	Herb	H	+	-
Molineria capitulata (Lour.) Herb.	A	M	Hypoxidaceae	Herb	Cr	+	-
Musa sikkimensis Kurz	A	M	Musaceae	Herb	Ph	+	-
Neomicrocalamus prainii (Gamble) Keng f.	A	M	Poaceae	climber	Ph	+	+
Ophiopogon intermedius D. Don	A	M	Asparagaceae	Herb	H	-	+
*Oplismenus undulatifolius (*Ard.) Roem. & Schult	A	M	Poaceae	Herb	H	+	+
Osbeckia stellata Buch.-Ham.ex D.Don	A	D	Melastomataceae	Shrub	Ph	+	-

Cont...

Table 1. Plant species recorded and their life forms in Zanübu mountain ecosystem

Name of the species	Vascular plant	D/M	Family	Habit	Life form	Below 2000 m	Above 2000 m
Persicaria chinensis (L.) H. Gross	A	D	Polygonaceae	Herb	Ch	+	+
Persicria nepalensis (Meisn.) H. Gross	A	D	Polygonaceae	Herb	Ch	-	+
Phoebe hainesiana Brandis	A	D	Lauraceae	Tree	Ph	+	+
Phoebe sp.	A	D	Lauraceae	Tree	Ph	-	+
Phyllanthus tenellus Roxb.	A	D	Phyllanthaceae	Shrub	Ph	+	+
Pilea scripta (Buch. - Ham. ex D. Don) Wedd.	A	D	Urticaceae	Herb	Ch	+	-
Potentilla lineata Trevir.	A	D	Rosaceae	Herb	H	-	+
Prunus campanulata Maxim.	A	D	Rosaceae	Tree	Ph	+	+
Prunus cerasoides Buch.-Ham. ex D.Don	A	D	Rosaceae	Tree	Ph	+	-
Prunus nepalensis Ser. (Steud)	A	D	Rosaceae	Tree	Ph	+	-
Pteridium aquilinum (L.) Kuhn	P		Dennstaedtiaceae	Herb	Ch	+	+
Quercus lamellosa Sm.	A	D	Fagaceae	Tree	Ph	-	+
Rhododendron arboretum Sm.	A	D	Ericaceae	Tree	Ph	-	+
Rhus chinensis Mill.	A	D	Anacardiaceae	Shrub/ Small tree	Ph	+	-
Rubus ellipticus Smith	A	D	Rosaceae	Shrub	Ph	+	-
Rubus moluccanus L.	A	D	Rosaceae	Shrub	Ph	+	+
Sarcococca hookeriana Baill.	A	D	Buxaceae	Shrub	Ph	-	+
Saurauia napaulensis DC.	A	D	Actinidiaceae	Shrub	Ph	+	-
Schima wallichii (DC.) Korth	A	D	Theaceae	Tree	Ph	+	-
Senecio scandens Buch.-Ham.ex D. Don	A	D	Asteraceae	Climber	Ph	-	+
Smilax zeylanica L	A	M	Smilacaceae	Climber	Ph	+	-
Spondias pinnata (L.f.) Kurz	A	D	Anacardiaceae	Tree	Ph	+	-
Symplocos sp.	A	D	Symplocaceae	Tree	Ph	-	+
Syzygium cumini (L.) Skeels	A	D	Myrtaceae	Tree	Ph	+	-
Tetrastigma lanceolarium (Roxb.) Planch.	A	D	Vitaceae	Climber	Ph	+	-
Trema orientalis (L.) Blume	A	D	Cannabaceae	Tree	Ph	+	-
Turpinia sp.	A	D	Staphyleaceae	Tree	Ph	-	+
Valeriana jatamansi	A	D	Caprifoliaceae	Herb	Cr	-	+
Viburnum cylindricum Buch.- Ham.ex D.Don	A	D	Adoxaceae	Shrub	Ph	-	+
Viola pilosa Blume	A	D	Violaceae	Herb	H	-	+
Vitex quinata (Lour.) F.N. Williams	A	D	Lamiaceae	Shrub	Ph	+	-
Zanthoxylum armatum DC.	A	D	Rutaceae	Shrub	Ph	-	+
Zanthoxylum oxyphyllum Edgew.	A	D	Rutaceae	Shrub/ small tree	Ph	-	+
Zizyphus incurva Roxb.	A	D	Rhamnaceae	Tree	Ph	+	+

Ch- Chamaephyte; Cr- Cryptophyte; H- Hemicryptophyte; Ph- Phanerophyte; Th- Therophyte, A- Angiosperm, G- Gymnosperm, P- Pteridophyte, D- Dicot, M-Monocot

Table 2. Number of species recorded in the two sites and comparison of biological spectrum of Zanübu mountain range of Phek district, Nagaland, with Raunkiaer's normal spectrum

Life form classes	Species recorded		Life-form (%)		Raunkiaer's normal spectrum (%)
	Site I	Site II	Site I	Site II	
Phanerophytes	45	48	64.29	65.75	46
Chamaephyte	11	9	15.71	12.33	9
Hemicryptophyte	3	8	4.29	10.96	26
Cryptophyte	5	7	7.14	9.59	6
Therophyte	6	1	8.57	1.37	13

influencing ecosystem processes (Devi et al 2014, Arila and Gupta 2016). Jamir et al (2006) reported that rainfall appears to be the most important operative factor in the evolution of biological spectrum, because the montane humid forests of Meghalaya which receive annual rainfall of 1200mm represented 51% of phanerophytes. The present study area, receiving an average annual rainfall of 1527mm also comes under the category of montane wet temperate forest of Nagaland, and represents 66.95% of phanerophytes, thus revealing the dominance of phaenerophytic climate.

Altitude is the main factor influencing both biodiversity and vegetation structure (Arila and Gupta, 2016). This study indicates that the life-form pattern clearly changes along the altitudinal gradient. In the present study, hemicryptophytes and cryptophytes showed an increasing trend towards high altitude while therophytes and chamaephytes showed a decreasing trend. Hussain (2009) highlighted that in open physiognomies, hemicryptophytes prevail, whereas in dense ones phanerophytes is the best representation class. The Zanübu mountain ecosystem is surrounded by a number of villages, and the lower elevation forest is subjected to anthropogenic activities such as grazing, hunting, firewood collection, shifting cultivation and collection of wild edible plant resources, as the forest is a source of livelihood to the rural people. A comparison of biological spectrum of the study area with Raunkiaer's (1934) normal biological spectrum (Table 2) reveals that phanerophytes, chamaephytes, and cryptophytes constituted higher percentages (66.95%, 10.17% and 9.32%, respectively) than the Raunkiear's normal spectra, while hemicryptophytes (8.47%) and therophytes (5.09%), were comparatively smaller in percentage than the Raunkiaer's normal spectra (Table 2). In the present study, a good percentage of phanerophytes in both the study sites indicate a humid bioclimate and its predominance along the altitudinal gradient reflected a significant role of the tall trees with their dense close canopy in enhancing humidity in the atmosphere thereby providing excellent conditions for the luxuriant growth of various types of ferns, mushrooms, and various medicinal herbs. The higher percentage of chamaephytes reflects the performance of chamaephytes in affecting other associated species through their competitive ability, and hence, the site facing anthropogenic stress show majority of chamaephytes (Devi et al 2014). The higher percentage of cryptophytes than the Raunkiear's normal spectra reflects the performance of Cryptophytes in withstanding unfavourable conditions as they have underground perennating organs like rhizomes, bulbs etc. from which they draw their energy during these unfavourable conditions.

A similar biological spectrum of different areas shows similar climatic conditions (Manan et.al, 2022).The climate of a study area differs from subtropical; moist temperate to sub-alpine meadow type vegetation at different altitudes (Khan et al 2015 and 2016). The climate of Zanübu mountain range vary from temperate to subtropical climates and the dominant life forms revealed the phytoclimate to be “phanero-chamaephytic” type. Similar to our findings, Usharani et al (2015) reported “phanero-chamaephytic” type of phytoclimate in the Konthoujam Sacred Grove in Manipur, India. A sacred grove is a patch of vegetation which is left undisturbed because of its association with some deity.

CONCLUSION

Analysis of life forms gives a clear picture of the biological spectrum of the Zanübu mountain ecosystem and revealed the phytoclimate to be ”phanero chamaephytic“ type in both the two sites. The present study reveals that phanerophytes, chamaephytes, and cryptophytes constituted higher percentages than in Raunkiear's normal spectra, while hemicryptophytes and therophytes were comparatively smaller in percentage than in Raunkiaer's normal spectra. In the higher elevation site (Site II), the prevalence of “phanero-chamaephytic” type of phytoclimate, with hemicryptophytes and cryptophytes as the third and fourth dominant life form classes respectively, indicates the fairly undisturbed status and protection of the forest through community conservation efforts, inspite of the presence of some disturbances. In the lower elevation site (Site I), the prevalence of "phanero-chamaephytic" type of phytoclimate with therophytes as the third dominant life form class clearly indicates that some anthropogenic activities are operating in the lower altitude. This study can serve as baseline information for use by policymakers to develop conservation plans for the sustainable use of plant resources and to protect economically valuable flora by educating the native communities residing there.

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Species Richness and Diversity of Lepidoptera in an Agricultural Ecosystem of Bhabar Region in district Nainital, Uttarakhand

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***Abstract*:** Species richness, abundance, and species diversity of the insect order Lepidoptera was studied in an agricultural ecosystem of Bhabar region in Chhoi, district Nainital, Uttarakhand from March 2018 to February 2020. 838 individuals of Lepidopterans were collected, which belonged to 68 species of 12 families. Family Nymphalidae was the most dominant family with 19 species and 30.9% of total individuals, followed by Pieridae (14 species and 39.7% individuals), Lycaenidae (11 species and 12.7% individuals), Papilionidae (8 species and 9.3% individuals), Erabidae (6 species and 3.5% individuals), Hesperiidae (3 species and 1.6% individuals), Noctuidae (2 species and 3% individuals), Eupterotidae, Zygaenidae, Sphingidae, Crambidae, Geometridae (1 species and 1.5% individuals each). Significant correlation was observed between temperature and species richness, and abundance of individuals collected. The highest diversity of Lepidopterans was (H'=1.857), evenness (E=0.9806; highest value is 1), Margalef's species richness (d=2.457), and Dominance Index (D=0.358). Foraging activity of Lepidopterans as flower pollinators/visitors was also recorded.

***Keywords*:** Lepidoptera, Species richness, Abundance, Diversity Indices, Agricultural ecosystem, Bhabar region

Insects are the most dominating and diverse organisms on the earth, inhabit all habitat types and play major roles in the function and stability of terrestrial and aquatic ecosystems (Godfray 2002). They make up more than 50% of the known global biodiversity. Insects are important because of their diversity, role in ecosystems, human health, influence on agriculture, and natural resources (Losey et al 2006, Premalatha et al 2011). Slightly over one million of insect species have been described, of which five insect orders are the most abundant in their levels of species richness: Coleoptera, Lepidoptera, Hymenoptera, Diptera and the Hemiptera (Jach and Balke 2008). The order Lepidoptera with more than 150,000 species is the second largest and the most diverse order in the Class Insecta (Gullan and Cranston 2010) and are the most diverse group of organisms in most of the ecosystems, serving as important pollinators, environmental bio-indicators, and for making quantitative comparisons among insect fauna (Siregar et al 2016, Subedi and Subedi 2019). Lepidoptera are also known to be very sensitive to any changes in the environment, and are affected both by biotic and abiotic factors (Haber 2006).

Biodiversity studies on Lepidoptera have the advantages because of their high diversity, relatively easy to sample and identify, and are found in many habitats. Species richness provides an extremely useful measure of diversity when complete information of species in the community is available. Insect pollinators and flowering plants have mutual relationships and maintain healthy ecosystem (Atmowidi et al 2007). Many groups of insects belonging to the insect orders Hymenoptera, Diptera, Coleoptera, Lepidoptera, Thysanoptera, Hemiptera and Neuroptera are of prime significance in the pollination of different agricultural, horticultural, and medicinal herbal crops (Bhowmik et al 2014, Subedi and Subedi 2019). A total of 1504 lepidopteran species have been reported from different habitats in the Indian subcontinent (Tiple 2011). There are reports on species richness, diversity and distribution of Lepidoptera in different habitats (Arya et al 2014, Roy et al 2014, Garia et al 2016, Thiruvengadam et al 2021), but no such reports are available from agricultural ecosystem of Bhabar region in Uttarakhand. The objective of the present study was to estimate the species richness, abundance, species diversity, and foraging activity of Lepidoptera as pollinators in the agricultural ecosystem of Bhabar region in Uttarakhand.

MATERIAL AND METHODS

Geographically, village Chhoi is located in the sub-tropical zone at 29^0 58' N latitude and 79^0 60' E longitudes at an altitude of 348 m in the Bhabar region of Uttarakhand. The study area has sub-humid tropical climate and is situated in the foothills of central Himalayas. The climatic data indicates hot dry summer and cold winter. The maximum temperature reaches up to 39 °C (May) in summer, and minimum 8.0 °C (January) in winter. The maximum humidity ranged from 23% (May) to 78% (August). The average rainfall was 1734 mm and 75.8% of rainfall occurred in the rainy season. On this basis, the year can be divided in into three seasons, namely rainy (July to October), winter (November to February) and summer (March to June). Three crops are grown in a year: July to October (Paddy/Soybean), November to April (wheat/mustard) and seasonal vegetables (May-June).The agricultural fields are in the shallow layers of the soil (5 cm). The agro-ecosystems are highly productive, resources rich (water and nitrogen input from irrigation and livestock) and experience a fair amount of disturbance due to anthropogenic activities throughout the growing season.

Sampling of insects was conducted at an interval of 30 days from March, 2018 to February, 2020. The insects were collected by "Sweep Sampling Method" (Gadagkar et al 1990) and hand picking. The net sweeps were used to collect the insects The nets used in sweeping were made of thick cotton cloth with a diameter of 30 cm at mouth and a bag length of 60 cm. A randomly selected area of each study sites was divided into a quadrate of 10x10 m. Hand picking method was used for larger, ground living insects and insects living under the stones. Collected insects were identified with the help of keys and through the available literature. Insects were then separated into different orders and families and to the species level. The representative species were preserved in the laboratory. The species which could not be identified in the laboratory were sent to the Forest Research Institute, Dehradun for identification. The collected insect species were identified and placed into five trophic levels.

Shannon's diversity index or Shannon-Wiener diversity (H') (1963) was calculated as follows:

(A) Species Diversity: $$H'(S) = -\sum_{i=1}^{s} pi \log pi$$

(B) Seasonal Diversity: $$H'(P) = -\sum_{i=1}^{s} qj \log qj$$

Where, Pi= ni/N and qj= nj/N, ni = Number of individual of a species at a time I, nj = Number of individual present in a season j. N = Size of whole community, ∑ = Number of species/ Number of seasons. S = Total number of species, P = Number of seasons

(C) Evenness (Buzas and Gibson's Evenness) E2:

$$E2 = e^{H/S}$$

Where, S is the number of taxa and H is the Shannon Index

(D) Margalef's Species Richness Index (d):

Species richness was calculated using Margalef's Index (1970)

Margalef's Index (d) = (S-1)/ ln N

Where, S = total number of species, N = total number of individuals in sample, ln = natural logarithm

(E) Dominance Index (D):

$$C = \sum (ni/N)^2$$

Where, ni = Importance value for each species, N = Total of Importance values

RESULTS AND DISCUSSION

Species richness and abundance: A total of 838 individuals were collected from the study site. The pooled-up data of two years showed that lepidopteran fauna comprised of 68 species belonging to 12 families (Table 1). Family Nymphalidae was the most abundance with 19 species and a relative abundance of 27.9%, followed by Pieridae, Lycaenidae, Papilionidae, Erabidae, Hesperiidae, Noctuidae and Eupterotidae, Zygaenidae, Sphingidae, Crambidae, Geometridae (Table 2). In terms of number of individuals collected, family Pieridae was the most dominant with 333 individuals with a relative abundance of 39.7%, followed by Nymphalidae, Lycaenidae, Papilionidae, Erabidae, Hesperiidae, Noctuidae, Zygaenidae, Sphingidae, Crambidae and Eupterotidae and Geometridae (Table 2). Families Noctuidae, Zygaenidae, Sphingidae, Crambidae, Geometridae and Eupterotidae were considered as "minor constituents" because of their smaller number of species and abundance of individuals.

Maximum number of species and individuals were collected in the easily spring, summer and rainy seasons. The highest relative abundance (17.9%) was in July followed by October (14.9%), while it was least in February (1.4%). Relatively, *P. lemonias* was the dominant species (6.32%) followed by *P. brassicae* (5.37%) (Table 1). Strong correlation was observed between minimum temperature and species richness (r=0.828), maximum temperature and species richness (r=0.824), but there was a weak correlation between rainfall and species richness (r=0.486). Similarly, strong correlation was observed between minimum temperature and abundance of individuals (r=0.717), maximum temperature and abundance of individuals (r=0.653), but a weak correlation between rainfall and abundance of individuals (r=0.572). Less number of insects was recorded during winter season (November to February) which was due to foggy weather and harsh environmental conditions. The observations are similar to other reported studies (Regniere et al 2012, Nadia et al 2015, Ghani and Maalik 2019). It can thus be concluded that species richness and abundance of individuals is affected by average temperature of the study area.

Diversity indices: Species diversity (H') varied from 1.055 to 1.94 (Table 3). Maximum species diversity (H'=1.94) was recorded in June and minimum (H'=1.055) in November.Buza's Evenness (E) which takes into account the

Table 1. Species richness, number of individuals and relative abundance of Lepidopterans collected in the study site

Taxonomic composition	No. of individual	Relative abundance (%)
Family: Pieridae		
ieris brassicae Linnaeus	45	5.37
P. canidia indica (Sparrman)	25	2.98
Pontia daplidice Linnaeus	20	2.39
Eurema brigitta Cramer	41	4.89
Anapheis aurota Fabricius	19	2.27
Gonepteryx rhamni nepalensis Doubleday	7	0.84
Aporia agathon (Gray)	18	2.15
Pareronia valeria Cramer	25	2.98
Colias electo fieldi Menetries	18	2.15
Catopsilia pyranthe Linnaeus	36	4.30
C. pomona Fabricius	23	2.74
Belenois aurota Fabricius	21	2.51
Cepora nerissa phryne Fabricius	20	2.39
Leptosia nina (Fabricius)	15	1.79
Family: Nymphalidae		
Kallima inachus (Boisduval)	2	0.24
Vanessa indica Herbst	13	1.55
Symbrenthia hippoclus Cramer	18	2.15
Aglais cashmiriensis Kollar	25	2.98
Cynthia cardui Linnaeus	11	1.31
Precis iphita iphita Cramer	14	1.67
Sephisa dichroa (Kollar)	14	1.67
Precis lemonias lemonias Linnaeus	53	6.32
P. almana (Linnaeus)	20	2.39
P. orythia Linnaeus	7	0.84
Neptis sankara Kollar	13	1.55
Euthalia patala Kollar	5	0.60
Symphaedra nais (Forster)	6	0.72
Hypolimnas bolina Linnaeus	3	0.36
Phalanta phalantha (Drury)	11	1.31
Ariadne merione (Cramer)	4	0.48
Ypthima sp.	13	1.55
Danaus chryssippus (Linnaeus)	24	2.86
Euploea core (Cramer)	3	0.36
Family: Lycaenidae		
Heliophorus androcles Doubleday & Hewitson	2	0.24
H. sena Kollar	5	0.60
Talicada nyseus (Guerin-Meneville)	15	1.79
Leptotes plinius (Fabricius)	7	0.84

Cont...

Table 1 Cont...

Taxonomic composition	No. of individual	Relative abundance (%)
Neopithecops zalmora Butler	6	0.72
Zemeros flegyas Cramer	6	0.72
Zizeeria sp.	45	5.37
Catochrysops strabo Fabricius	7	0.84
Hypolycaena erylus Godart	6	0.72
Arhopala amantes Hewitson	5	0.60
Acytolepis sp.	2	0.24
Family: Papilionidae		
Atrophaneura aristolochioae Fabricius	12	1.43
Papilio polytes Linnaeus	19	2.27
Graphium doson axionides (Page & Treadway)	1	0.12
Papilio romulus Linnaeus	21	2.51
P. cyrus Linnaeus	9	1.07
P. demoleus Linnaeus	9	1.07
P. stichius Linnaeus	6	0.72
P. clytia clytia Linnaeus	1	0.12
Family: Hesperiidae		
Telicota sp.	2	0.24
Parnara guttata Bremer & Grey	9	1.07
Polytremis eltola Hewitson	2	0.24
Family: Erabidae		
Amata sp.	6	0.72
Eressa confinis (Walker)	1	0.12
Erebus sp.	1	0.12
Lithosiini sp.	2	0.24
Cyana coccinea Moore	8	0.95
Ceryx imaon Cramer	11	1.31
Family: Noctuidae		
Calpe ophideroides Guen.	5	0.60
Episteme adulatrix Kollar	2	0.24
Family: Eupterotidae		
Eupterote sp.	1	0.12
Family: Zygaenidae		
Campylotes histrionicus Westwood	6	0.72
Family: Sphingidae		
Daphnis nerii (Linnaeus)	3	0.36
Family: Crambidae		
Glyphodes orbiferalis Hampson	2	0.24
Family: Geometridae		
Anonychia grisea Warren	1	0.12
Total	838	100.0

distribution of species and their numbers across gradients has returned high values (0.9806; highest value is 1) indicating that no species was dominant in terms of abundance. Margalef's Richness Index was 2.457 indicating high species richness in the study area. Dominance Index (D) varied from 0.1887 to 0.36, and these values are reciprocal to evenness indices and have been observed in the present study also.

Diversity of the order Lepidoptera fluctuates with season. They are abundant for only a few months and are absent or rare during other months of the year. Similar observations have also been in the present as Lepidopterans were recorded less in abundance during winter season because of cold climatic conditions.The results obtained for various Diversity Indices in the present study indicate that values obtained are comparable to other reported values for Lepidoptera in different agro-ecosystems (Arya et al 2014, Usha and John 2015, Garia et al 2016, Rabeih 2018).

Foraging activity of Lepidoptera: The foraging activity of the Lepidopterans showed that the insects were less active in the morning but showed maximum activity during the afternoon. All 68 species of Lepidopterans collected were the most diverse pollinators in the agricultural ecosystem studied. Their large body size helps in sticking pollens to their legs and proboscis when they visit flowers for nectar. This ensures effective transfer of pollens when they visit another

Table 2. Total collected species, individuals of each family and its relative abundance

Family	Species		Individuals		H value
	Number	Relative abundance (%)	Number	Relative abundance (%)	
Nymphalidae	19	27.9	259	30.9	2.651
Pieridae	14	20.6	333	39.7	2.554
Lycaenidae	11	16.2	106	12.7	1.925
Papilionidae	8	11.7	78	9.3	1.793
Erabidae	6	8.8	29	3.5	1.466
Hesperiidae	3	4.4	13	1.6	0.831
Noctuidae	2	3.0	7	0.8	0.598
Eupterotidae	1	1.5	1	0.1	0
Zygaenidae	1	1.5	6	0.7	0
Sphingidae	1	1.5	3	0.4	0
Crambidae	1	1.5	2	0.2	0
Geometridae	1	1.5	1	0.1	0
Total	68	100.0	838	100.0	

Table 3. Diversity indices of Lepidoptera collected in Chhoi during March 2018 to February, 2020

Months	Species richness (S)	Abundance (N)	Relative abundance (%)	Shannon index (H')	Evenness (E)	Margalef's Index (d)	Dominance Index (D)
March	35	75	8.9	1.619	0.7212	1.688	0.2343
April	37	95	11.3	1.857	0.7114	2.216	0.1965
May	37	85	10.1	1.477	0.7296	1.385	0.2754
June	34	65	7.8	1.940	0.6957	2.457	0.1887
July	46	150	17.9	1.716	0.6956	1.828	0.2278
August	37	115	13.7	1.652	0.7451	1.662	0.2316
September	36	65	7.8	1.640	0.7365	1.674	0.2392
October	38	125	14.9	1.799	0.7556	1.924	0.1981
November	10	20	2.4	1.055	0.9572	0.869	0.360
December	9	16	2,0	1.061	0.9629	0.910	0.358
January	7	15	1.8	1.079	0.9806	1.028	0.347
February	6	12	1.4	1.099	1	1.116	0.333
Total		838	100.0				

flower thus making Lepidopterans very effective pollinators of crops. Similar observations are documented for Lepidopterans as pollinators of crops (Duara and Kalita 2013, Rader et al 2016, Das et al 2018).

CONCLUSIONS

A total of 838 individuals belonging to 68 species of 12 families were recorded in the agricultural ecosystem. The suitable ecological conditions and climatic factors such as temperature increase the insect's abundance in early summer and rainy seasons. Biodiversity indices showed relatively diversity values of Lepidoptera. The decline in diversity of pollinators could result in serious threat to crop pollination by reducing the crop yield. Hence, conservation of pollinator species by employing effective crop management techniques is encouraged for higher production of crops.

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Biology and Life-Fecundity Table of Invasive Fall Armyworm, *Spodoptera Frugiperda* (J.E. Smith) on Maize and Sorghum

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Abstract: The present study was undertaken to assess the biology and life- fecundity tables of *Spodoptera frugiperda* on maize and sorghum under laboratory condition. Lowest total life cycle duration of male was noticed on maize (27.61 days) and highest on sorghum (31.31 days). Similarly, minimum duration of life cycle of female *S. frugiperda* was (29.78 days) recorded on maize followed by sorghum (32.52 days). The survival of immature stages (l_x) to the extent of 0.77 and 0.74, per individual within a pivotal age of 22 and 27 days, the net reproductive rate (R_o) was 163.50 and 35.85, females per generation, the mean length of generation time (T) is 27.13, 32.45, days, innate capacity for increase in numbers (r_m) was 0.188 and 0.110 females per female per day and finite rate of increase in numbers (λ) to the extent of 1.20 and 1.12 females per female, on maize on sorghum respectively.The stable age-distribution of the population of *S. frugiperda* reared maize in egg, larval, pupal and adult stages contributed to the extent of 23.24, 63.61, 9.12 and 4.03 per cent, respectively. In sorghum, stable age-distributions were 23.16, 67.50, 7.50 and 1.84 per cent in egg, larval, pupal and adult, respectively.

Keywords: *Spodoptera frugiperda*, Maize, Sorghum, Fall armyworm, Biology, Life- fecundity table

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a highly migratory, dreaded and polyphagous herbivore native to tropical and subtropical America (Luginbill 1928 and Sparks 1979) spread all over the globe and assumed the position of level A1 threat. Short development cycle (Sharanabasappa et al 2018), wide host range (EPPO 2019), high prolificacy and high dispersal ability (Westbrook et al 2016) make it potentially dangerous insect-pest of subsistence and cash crops in large parts of the world. *S. frugiperda* being a polyphagous, gregarious and destructive pest attacks 353 plant species from 76 families principally Poaceae (106), Asteraceae (31) and Fabaceae (31) (Montezano et al 2018). *S. frugiperda* is documented under a variety of common names throughout the area it invades. The first common name on record given to it by Smith and Abbot (1797) is corn-bud-worm-moth. Other names are fall armyworm, grass caterpillar, southern army worm, southern grass worm, army worm, Daggy's corn worm, wheat cutworm, alfalfa worm, bud worm, overflow worm, buck worm, corn earworm, rice caterpillars, locust (Luginbill 1928). Besides America, the presence of *S. frugiperda* was first reported in Central and Western Africa in early 2016 (Goergen et al 2016) and later in most of sub-Saharan Africa (Day et al 2017). It has been officially confirmed in over 44 countries in sub-Saharan Africa (Prasanna 2018). In India the invasion of *S. frugiperda* was reported first in May 2018 on maize from Shivamogga, Karnataka (Sharanabasappa et al 2018). Recently most of countries in Asia including India, Bangladesh, China, Indonesia, Myanmar, Nepal, Sri Lanka, Taiwan and Vietnam reported severe infestation of FAW (Anonymous 2019). The invasion of fall armyworm in a country like India created challenging situation for the farmers, scientists and policy makers involved in achieving the goal of food security.

The basic studies of *S. frugiperda* on different food sources are important for addressing the effect of the nutritional composition on biology and life fecundity. The development and reproduction of the *S. frugiperda* is not only related to the external temperature and humidity, but also affected by light, nutrition and other factors (Baloch et al 2020). In fact, the quantity and quality of food in the larval phase greatly influence the adult activity of pest (Barros et al 2010). The life fecundity study is a potent instrument for investigating and understanding the effect of host plants on the growth, survival, reproduction and intrinsic rate of increase of insect populations. The life fecundity study is fundamental for the analysis of population ecology which provides a complete description of the survivorship, development, stage differentiation and reproduction of a population as well as basic population growth parameters. Hence the current research work was planned on the same line of basic research on *S. frugiperda*.

MATERIAL AND METHODS

The studies on the biology and life-fecundity tables of *S. frugiperdaon maize and sorghum* were carried under laboratory at constant temperature and humidity. Studies were conducted on two major cereal hosts i.e. maize (*Zea mays* L.) variety Narendra (M909) and sorghum (*Sorghum bicolor* (L.) Moench) variety Parbhani Shakti (ICSR 14001). These cereal host plants were grown following recommended package of practices as per V.N.M.K.V., Parbhani (Anonymous 2016), except plant protection; on the Research Farm of Department of Agricultural Entomology, College of Agriculture, Latur, during *kharif* 2019.The study of biology and life-fecundity tables of *S. frugiperda* reared on maize and sorghum were constructed by studying 100 eggs in a group of 20 per replication. The eggs were glued with the help of a soft wet camel hair brush on white tissue paper and kept in petri plate in order to facilitate observations on egg hatching. All the larvae soon after hatching were reared individually on fresh leaves, tender stem, and whorls of respective host plants. Fresh food was provided daily. The observations on the larval duration, pupation (%), growth index, pupal duration, total development period (egg to adult emergence), adult emergence (%), adult longevity and total life-cycle duration were recorded on respective host plants. The adults that emerged on the same day were sexed and one male and one female were paired together for copulation and egg laying in an oviposition cage. A cotton swab dipped in 50 % honey solution was provided as a food to the adults. The number of eggs laid by each female on host leaves in cage were counted daily till the death of the female moth. The observations on initiation of oviposition, last oviposition and death of female were recorded. From this, pre-oviposition, oviposition and post-oviposition periods were worked out on respective host plants. The observations were made daily on hatching, larval and pupal development, successful adult emergence, fecundity and age-specific mortality in eggs, larvae, pupa and adults. The total number of adults emerged on a particular day were transferred to a separate cage in the ratio of 3 : 1 (male : female) for determining the age-specific fecundity. According to Southwood (1968), the number of female births (mx) was calculated by dividing the number of eggs laid per female by two considering the sex ratio of 1:1.

The life-fecundity tables under laboratory conditions were constructed by using the following column headings proposed by Birch (1948), elaborated by Howe (1953) and Atwal and Bains (1974).

x = Pivotal age in days

l_x = Survival of females at age 'x'

m_x = Age schedule for female births at age 'x'

The value of 'x', 'l_x' and 'm_x' was calculated from the data on life-tables.

Net reproductive rate: The sum of products '$l_x m_x$is the net reproductive rate represented by R_o (Lotka 1925). The net reproductive rate in each generation was measured in terms of females multiplied per generation was calculated by the following formula.

$$R_o = \Sigma\, l_x m_x$$

Mean generation time: The precise value of cohort generation time (T_c) is the mean age of mothers in a cohort at the birth of female offsprings. It was calculated as follows.

$$T_c = \frac{\Sigma\, l_x\, m_x\, X}{R_o}$$

Innate capacity for increase in numbers: The numbers of individuals survived and mean number of female offspring's produced at each age interval were recorded and the arbitrary value of innate capacity for increase in number $r_c$was calculated by using formula given by Loughlin (1965).

$$r_c = \frac{\mathrm{Log}_e\, R_o}{T_c}$$

The intrinsic rate of increase (r_m)was then calculated from the value of arbitrary 'r_m' by taking three trial values arbitrarily selected on either side of it differing in second decimal place by interpolation with formula given by Birch (1948) and Watson (1964).

$$\Sigma\, e^{7\text{-}rmx} l_x m_x = 1096.6$$

Table was then constructed with column 'X' and '$l_x m_x$' for each trial 'r_m'. The three trial values of $\Sigma\, e^{7\text{-}rmx} l_x\, m_x$were then plotted on the horizontal axis against their respective arbitrary 'r_m' on the vertical axis. The points were joined to give a line which intersected a vertical line drawn from the desired values of $\Sigma\, e^{7\text{-}rmx} l_x\, m_x$= 1096.6. The point of intersection gave the value of true 'r_m' accurate to three or four decimal places. The precise generation time (T) was calculated from the equation

$$T = \frac{\mathrm{Log}_e\, R_o}{r_m}$$

Finite rate of natural increase: The finite rate of natural increase (λ) i.e. females per female per day were calculated as: λ= anti $\log_e r_m$

Stable age-distribution: The stable age- distribution was worked out with the knowledge of 'rm' and the age-specific mortality of the immature as well as matures stages. The l_x(life-table age-distribution) was calculated from the 'l_x' table with the formula as follows:

$$l_x = \frac{l_x + (l_x+1)}{2}$$

The l_x was multiplied with $e^{-rm\ (x+1)}$and the percentage distribution of each pivotal age (x) was worked out. By putting together, the percentage under each pivotal age for respective stages *viz.,* egg, larva, pupa and adult, the expected percentage distribution of each stage in a stable age-distribution was calculated.

RESULTS AND DISCUSSION

The reproductive development of *S. frugiperda* on maize and sorghum revealed significantly highest fecundity 436.44 eggs per female on maize followed by sorghum (106.44 eggs/female) (Table 1). The results of present investigation agree with findings of Maruthadurai and Ramesh (2020) evidenced that fecundity of *S. frugiperda* was 1125.40 eggs per femaleon fodder maize. Hutasoit et al (2020) and Sharanabasappa et al (2018) observed average fecundity was 1662 and 1064.80 eggs per female on maize and sorghum, respectively. The mean incubation period varied significantly and minimum (2.00 days) on maize followed by sorghum (2.26 days). Guo et al (2020) showed that the egg period of *S. frugiperda* was 2 days on maize, potato and tobacco, Maruthadurai and Ramesh (2020) exhibited the egg period of 2.20 on fodder maize. The per cent egg hatchability was significantly highest to the extent of 94 %, which was observed on maize followed by sorghum 89 %. Montezano et al (2019) observed that the egg hatchability of *S. frugiperda*was 97.40 % on an artificial diet. Sharanabasappa et al (2018) showed that the egg hatchability of *S. frugiperda* wason average 96.60 % on maize.

Table 1. Biology and reproductive parameters of *S. frugiperda* on maize and sorghum

Parameters	Host plants	
	Maize (Mean± SD)	Sorghum (Mean± SD)
Fecundity (no/female)	436.44±22.44	106.44±11.18
Incubation period (days)	2±0.33	2.26±0.21
Egg hatchability (%)	94±1.05	89±1.82
Larval period (days)	12.58±0.75	15.93±0.94
Instar period (days)		
I	2.46±0.06	3.17±0.05
II	2.05±0.03	2.31±0.03
III	2.01±0.04	2.46±0.02
IV	2.00±0.03	2.62±0.02
V	2.02±0.03	2.69±0.02
VI	2.04±0.02	2.68±0.03
Pupation (%)	88±0.84	91±1.17
Growth ratio (days)	6.99±0.26	5.71±0.22
Pupal period (days)	6.74±0.44	7.99±0.24
Total developmental period (days)	21.32±0.07	26.18±0.05
Adult emergence (%)	92±0.49	91±0.69
Pre-oviposition period (days)	4.22±0.17	3.80±0.29
Oviposition period (days)	1.88±0.04	1.14±0.05
Post-oviposition period (days)	2.36±0.02	1.40±0.04
Adult longevity (days)		
Male	6.29±0.09	5.13±0.07
Female	8.46±0.03	6.34±0.03
Total life cycle duration (days)		
Male	27.61±0.60	31.31±0.77
Female	29.78±0.66	32.52±0.44
Male: Female ratio	1:1.20	1:1.31

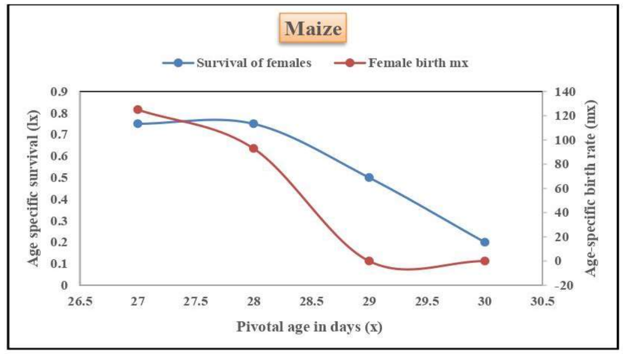
Mean±SD (n=100/host); SD - Standard deviation

The total larval duration of *S. frugiperda*was significantly shortest on maize (12.58 days) followed by sorghum (15.93 days). Plessis et al (2020) determined that mean developmental period of *S. frugiperda* larvae on sweet corn was 34.39, 20.58, 14.86, 11.38 and 10.45 days at 18, 22, 26, 30 and 32 ± 1°C, respectively. Maruthadurai and Ramesh (2020) observed larval period of 13.80 days on fodder maize. The per cent pupation of was significantly higher on sorghum (91 %) followed by maize (88 %). Barros et al (2010) observed that the percent pupation of *S. frugiperda* was 16.9, 33.8, 18.0 and 32.5 % on cotton, millet, corn and soybean, respectively. The mean pupal duration was significantly minimum on maize (6.74 days) followed by sorghum (7.99 days). Significantly highest growth index was in larvae fed on maize (6.99) followed by sorghum (5.71). This indicates that the growth index of *S. frugiperda* minimized on sorghum and maximized on maize. Kalyanet al (2020) also concluded that the mean pupal period of *S. frugiperda* was 8.96 days on maize. Hutasoit et al (2020) also documented that the pupal period of *S. frugiperda* was 6.31 and 6.76 days in male and female, respectively on maize.

The total developmental period was significantly lower on maize (21.32 days) followed by sorghum (26.18 days). Montezano et al (2019) and Sharanabasappa et al (2018) observed that total developmental period of *S. frugiperda* were 27.09 and 28.9 days on artificial diet and on maize, respectively. The per cent adult emergence of was significantly highest was on maize (92 %) followed by sorghum (91 %). Barros et al (2010) exhibited that the per cent adult emergence of *S. frugiperda* was 71.0 on corn. The mean pre-oviposition period, mean oviposition period and mean post oviposition period was significantly lowest on sorghum (3.80, 1.14 and 1.40 days, respectively) followed by maize (4.22, 1.88 and 2.36 days, respectively). Sharanabasappa et al (2018) also observed d the pre-oviposition period, oviposition period and post oviposition period of *S. frugiperda* was 3.47, 2.80 and 4.30 days on maize, respectively. The mean adult longevity of male *S. frugiperda* was 6.29 days on maize followed by sorghum (5.13 days). The adult longevity of female *S. frugiperda* was 8.46 days on maize and 6.34 days on sorghum. Adult females lived longer than males irrespective of host plants. Lekha et al (2020) concluded that the adult male and female longevity on different diets ranged from 4.50-8.00 and 7.00-10.33 days, respectively. Kalyanet al (2020) stated that the longevity of adult male and female *S. frugiperda* on maize was 10.67 and 13.00 days, respectively. The significantly lowest total life cycle of male *S. frugiperda* was on maize (27.61 days) followed by sorghum (31.31 days). The minimum total life cycle duration of female *S. frugiperda* was on maize (29.78 days) followed by sorghum (32.52 days). This indicates that the total life cycle of male and female *S. frugiperda* shortened on maize and slightly extended on sorghum and females lived longer than males irrespective of host plants.

Life-fecundity tables of *Spodoptera frugiperda*(J.E. Smith) on maize and sorghum: The *S. frugiperda* survived to the extent of 94, 83 and 77 per cent in egg, larval and pupal stages, respectively in a cohort of 100 eggs when reared on maize (Table 2). There was successful emergence of 35 and 42 per cent male and female adults. The male to female sex ratio was 1:1.20. On sorghum survival of *S. frugiperda* was 89, 81 and 74 per cent in respect of egg, larval and pupal stages, respectively in a cohort of 100 eggs when reared on sorghum. During rearing from egg to adult emergence, 32 per cent male and 42 per cent female adults were emerged successfully. The male to female sex ratio was 1:1.31 (Table 2).

In maize the survival of immature stages (l_x) of *S. frugiperda* was 0.77 (based on one individual) per individual within a pivotal age of 22 days on maize plant (Fig. 3). The pre-oviposition period ranged from 23 to 26 days of pivotal



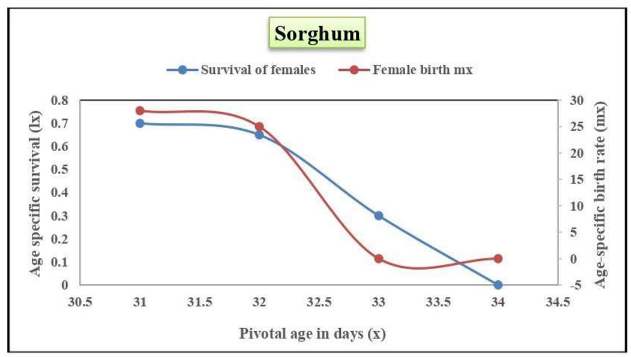


Fig. 2. Daily age- specific survival (l_x) and birth rate (m_x) of *S. frugiperda* on maize and sorghum

Table 2. Survival of life-stages of *S. frugiperda* on maize and sorghum

Number of eggs observed	Number of survived life-stages				
	Eggs (0-2 days duration)	Larvae (3- 15 days duration)	Pupae (16-22 days duration)	Adults	
				Male	Female
Survival of life-stages of *S. frugiperda* on maize					
20	20	15	15	6	9
20	18	17	15	7	8
20	20	16	16	9	7
20	18	18	15	7	8
20	18	17	16	6	10
100	94	83	77	35	42
Survival of life-stages of *S. frugiperda* on sorghum					
20	17	17	16	7	9
20	20	16	14	5	9
20	18	15	13	6	7
20	16	18	16	7	9
20	18	15	15	7	8
100	89	81	74	32	42

age. The numbers of eggs laid per female per day were divided by two to get the number of female births (m_x). The female contributed the highest eggs (m_x=125.00) on the first day of oviposition at 27th day of pivotal age. Thereafter female births decreased. The first female mortality was observed on 29 day of pivotal age (l_x= 0.50) after that female mortality was increased slowly. The female laid eggs for 2 days. The net reproductive rate (R_o) representing the total female births per female per generation and it was females per female per generation in *S. frugiperda* population on maize. were 163.50. Thus, the population of *S. frugiperda* would be able to multiply at the rate of 163.50 females per female per generation on maize. In sorghum, the survival of immature stages (l_x) was 0.74 (based on one individual) per individual within a pivotal age of 27th day on sorghum. The pre-oviposition period ranged from 28th to 30st days of pivotal age. The highest female birth (m_x=28.00) was observed on 1st day of oviposition at 31st day of pivotal age and thereafter female births decreased (Fig. 3). The first female mortality was observed on 32nd day (l_x=0.65) of pivotal age and increased gradually thereafter. The female oviposited for 2 days. The net reproductive rate (R_o) representing the total females per female per generation were 35.85. Thus, the population of *S. frugiperda* was able to multiply 35.85 times per generation on sorghum.

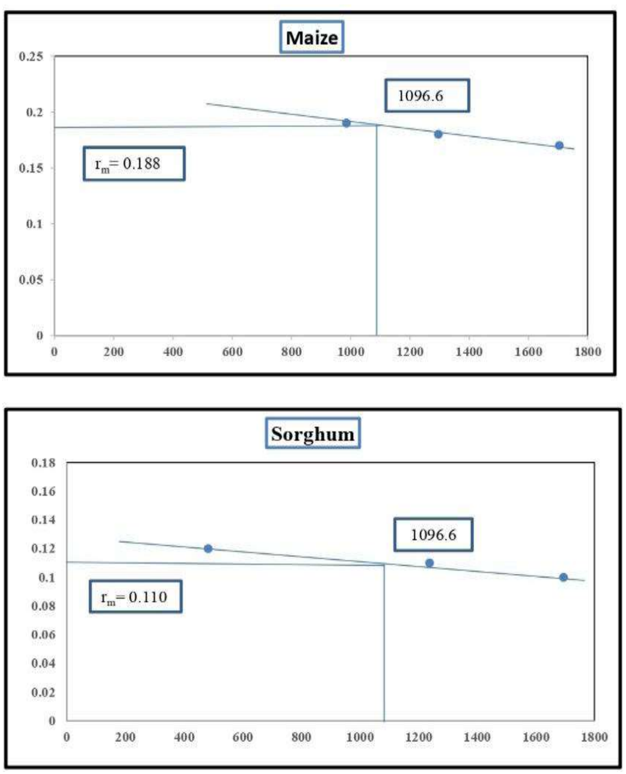


Fig. 3. Intrinsic of increase (r_m) of *S. frugiperda* on maize and sorghum

In maize, the mean length of generation (T_c) was 27.42 days (Table 3). The arbitrary value for intrinsic rate of increase (r_c) was 0.185 female per female per day. The precise generation time (T) was 27.13 days, while the finite rate of increase in numbers (λ) was 1.20 females per female per day. The corrected innate capacity for increase in numbers (r_m) was 0.188 female per female per day. In sorghum, the mean length of generation (T_c) was 31.45 days. The arbitrary value for intrinsic rate of increase (r_c) was 0.113 female per female per day. The precise generation time (T) was 32.45 days, while the finite rate of increase in numbers (λ) was 1.12 females per female per day. The corrected innate capacity for increase in numbers (r_m) was 0.110 female per female per day. Hutasoit et al (2020) also reported that the gross reproduction rate (GRR), net reproduction rate (Ro), intrinsic rate of increase (r), average generation time (T) and doubling time (DT) of *S. frugiperda* on maize were 1233.94 individuals per generations, 422.46 individuals per parents per generations, 0.22 individuals per parents per generations, 26.59 days, 3.04 days, respectively. Guo et al (2020) documented that the intrinsic rate of increase (r), finite rate of increase (λ) and mean generation time (T) were 0.1681, 0.0738 and 0.0270 per day; 248.3584, 19.3282 and 3.3757 offspring per female and; 32.7882, 39.9029 and 41.1053 days on maize, potato and tobacco, respectively.

On reducing stable age- distribution, population of *S. frugiperda* on maize in egg, larval, pupal and adult stages

Table 3. Population growth statistics of *S. frugiperda* on maize and sorghum

Parameters	Hosts	
	Maize	Sorghum
Mean length of generation (days)	27.42	31.45
Innate capacity for increase in numbers (female/female/day)	0.185	0.113
Corrected r_m $\sum^{7\text{-}ermx} l_x m_x$ = 1096.60 (female/female/day)	0.188	0.110
Corrected generation time (days)	27.13	32.45
Finite rate of increase in numbers (λ) (females/female/day)	1.20	1.12

Table 4. Stable age- distribution, population of *S. frugiperda* on maize and sorghum

Stages	Hosts	
	Maize	Sorghum
Egg	23.24	23.16
Larva	63.61	67.50
Pupa	9.12	7.50
Adult	4.03	1.84

(pre-oviposition, oviposition and post oviposition) distributed to the extent of 23.24, 63.61, 9.12 and 4.03 per cent, respectively (Table 4). In sorghum reducing stable age-distribution, population of *S. frugiperda* in egg, larval, pupal and adult stages (pre-oviposition, oviposition and post oviposition) distributed to the extent of 23.16, 67.50, 7.50 and 1.84 per cent, respectively.

CONCLUSION

The comparison of two or more populations by means of their net reproductive rates may be misleading unless the mean length of generations is the same. Two or more populations may have the same reproductive rate but their intrinsic rate of increase may be quite different because of different length of their generation. Indeed, it is evident that based on net reproductive rates (R_o) and innate capacity for increase in numbers (r_m), maize occupied first position followed by sorghum. Life-tables giving the statistics on the innate capacity of increase in numbers of a particular species provide insight into the characteristic life patterns of different species. In the present studies, from the point of view of pest multiplication, maize with high r_m value would be the most suitable host and sorghum with low r_m value would be the least suitable host among the evaluated.

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Effect of Bee Attractants on Fruiting Behaviour and Fruit Quality of Kiwifruit (*Actinidia deliciosa* A. Chev.)

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Abstract: The study was carried out to compare hand pollination with bee attractants for their effectiveness to improve fruit set, fruit size and quality of kiwifruit. Bee scent (1.25%) spray resulted in enhancing the fruit quality attributes and also had minimum proportion of 'C' grade fruits (29.77%) and titratable acidity in fruit juice (1.15%). Bee scent treatment manifested a substantial increase in the fruit set, yield, number of seeds per fruit, fruit length, diameter, weight, TSS and total sugars by 35.69, 25.20, 38.45, 20.25, 11.13, 14.45, 15.53 and 14.92 per cent, respectively over control. Jaggery solution (10%) was second most effective bee attractant treatment after Bee scent (1.25%) to improve the fruit set, yield and fruit quality attributes of kiwifruit. Seed set in the fruits exhibited highly positive and significant relationship with fruit set, yield, fruit size, weight, TSS and total sugars. The commercial bee attractant Bee scent (1.25%) and local bee attractant Jaggery solution (10%) have shown the potential to be used in commercial kiwifruit production system as a suitable substitute for laborious practice of hand pollination.

Keywords: Kiwifruit, Monty, Bee attractants, Fruit set, Yield and fruit quality

Kiwifruit (*Actinidia deliciosa* A. Chev.) known as Chinese gooseberry is a rich source of vitamin C and minerals like potassium, phosphorus and iron. Numerous edible seeds of kiwifruit containing vitamin E and omega-3 fatty acids are natural blood thinner that can significantly reduce the risk of blood clots. Kiwifruit can be successfully grown in mid hills ranging from 900 to 1800 m above mean sea level. In India, kiwifruit is grown in Himachal Pradesh, Jammu & Kashmir, Uttarakhand, Arunachal Pradesh, Sikkim, Meghalaya and Nilgiri hills but Himachal Pradesh is the first state to demonstrate its cultivation, where 254 MT of fruits are produced annually from an area of 182 hectares (Anonymous 2020). Kiwifruit is a functionally dioecious plant, therefore, flowers must be pollinated by external means. The flowers of both staminate and pistillate vines produce no nectar, which reduces bee visitation of the flowers and results in pollination deficit that lead to smaller size fruits and low productivity. Size and weight of the fruits play a crucial role for marketing as fruits having weight of >80 g are accepted in the market. Kiwifruit is a multi seeded berry and fruit weight is highly dependent on number of seeds in the fruit, therefore, requires large number of pollens for effective pollination to produce fruits with good size and quality. Bee attractants mimic the pheromones of honey bees and attract them to the flowers. Use of bee attractants in crops increases the pollination efficiency, fruit set and yield. Commercial bee attractants like Bee scent, Fruit Boost, Bee Here and Bee-Q significantly increase the number of bee visits on the flowers. Other than commercial products, jaggery solution, honey solution and sugar solution can also be used as bee attractants (Jayaramappa et al 2011). These products increase the nectar content of flowers being rich either in sucrose, fructose, maltose, lactose, galactose, mannose or raffinose. Composition of nectar also affects the efficiency of pollination and nectars rich in sucrose are more attractive to bees than glucose and fructose (Silva and Dean 2000). Conventionally, hand pollination is employed for effective pollination in commercial production of kiwifruit in India but the success of hand pollination is much tedious in its nature and dependent on environmental factors. Bee attractants could be useful to combat the hand pollination. Keeping above facts in view, the present investigation was carried out with the objective to assess the effect of bee attractants on fruit set, yield and fruit quality characteristics in commercial kiwifruit production system.

MATERIAL AND METHODS

The studies were carried out during 2017-18 at Dr Y S Parmar University of Horticulture & Forestry, Nauni, Solan, India. It is situated at an altitude of 1276 m above mean sea level with latitude of 30.86º North and longitude of 77.17º East in the hilly regions of the Western Himalayas. The area falls under sub-temperate, sub-humid mid hills agro-climatic zone of Himachal Pradesh. The average annual rainfall of the area is about 800-1300 mm. Seven-year-old kiwifruit vines cv. 'Monty' planted at 4.0 m×6.0 m and trained to T-bar trellis system were selected for the study. The vines of male variety 'Allison' were uniformly distributed in the orchard in the ratio of 1:9. The experiment was laid out in Randomised Block Design with seven treatments which were replicated thrice. The treatments were applied twice during the month of April-May. First and second sprays were given at 5 and 50 per cent flowering, respectively. Treatment solutions were sprayed at low volume with knapsack sprayer during 7:00-8:00 hrs in the morning on all flowering branches covering the whole canopy of respective vine.

Fruit set was recorded 20 days after second application of treatments. Number of flowers and fruits set on marked branch were counted and fruit set was expressed in percentage. Number of fruits on marked and randomly selected branches were counted at the time of harvest to calculate the number of fruits per metre branch. To determine the yield, fruits harvested from each vine were weighed. The yield (kg/vine) obtained from each vine was multiplied by number of vines accommodated in one hectare and expressed as tonnes per hectare (t/ha). Fruits harvested from each vine were graded on the basis of size and weight of individual fruit. The fruits weighing > 80 g were categorised under 'A' grade, 50-80 g as 'B' grade and < 50 g as 'C' grade. Each grade fruits harvested from individual vine were weighed and expressed in percentage of total yield. The length and diameter of the fruit was measured. The length of individual fruit was divided by its diameter to express the fruit shape index. Randomly selected fruits were weighed. Number of seeds/fruit was counted by macerating the seeds and washed with water to remove mucilage from the seeds. After drying the seeds on filter paper, seed number was counted manually. The firmness of the fruit was determined with the help of pressure tester (Magness-Taylor). The total soluble solids (TSS) of fruits were determined with Erma hand refractometer (0-32°Brix). Titratable acidity, sugars and ascorbic acid content in the fruit juice were determined as per the standard procedure described by AOAC (1980). The data recorded were subjected to analysis of variance as described by Panse and Sukhatme (2000) using OPSTAT online software.

RESULTS AND DISCUSSION

There was significant impact of bee attractant treatments on fruit set, number of fruits/branch, yield and proportion of different grade fruits (Table 1). The highest fruit set (86.12%) was with Bee scent sprays, closely followed by hand pollination and jaggery solution sprays. All the treatments except sugar solution and honey solutions had significantly higher fruit set as compared to control. All the bee attractant treatments except sugar solution significantly increased the number of fruits per branch. However, highest number of fruits per branch (10.84) was under Bee scent treatment which was statistically at par with all other treatments except sugar solution and control. The highest fruit yield (3.99 t/ha) was obtained from vines treated with Bee scent which was closely followed by hand pollination and jaggery solution sprays . Proportion of 'A' grade fruits was not significantly influenced by different bee attractant treatments, however, vines sprayed with Bee scent had highest proportion of 'B' grade fruits (62.13%) and lowest proportion of 'C' grade fruits (29.77%). Bee scent treatment was significantly superior to all other treatments except hand pollination and jaggery solution with respect to production of bigger size fruits.

The higher fruit set, yield and proportion of bigger size fruits may be ascribed to homogenous deposition of pollen grains on stigma of female flowers by hand pollination or frequent visit of honey bees attracted by bee scent and jaggery solutions. This led to more pollinated flowers

Table 1. Effect of bee attractants on fruit set, yield and proportion of different grade fruits in kiwifruit cv. 'Monty'

Treatment	Fruit set (%)	Number of fruits per metre branch	Total yield (T/ha)	Proportion of different grade fruits (%)		
				Grade A	Grade B	Grade C
Jaggery solution (10%)	84.47 (66.83)	9.37	3.80	7.50	59.32	33.17
Sugar solution (10%)	72.60 (58.68)	7.42	3.45	6.31	53.54	40.14
Honey solution (10%)	76.80 (61.66)	8.41	3.66	6.63	56.26	37.09
Sugarcane juice (10%)	81.90 (65.05)	9.03	3.72	7.05	57.43	35.51
Bee scent (1.25%)	86.12 (68.43)	10.84	3.99	8.08	62.13	29.77
Hand Pollination	84.87 (67.45)	10.07	3.91	7.70	60.97	31.32
Control (water spray)	63.47 (52.80)	5.52	3.18	5.48	52.23	42.29
CD (p=0.05)	13.98 (9.93)	2.84	0.25	NS	3.14	2.22

resulting in increased fruit set and subsequently increased proportion of bigger size fruits and yield. The presence of queen mandibular pheromone in Bee scent and increased nectar sugar concentration in other attractants might have attracted a greater number of worker bees to the treated flowers. Composition of nectar affects the efficiency of pollination as nectars rich in sucrose are more attractive to bees than glucose and fructose (Silva and Dean 2000). Thus, jaggery solution having higher sucrose content might have attracted more bees as it is composed of 70 per cent sucrose and less than 10 per cent of glucose and fructose (Nath et al 2015). Sattigi et al (2001) recorded higher proportion of larger size fruits and minimum proportion of malformed fruits in watermelon with Bee-Q treatment. Jayaramappa et al (2011) with Fruit Boost and Bee-Q treatments in ridge gourd, obtained higher fruit yield in comparison to open pollination.

The different bee attractant significantly improved the physico-chemical fruit quality characteristics of kiwifruit (Table 2). The vines treated with different bee attractant treatments except sugar solution produced significantly bigger size fruits, however, biggest fruits with fruit length of 66.50 mm and diameter of 46.02 mm were produced by Bee scent sprayed vines, followed by hand pollination and jaggery solution. Fruit shape index was significantly higher in jaggery solution, Bee scent, hand pollination and sugarcane juice treated vines with highest value of 1.45 in jaggery solution. Fruit weight was significantly increased by all the treatments except sugar solution. However, fruits with maximum weight (68.75 g) were harvested from Bee scent treated vines which was statistically at par with those of jaggery solution, hand pollination and sugarcane juice treatments. Maximum number of seeds per fruit (597.16) was under Bee scent treatment which was closely followed by hand pollination and jaggery solution. Fruit firmness was significantly improved in all the treatments except sugar solution. The maximum fruit firmness (7.0 kg/cm^2) was in Bee scent treatment which was statistically at par with hand pollination and jaggery solution. All the treatments except sugar solution significantly increased the total soluble solids content of fruit juice. However, fruits harvested from Bee scent treated vines exhibited highest total soluble solids (12.20 ºB) in fruit juice, closely followed by hand pollination, jaggery solution and sugarcane juice. Total and reducing sugars content in fruit juice were significantly increased by all the bee attractant treatments. Maximum total sugars (5.47%) and reducing sugars (4.35%) were recorded under Bee scent treatment. Titratable acidity in the fruit juice was decreased significantly by all the treatments and lowest was (1.15%) in Bee scent treatment. The maximum ascorbic acid content (60.50 mg/100 g fruit) was in Bee scent treatment which was closely followed by hand pollination, jaggery solution and sugarcane solution.

The enhancement in size and weight of fruits with the application of bee attractant treatments may be associated with the increase in number of seeds in the fruit which act as a source of auxin and gibberellins resulting in enhancing cell division and cell elongation leading to the improvement in size and weight of fruits. Mcpherson et al (2001) reported a positive correlation between seed number and fruit weight in kiwifruit. The increase in number of seeds per fruit under bee attractant treatments might be due to higher bee visits to the treated vines that led to inter floral pollen movement. This improved effectiveness in pollination led to more fertilised ovules and finally resulted in setting of a greater number of seeds. Anita et al (2012) also recorded significantly higher fruit size, weight, total soluble solids and sugars content in guava with Fruit Boost and Bee scent treatments. Malerbo-Souza et al (2004) observed higher acid and lower vitamin C content in Valencia orange fruits obtained from the trees covered against bee visitation.

There was a positive and highly significant relationship of number of seeds in fruit with fruit set, yield and physico-

Table 2. Effect of bee attractants on fruit quality attributes of kiwifruit cv. 'Monty'

Treatment	Fruit length (mm)	Fruit diameter (mm)	Fruit shape index	Fruit weight (g)	Number of seeds	Firmness (kg/cm^2)	TSS (ºB)	Total sugars (%)	Reducing sugars (%)	Titratable acidity (%)	Ascorbic acid (mg/100 g)
Jaggery solution (10%)	64.24	44.32	1.45	66.44	552.03	6.73	11.76	5.18	3.90	1.16	58.34
Sugar solution (10%)	56.66	42.74	1.32	62.83	496.20	6.10	10.86	4.86	3.32	1.23	53.93
Honey solution (10%)	58.03	43.76	1.32	64.87	514.00	6.46	11.16	4.88	3.42	1.20	56.54
Sugarcane juice (10%)	63.11	44.16	1.42	65.36	537.40	6.60	11.73	5.02	3.89	1.17	57.98
Bee scent (1.25%)	66.50	46.02	1.44	68.75	597.16	7.00	12.20	5.47	4.35	1.15	60.50
Hand Pollination	65.46	45.70	1.43	67.69	567.33	6.96	12.10	5.20	4.00	1.16	59.39
Control (Water spray)	55.30	41.41	1.33	60.07	431.33	5.86	10.56	4.76	3.10	1.26	51.84
CD (p=0.05)	3.99	2.35	0.07	3.55	56.24	0.33	0.56	0.08	0.09	0.01	4.52

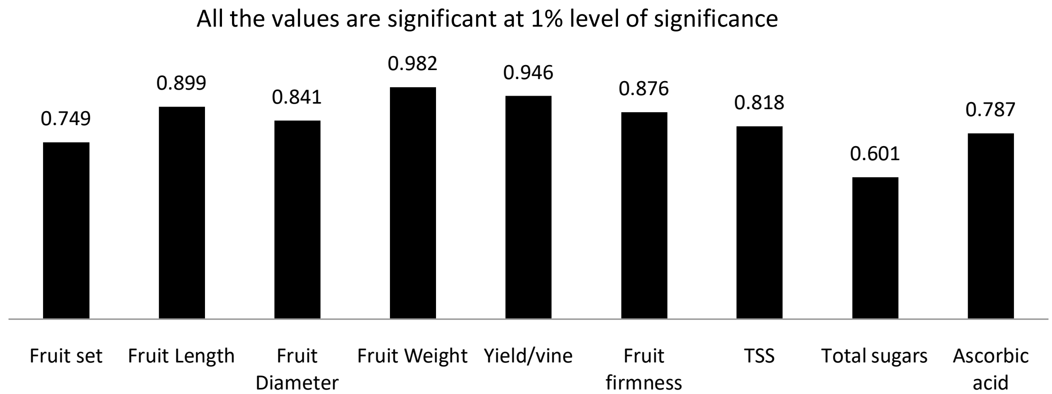

Fig. 1. Correlation coefficient of seed numbers/fruit with fruit set, yield and fruit quality attributes of kiwifruit cv. 'Monty'

chemical fruit quality characteristics. Number of seeds per fruit was positively and significantly correlated with fruit set and yield) (Fig. 1). The number of seeds in the fruit established a high degree positive correlation with fruit length, diameter, weight, firmness, total soluble solids, total sugars and ascorbic acid . The positive relationship of number of seeds in the fruit with fruit set, yield and physico-chemical fruit quality attributes might be due to fruit development co-ordinated by release of various phyto-hormones (auxins, gibberellins and cytokinins) by the developing embryos. The number of pollen grains deposited on the stigma by pollinators directly relates to seed formation and determines fruit size (Delaplane et al 2000). This is supported by Abrol et al (2017), who, established a positive relationship of seed number with fruit weight and yield of strawberry.

CONCLUSIONS

Bee scent (1.25%) has proved to be the most effective treatment in the present investigation and significantly improved fruit set, yield, fruit size, weight and other fruit quality attributes. Besides, commercial bee attractant 'Bee scent', indigenous bee attractant jaggery solution (10%) was also equally effective in that aspect. Thus both the aforesaid attractants have shown the potential to be used in commercial kiwifruit production system as a suitable substitute for laborious practice of hand pollination.

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Thermal Indices of *Spodoptera frugiperda* (J. E. Smith) on Maize in Northern India

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Abstract: The growth and development of *Spodoptera frugiperda* (J.E. Smith) was studied on maize hybrid PMH 10 under laboratory conditions at five alternating temperature viz., 18:07, 24:12, 28:17, 32:22 and 36:27°C during 2021-22. The duration of different developmental stages viz., incubation, larva, pupa, and adults reduced significantly with increase in temperature combinations of 18:7, 24:12, 28:17, 32:22 and 36:27°C. The thermal constant for egg, larval, pupal and adult stages was 45.45, 333.33, 166.67 and 125.00 Degree Days (DD), respectively totalling to 670.45 DD while, the lower developmental threshold was 12.59, 12.33, 12.67 and 10.50°C for the respective stages. Such study can be utilized in development of prediction models, aiding in the early prediction of an insect attack and enabling prompt pest control.

Keywords: Alternating temperature, Biology, Degree days, Developmental threshold, Maize, *Spodoptera frugiperda*, Thermal constant

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae; Lepidoptera) is an invasive pest, recently been reported from India in 2018 and Punjab in 2019 capable of causing huge economic losses (Suby et al 2020, Anonymous 2019). It is a migratory, polyphagous pest having wide range of host plants which feeds on more than 350 plant species related to 76 families (Montezano et al 2018). Fall armyworm has a strong flight capacity and is capable of covering 500 km aided with wind currents before oviposition (CABI 2020). The presence of this pest has been declared from 100 countries due to its natural distribution capacity and the invasiveness of this pest is proliferating rapidly (Prasanna et al 2018, Baloch et al 2020). In India, it has spread to almost 90 per cent of maize growing areas and has been declared as an “invasive pest” (Suby et al 2020). Global climate change has notable effect on agricultural crops and their associated pests. Directly the global climate change influences the reproduction, development, survival and dispersal of pests, whereas indirectly alters the interrelation between pests, their environment and natural enemies (Prakash et al 2014). Changes in climate may alter the functioning of host plants as well as pests under adverse climatic conditions leading to pest outbreaks. As in case of higher temperature, the pest will multiply rapidly due to presence of favorable conditions for development and in case of drought stress, the host's capability to respond to pest outbreak will be hindered (Boggs 2016). According to IPCC (2023), with every 1.5ºC rise in temperature, there will be 45-58 per cent increase in number of days per year with a maximum temperature of 35ºC. If the global temperature intensifies as predicted, fall armyworm may increase its number of generations per year and broaden their infestation range to higher latitudes and elevations (Ramirez-Cabral et al 2020).

Abiotic factors i.e. temperature, relative humidity, rainfall, CO_2 concentrations and sunshine hours greatly influence the reproduction and distribution processes of the insect-pests. Variations in these factors alter populations of insects. Studying the actual relationship between change in abiotic factors and its effect on pest populations will be helpful in forecasting and avoiding pest in addition to predicting crop losses. Temperature is one of the most important factors which affects the rate of growth, development and multiplication of any insect. Insects need a specific thermal constant value for its lifecycle to be completed. Insect development is notably outstripped under fluctuating temperature conditions within appropriate range than that under constant temperature conditions. Temperature also decides the number of larval instars during development and amount of time taken by each instar. Temperature also affects a species' occurrence and establishment in a given area (Fand et al 2014). It establishes the limits of biological activity and temperature thresholds for all growth phases which can be estimated. Thermal indices and temperature-dependent developmental rates of insects aid in understanding the environmental circumstances that cause them to become pests. Therefore, an understanding of the influence of thermal variations is imperative so that pest susceptibility to climate change can be measured. Such information will enable forecasting the effects of climate change on the population growth and distribution of the pest. Moreover, it will help in predicting the susceptible stages of the pest in the fields which will assist farmers and stakeholders to timely devise and use management strategies accordingly. The present study aims in utilizing linear regression model to understand the thermal features and thermal requirements of the *S. frugiperda* population that was collected from Northern India.

MATERIAL AND METHODS

The experiment was conducted at Insect Ecology Laboratory, Department of Entomology, Punjab Agricultural University, Ludhiana, India (30° 45' N, 75° 40' E and 247 meters above sea level), during 2021-22.

Rearing of *S. frugiperda*: The larvae of *S. frugiperda* were collected from fields of PAU, Ludhiana and were reared on cut pieces (2-2.5 inch long) of maize stems (about 20-25 days old) kept inside glass battery jars (10×15 cm). These larvae were kept in separate vials due to its cannibalistic nature. The vials were provided with holes in the lid for air passage. The food was changed after 2-3 days as per need until the pupae were formed. The fresh pupae were transferred to glass battery jars having 2.5 cm thick layer of moist sand (already sanitized under sun heat) at the bottom to avoid contamination. The adults freshly emerged from the jars were sorted out into males and females. The pairs (male and a female) were transferred to oviposition cages (16×10 cm). Maize seedlings of 4-5 leaf stage of the PMH 10 hybrid raised in small earthen pots (12 cm diameter) were kept inside each cage exclusively for oviposition purpose. The plants were observed daily for egg laying and the seedlings with eggs were replaced with fresh ones at regular intervals until the adults died. The leaf sheath portion containing the eggs were kept in Petri plates provided with moist cotton swabs. Petri plates were checked regularly for hatching of the neonates. These neonates served as initial culture of *S. frugiperda* and was further multiplied to obtain F_1 and F_2 population. The F_2 population obtained from this culture was used for carrying out the experiment. The culture was maintained at the temperature 25±2°C and relative humidity of 70± 5 per cent.

Development of *S. frugiperda* at different alternating temperatures: The meteorological data of Punjab for the previous two years were collected from the PAU agrometeorological observatory and accordingly five alternating temperatures viz., 18:7 (December-January), 24:12 (February-March and October-November), 28:17 (April-May), 32:22 (August- September) and 36:27°C (June-July), respectively encountered by the insect in its native habitat along with L:D photoperiod (14:10 hrs) and 70±5 per cent relative humidity (R.H.) were selected. Alternating temperature regimes entailed maintaining two consistent temperatures, namely the maximum and minimum temperature, per day. The same R.H. was maintained at both temperatures while the highest temperature was held for 14 hours and the lowest temperature for 10 hours. The maximum temperature corresponded to the light phase while minimum temperature corresponded to the dark phase. One newly laid egg mass (100-150 eggs) was collected from the stock culture and placed in Petri plates of 10 cm diameter. There were five replications, each having 10 egg masses. These Petri plates were incubated in growth chambers. The eggs were checked every 24 hours for the appearance of neonates to record the incubation period. Further the larval and pupal duration were also recorded. The pupae formed were kept in glass battery jars containing moist sand for adult emergence. Each observation was recorded at 24 hours interval.

Data analysis: The mean and standard error (SE) were calculated for different parameters studied using CPCS software. To estimate the mean temperature from the alternating temperature for establishing a linear relationship between development rate and temperature the following equation was used (Mironidis and Savopoulou-Soultani 2008):

Mean temperature (°C) = {(Maximum temperature * 14) + (Minimum temperature * 10)}/24

For the Linear regression analysis, developmental rate (R) for all the stages (egg, larval, pupal and adult) was worked out (Selvaraj et al 2014):

$$R= 1/D$$

where, D = Development duration of the particular stage.

Development threshold (T_o) and thermal constant (K) were calculated by regressing the developmental rates of egg, larval and pupal stages on temperature (Kipyatkov and Lopatina 2010). The regression equation, Y=bX-a

where, K=1/b

where, b: Regression coefficient between development rate and temperature

T_o was the ratio of regression intercepts (a) and (b)

$$T_o= -a/b$$

Regression coefficient between temperature and developmental rate was calculated using data analysis pack tool in Microsoft Excel.

RESULTS AND DISCUSSION

Influence of different alternating temperature on the development of *S. frugiperda* on maize: The development duration decreased significantly with increase in temperature for all the life stages. The incubation period of *S. frugiperda* was maximum (4.8 days) at the lowest test temperature of 24:12° C (Table 1). As the temperature increased to 36:27°C, there was 54.17 per cent reduction in the incubation period (2.2 days). The eggs did not hatch at 18:07°C. The temperature combinations ranging from 24:12 to 36:27°C were observed to be favorable for development of eggs of *S. frugiperda* on maize. The egg development was inversely related to temperature. The incubation period was significantly positively correlated with temperature (r= 0.987). Similarly, the maximum larval duration (29.50 days) was at 24:12°C (lowest test temperature) which was shortened by 59.39 per cent in 11.98 days with further increase in temperature to 36:27°C. The correlation between developmental rate of larvae of *S. frugiperda* and temperature was significant and positive (0.976). Similar trend was observed in case of pupal period in which the maximum pupal duration was 24.7days at minimum temperature of 24:12°C. The pupal development reduced 64.37 times and reached 8.8 ±0.09 days on increasing the temperature to 36:27°C. Positive correlation (0.991) was observed between the pupal duration of *S. frugiperda* and temperature. Adult longevity of both male and female decrease significantly with increase in temperature. The minimum adult longevity was at 36:27°C (6.06 days: males and 6.82 days: females) (Table 1). Both male and female lived longer at 24:12°C (8.66± and 9.46 days, respectively). At all alternating temperature combinations, female longevity was more as compared to males. The correlation coefficient between temperature and adult longevity for both male and female was significantly positive (0.880: male, 0.876: female). The maximum time taken by *S. frugiperda* to complete its life cycle on maize was 68.06days at 24:12°Cand was reduced by 56.83 per cent on increasing the temperature to 36:27°C thereby, completing the total life cycle in 29.38 days. The total time taken to complete all the life stages of *S. frugiperda* was significantly influenced by the temperature and was positively correlated by the temperature (0.975). Sarkar et al (2021) also observed similar trend of development period of the same pest with increasing temperature. Significant decrease in total developmental period of *S. frugiperda* with increasing temperature was also observed by Ramzan et al (2021). Du Plessis et al (2020) also observed the same trend.

Linear Regression Model and Validation

Egg: The linear regression line describing the relationship between the temperature (x) and developmental rate for egg stage (Y_1) was Y_1=0.022x- 0.277 (Y=bx-a), where a= intercept and b= slope (Fig. 1). In this model, temperature explains 97 per cent variation in developmental rate of eggs (R^2=0.97). The thermal constant (1/b) for the egg stage was found to be 45.45 degree days (DD) (Table 2). The developmental threshold (-a/b), the temperature below which the embryonic growth ceases was found to be 12.59°C. Du Plessis et al (2020) recorded thermal constant for eggs of *S. frugiperda* as 35.73 DD and the minimum temperature required for the egg development as 13.01°C. The linear equation for the egg stage was recorded as Y= 0.0280x-0.3641. Similarly, Dahi et al (2020) calculated the linear regression equation under constant temperatures of 20, 25 and 30°C for egg stage of *S. frugiperda* as Y= 3.31x- 52.3 with threshold value as 15.79°C and thermal constant of 30.00 DD required for completion of egg stage. Viswajyothi et al (2017) worked out the linear regression equation for egg stage of *Sesamia inferens* Walker as Y = 0.0157X-0.1982 with a thermal constant of 63.69 DD and developmental threshold of 12.62°C in maize crop. Similarly, Selvaraj et al (2014) calculated the thermal constant of 47.6 DD and developmental threshold of 13.8°C for *S. inferens* in maize crop.

Larva: The linear regression line between temperature (X) and developmental rate of total larval stage Y_2= 0.003x-0.038. The temperature explains 95 per cent variation in

Table 1. Influence of alternating temperature on the duration (days) of *S. frugiperda* on maize under laboratory conditions

Temp. (°C)	Eggs		Larva		Pupa		Adult male		Adult female		Total developmental	
	Mean±SE	R	Mean±SE	R	Mean±SE	R	Mean±SE	R	Mean±SE	R	Mean±SE	R
18:07	-	-	-	-	-	-	-	-	-	-	-	-
24:12	4.8±0.37	0.208	29.50±0.24	0.034	24.7±0.13	0.040	8.66±0.07	0.116	9.46±0.04	0.106	68.06±0.49	0.015
28:17	4.2±0.35	0.238	20.82±0.09	0.048	13.9± 0.07	0.072	8.16±0.04	0.123	8.72±0.04	0.115	47.22±0.29	0.021
32:22	2.8±0.39	0.347	16.80±0.17	0.059	10.9± 0.06	0.091	8.02±0.06	0.125	8.62±0.06	0.116	39.06±0.40	0.026
36:27	2.2±0.20	0.455	11.98±0.25	0.083	8.8± 0.09	0.113	6.06±0.05	0.165	6.82±0.05	0.147	29.38±0.65	0.034
CD (p=0.05)	0.89	r=0.987**	0.39	r=0.976 **	0.24	r=0.991**	0.15	r= 0.880**	0.10	r= 0.876**	1.05	r=0.975**

T= Temperature (°C), R= Developmental rate (1/D), r= correlation coefficient between developmental rate and temperature, ** = Significant at 1% level development rate of larvae (R^2=0.95) with thermal constant of 333.33 DD and threshold temperature of 12.33°C, respectively (Fig. 1, Table 2). Earlier, Du Plessis et al (2020) calculated the total thermal constant for the larval stage of FAW as 202.67 DD and the threshold temperature as 12.12°C. Dahi et al (2020) calculated the linear regression equation for larval stage as Y = 0.28x- 2.89 and reported that threshold temperature of 10.39°C and 360.2 DD is required for the completion of larval stage of *S. frugiperda*. Selvaraj et al (2014) calculated the linear regression equation for small (1^{st}-3^{rd} instar) and large larva (4^{th}-6^{th} instar) as Y= 0.002X-0.020 and 0.005X- 0.056, respectively with thermal constant of 700 DD for total larval development and reported the temperature thresholds for the small and large larva to be 10°C and 11.2°C, respectively. In present studies, because the minimum threshold temperature for the larval stage was lower than that for the egg stage, this suggests that the eggs may not develop but hatch at temperatures which are unsuitable for larval development.

Pupa: The linear regression line between temperature (X) and developmental rate of pupa (Y_3) was Y_3=0.006x- 0.076 (Y=bx-a) (Fig. 1). In this model, temperature explains 99 per cent variation in developmental rate of pupa (R^2=0.99). The thermal constant (1/b) for the pupal stage was found to be 166.67 DD and the development threshold (a/b) was found to be 12.67°C (Table 2). Du Plessis et al (2020) worked out the linear regression equation for the pupal stage of FAW as Y= 0.0067x- 0.0869. The thermal constant for the pupal development was calculated as 147.06 DD and also the lower temperature threshold was 13.06°C. Dahi et al (2020)

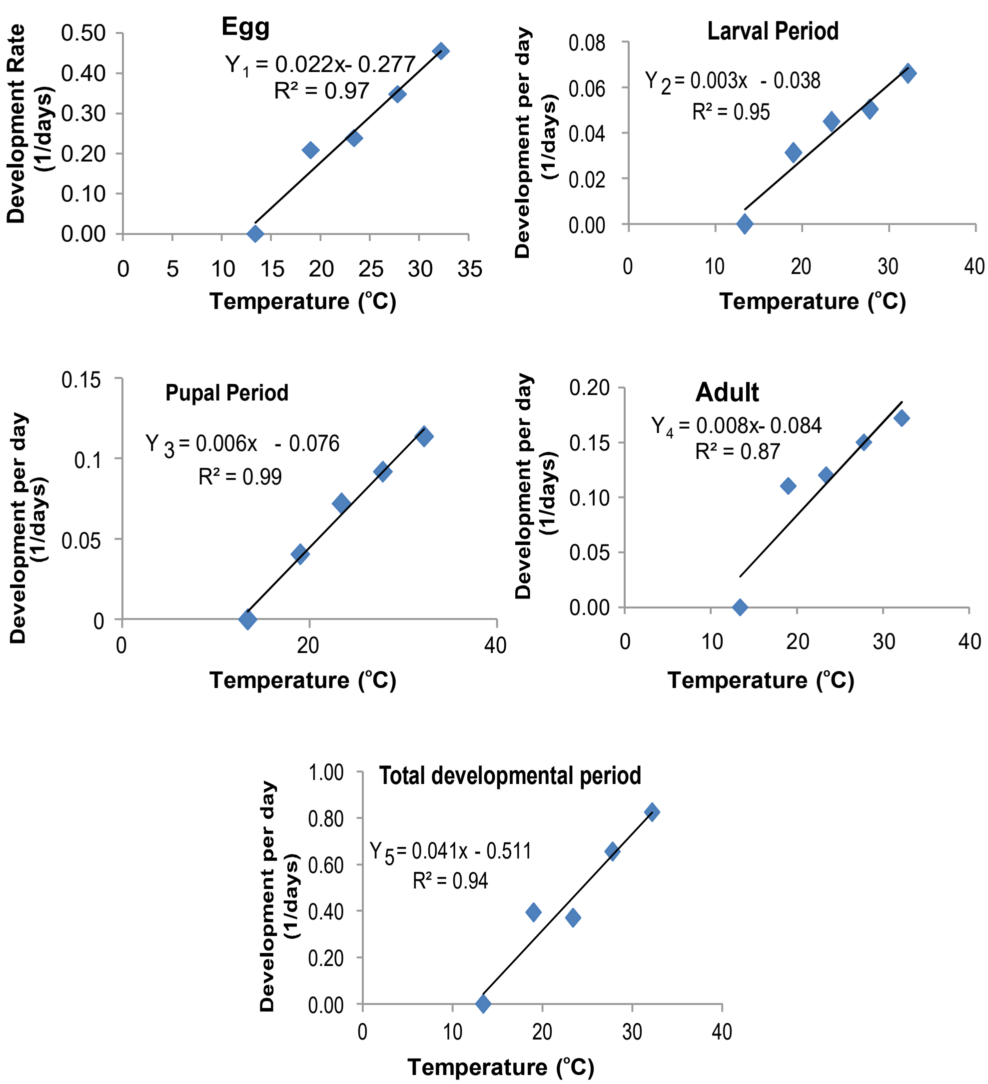

Fig. 1. Regression between temperature (X) and developmental rate (Y) of different stages of *Spodoptera frugiperda* on maize

Table 2. Regression equation for different developmental stages of *S. frugiperda* in maize

Growth stage	Regression equation (Y=bX-a)	Thermal constant in DD (K=1/b)	Threshold (°C) (T_0=-a/b)	R^2
Egg	Y_1 = 0.022x - 0.277	45.45	12.59	0.97
Larval	Y_2 = 0.003x - 0.038	333.33	12.33	0.95
Pupa	Y_3 = 0.006x - 0.076	166.67	12.67	0.99
Adult	Y_4 = 0.008x - 0.084	125.00	10.50	0.87
Total developmental period	Y_5 = 0.041x - 0.511	670.45 DD	12.46	0.94

X= Temperature, Y_1 = Developmental rate of egg, Y_2 = Developmental rate of total larval stage, Y_3 = Developmental rate of pupa, Y_4 = Developmental rate of adult, Y_5 = Developmental rate of total developmental period, DD = Degree Days

also recorded a lower temperature threshold of 14.05°C and thermal constant of 37.33 DD for completion of pupal stage of FAW.

Adult: The linear regression line between temperature (X) and developmental rate of adult (Y_4) was Y_4=0.008x- 0.084 (Y=bX- a) (Fig. 1). In this model, temperature explains 87 per cent variation in developmental rate of adults (R^2=0.87). The thermal constant (1/b) for the adult stage was found to be 125.00 DD and the development threshold (a/b) was 10.50°C (Table 2). Similarly, the linear regression equation for *Leucinodes orbonalis* Guenee was worked out for the adult male as Y= 0.0379x- 0.49 with thermal constant of 26.38 DD and minimum temperature threshold as 12.92°C. In case of adult female, the equation was calculated as Y= 0.0247x- 0.289 with thermal constant of 40.50 DD and threshold temperature of 11.71°C (Dhaliwal and Aggarwal 2021). Among all the developmental stages, the developmental threshold is highest for pupa and lowest for adult. Adult stage has more tolerance to low temperature than egg and pupal stages, while pupa has the least. Adult stage need maximum heat units to be accumulated to complete that particular stage taking more time compared to other two stages. Pupal stage has the shortest duration requiring least amount of heat units to be accumulated and egg as well as larval stage has intermediate amount of heat unit requirement and developmental threshold.

Total developmental period: The linear regression line between temperature (x) and developmental rate of total developmental period (Y_5) was Y_5= 0.041x- 0.511 (Y=bx- a) (Fig. 1). In this model, temperature explains 94 per cent variation in developmental rate (R^2=0.94). The thermal constant was 670.45 DD and the development threshold was 12.46°C (Table 2). Du Plessis et al (2020) calculated the linear regression equation for egg to adult stage of FAW as Y= 0.0026x- 0.0322. The number of degree days required for egg- adult development was 391.61 DD and threshold temperature was 12.57°C. Moreover, Dahi et al (2020) recorded temperature threshold and thermal constant of 12.49°C and 527.3 DD for FAW to complete one generation.

CONCLUSION

The temperature combination of 24:12°C prevailing under Punjab conditions during February-March and October-November is good for the survival of FAW but do not favours the further growth and development of this pest. The temperature combination of 28:17 and 36: 27°C coinciding with April-May and June-July do not pose any limitations for its survival. During these months of the year the insect proliferates rapidly with certain limitations of higher temperature. However, the temperature combination of 32:22°C during August-September proves to be most ideal for the growth and development of FAW under Punjab conditions. In addition to this, *S. frugiperda* requires 670.45 DD to complete its life cycle. The development rates of the pest at various temperatures can be predicted using estimates of the developmental thresholds and thermal requirements. Consequently, can help in planning the most effective period to start monitoring the pest in the field and timely action for effective suppression of the pest in maize fields.

AUTHOR CONTRIBUTIONS

Naveen Aggarwal and Jawala Jindal designed and supervised the experiment and also wrote the original draft of manuscript, reviewed and edited the manuscript. Pukhraj Singh carried out the experiment and recorded the data. Oshin Bhargav and Kanu Priya Sharma analyzed and investigated the data and also helped in writing the manuscript. All authors read and approved the final manuscript.

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Assemblage of Butterflies in Diverse Ecosystems of Cuddalore District, Tamil Nadu, India

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Abstract: In the present study, pollard walk method was followed to estimate the diversity and assemblage of butterflies in diverse ecosystems of Cuddalore district, Tamil Nadu during March 2022 to February 2023. A total of 60 species and 44 genera were identified under five families *viz.,* Papilionidae (8 species), Pieridae (9), Nymphalidae (20), Lycaenidae (16) and Hesperiidae (7) were observed in the diverse ecosystems. The highest number of species were recorded in horticultural ecosystem (59 species) followed by semi-urban ecosystem (40) and agricultural ecosystem (38). The highest values for diversity indices of Simpson index (λ) (0.971), Shannon-Wiener (H1) (3.713), Margalef index (8.610), Menhinick (2.118) were recorded in horti-ecosystem and this higher index values indicate that the species are more diverse in the horti-ecosystem. The agricultural intensification decreases the butterfly fauna and unexpectedly, the semi-urban ecosystem which includes avenue trees, kitchen garden, ornamental flower plants, parks/ lawns serves a better habitat for butterflies. Therefore, the Evenness_e^H/S (0.805) and Equitability- J (0.941) were maximum in the semi-urban ecosystem. Berger Parker index (0.076) was maximum in Agro-ecosystem, which shows the community is dominated by the most common butterfly pest species in the rice crop.

Keywords: Biodiversity, Butterfly, Diversity Indices, Dominance, Ecosystem

Butterflies are an indicator species which responds rapidly to environmental and land use changes (Ekroos et al 2013) and have been recognized as ecological indicators in diverse ecosystems around the world (Stuhldrehera and Fartmann 2018). More than 18,000 butterfly species are known, and 90 % of these species are distributed in tropical areas (Bonebrake et al 2019). However, tropical butterfly diversity is threatened by habitat loss and global climate change (Jain et al 2017, Kirubaharan et al 2022). Butterflies perform important ecological functions, such as pollinating many plant species, and are thus highly valuable from a conservation perspective (Santos et al 2020). Butterflies are sensitive to climate and environmental change because of their short generation times, high mobility, and specific habitat preferences (Parmesan 2006). India hosts about 1,504 species belonging to different families viz., Papilionidae, Pieridae, Lycaenidae, Nymphalidae, Riodinidae and Hesperiidae which include nearly 100 endemic species (Varshney and Smetacek 2015, Upadhye et al 2020). Around 328 species are estimated to occur in the state of Tamil Nadu (Pavendhan 2017). The diversity of butterflies depends on plant diversity in a particular area (Padhye et al 2006, Sharmila and Thatheyus 2022). Kanagaraj and Kathirvelu (2018) recorded 52 species and 40 genera of butterflies in the coastal area of Cuddalore District, Tamil Nadu during December 2013 to November 2014. Landscape heterogeneity can also affect the dispersal of butterflies, and non-arable patches across agricultural landscapes are important for butterfly movement, especially for low-mobility species. The impact of land-use interactions on biodiversity patterns has been poorly explored (Bonebrake et al 2019, Hendershot et al 2020). Agricultural intensification is widely accepted as a major cause for biodiversity decline. It is a broad concept encompassing many factors, such as the loss of habitat, fragmentation of ecosystems and increased input of insecticides, pesticides and herbicides. The present study is aimed to examine the assemblage and diversity of butterflies in various ecosystem of Cuddalore district, Tamil Nadu, India.

MATERIAL AND METHODS

The butterflies were observed in the Bhuvanagiri (11.4459° N, 79.6530° E), Chidambaram (11.3921° N, 79.7147° E), Cuddalore (11.7480° N, 79.7714° E), Kattumannarkoil (11.2800° N, 79.5519° E) and Kurinjipadi (11.5642° N, 79.5960° E) in the Cuddalore District from various ecosystems *viz.,* agricultural land, bushy areas, grassland, orchards etc. The data was compiled and classified as agricultural, horticultural and semi-urban ecosystem from each study site. A 2.5 km transect was selected within each ecosystem (i.e., five transects for each ecosystem) at each study site. Each transect was monitored monthly from March 2022 to February 2023 as per Pollard walk method (Pollard 1977). To characterize diversity along each transect, a catch-and-release method was used during conditions suitable for butterfly activity (i.e., sunny days with wind speeds < 40 km/h between 08:30 AM and 12:00 PM). During surveys, one observer and one recorder walked at a constant pace of 1–1.5 km/h along the transect and recorded and identified all butterflies within 5 m of the transect line. A sweep net was used to capture individual butterflies, if capture was necessary for identification and immediately release after identification. When identification was not possible in the field, photographs were taken to identify the butterflies later. Butterflies were identified up to species level with the aid of relevant field guides and keys (Gunathilagaraj et al 1998, Kehimkar 2016). The status of butterflies was assessed using Treadaway's Checklist (1995). The scale of occurrences was used to evaluate the status of butterflies as very rare (1-3 occurrences), rare (4-10 occurrences), common (11-20 occurrences) and very common (21-above occurrences). The diversity indices namely Dominance (D), Simpson (λ), Shannon-Wiener (H1), Evenness_e^H/S, Brillouin, Menhinick, Margalef, Equitability_J, Fisher_alpha, Berger-Parker and Chao-1 of dominance were analysed with Past version 4.0 (Hammer et al 2001).

RESULTS AND DISCUSSION

The total of 60 species and 44 genera were identified under five families *viz.,* Papilionidae (8 species), Pieridae (9), Nymphalidae (20), Lycaenidae (16) and Hesperiidae (7) were observed in the diverse ecosystems. The highest number of species were recorded in horticultural ecosystem (59 species) followed by semi-urban ecosystem (40) and agricultural ecosystem (38) (Table 1, Fig. 1). The total of 17 species were found to be very common in horticultural ecosystem which comprises bushy areas, grassland, orchards, plantation crops and weeds etc. whereas, the 18

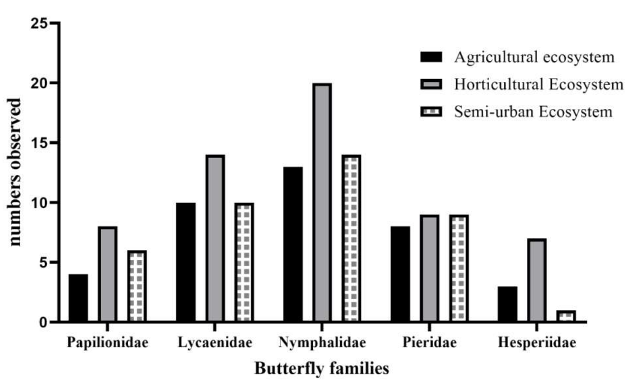

Fig. 1. Population assemblage of butterfly families in diverse ecosystem of Cuddalore district, Tamil Nadu

species were recorded very rare in horticultural ecosystem (Table 1). The six species, *D. genutia, E. core, C. pomona, C. pyranthe, E. brigittia* and *L. nina* were found to be very common in semi-urban ecosystem, which mainly feeds on avenue trees, kitchen garden, lawns, ornamental flower plants, parks, etc. The species *G. agammemnon, Chilades pandava, C. putli, Jamides celeno, Prosotas dubiosa, H. bolina M. phedima* and *Psuedocoladenia dan* were recorded very rare in the semi-urban ecosystem. Paul and Sultana (2020) revealed the importance of small green patches of urban and suburban areas in cities serving as a preferred habitat for butterflies. Devi et al (2021) reported that the presence of *Senna siamea* attracts the *Catopsilia pyranthe* butterfly which is commonly found along the roadsides in semi-urban areas.

In agro-ecosystem, the five species, *L. boeticus, M. leda, C. pyranthe, E. brigittia* and *P. mathias* were found to be very common. The species *Pachliopta aristolochiae, P. demoleous, P. polytes, C. putli, Byblia ilithyia, Mycalesis perseus* and *Neptis hylas* were recorded very rare in agricultural ecosystem. Large-sized crop fields cause a homogenization of landscapes and thus increases barrier effects for many butterfly species (Batary et al 2017, Hass et al 2018). Crops such as cereals, cotton, pulses, sesamum, sugarcane, weeds were predominantly found in the agro-ecosystem as these crops are hosts of the above species. Soniya and Palot (2002) observed that the *M. leda* and *P. mathias* were abundant in the vegetative stage of the rice crop. Moorthy et al (2022) reported the blue butterfly (pod borer), *L. boeticus* was known to attack different leguminous vegetables. Kathirvelu et al (2022) documented that the caterpillars of many species of butterflies fed and developed on weed plants, thereby suppressing weeds like milkweeds, knotweed, flannel weed, hogweed on agricultural and horticultural farms. Arya et al (2020) observed that 85.92% male and 14.08% female butterflies were feeding at various sites as puddles, moist soil, mammalian dung and algal mats. However, these feeding sites were primarily found in the agricultural and horticultural farms.

Among the ecosystems, horticultural ecosystem recorded dominance (D) value less than one (0.029) and this indicates more diversity, followed by semi-urban ecosystem (0.037) and agro-ecosystem (0.039). The highest diversity indices of Simpson index (λ) (0.971), Shannon-Weiner (H1) (3.713), Margalef index (8.610) and Menhinick (2.118) were high in horti-ecosystem and this higher index values indicate that the species are more diverse in the horti-ecosystem (Table 2). Karmakar et al (2022) observed that the highest values of Simpson, Shannon and Margalef diversity indices were obtained in the roadside and garden habitat, whereas

Table 1. Inventory of butterfly species in Cuddalore district, Tamil Nadu during 2022-23

Scientific name	Common name	Agricultural ecosystem		Horticultural ecosystem		Semi-urban ecosystem	
		n	SD	n	SD	n	SD
Family: Papilionidae							
Graphium agammemnon	Tailed Jay	0	-	5	R	3	VR
Graphium doson	Common Jay	0	-	1	VR	0	-
Graphium sarpedon	Common Bluebottle	0	-	1	VR	0	-
Pachliopta aristolochiae	Common Rose	2	VR	12	C	5	R
Pachliopta hectar	Crimson Rose	4	R	17	C	11	C
Papilio demoleous	Lime Butterfly	2	VR	25	VC	16	C
Papilio polymnestor	Blue Mormon	0	-	7	R	4	R
Papilio polytes	Common Mormon	1	VR	12	C	9	R
Family: Lycaenidae							
Castalius rosimon	Common Peirrot	11	C	24	VC	14	C
Catochrysops strabo	Forget-Me-Not	4	R	11	C	8	R
Chilades pandava	Plains Cupid	8	R	12	C	2	VR
Chilades putli	Small Grass Jewel	3	VR	12	C	1	VR
Curetis thetis	Indian sunbeam	0	-	1	VR	0	-
Euchrysops cnejus	Gram Blue	15	C	0	-	0	-
Everes lacturnus	Indian Cupid	0	-	2	VR	0	-
Jamides celeno	Common Cerulean	4	R	9	R	2	VR
Lampides boeticus	Pea Blue	31	VC	3	VR	0	-
Prosotas dubiosa	Tailless Line Blue	0	-	4	R	3	VR
Pseudozizeeria maha	Pale Grass Blue	4	R	11	C	14	C
Rapala varuna	Indigo flash	0	-	2	VR	0	-
Spalgis epius	Apefly	0	-	12	C	8	R
Zizeeria karsandra	Dark Grass Blue	9	R	21	VC	11	C
Zizina indica	Lesser Grass Blue	0	-	8	R	6	R
Zizula hylax	Tiny Grass Blue	6	R	14	C	11	C
Family: Nymphalidae							
Acraea violae	Tawny Coster	16	C	28	VC	11	C
Ariadne	Angle Castor	0	-	1	VR	0	-
Ariadne merione	Common Castor	19	C	21	VC	9	R
Byblia ilithyia	Joker	3	VR	12	C	19	C
Danaus chrysippus	Plain Tiger	16	C	26	VC	19	C
Danaus genutia	Striped Tiger	11	C	35	VC	29	VC
Euploea core	Common Crow	8	R	28	VC	21	VC
Euthalia aconthea	Common Baron	0	-	3	VR	0	-
Hypolimnas bolina	Great Eggfly	0	-	3	VR	1	VR
Hypolimnas misippus	Danaid Eggfly	0	-	8	R	0	-
Melanitis leda	Common Evening Brown	21	VC	3	VR	8	R
Melanitis phedima	Dark Evening Brown	7	R	9	R	2	VR
Mycalesis perseus	Common Bushbrown	1	VR	14	C	0	-
Neptis hylas	Common Sailor	2	VR	12	C	9	R

Cont...

Table 1. Inventory of butterfly species in Cuddalore district, Tamil Nadu during 2022-23

Scientific name	Common name	Agricultural ecosystem		Horticultural ecosystem		Semi-urban ecosystem	
		n	SD	n	SD	n	SD
Junonia almanac	Peacock pansy	10	R	21	VC	8	R
Junonia hierta	Yellow Pansy	0	-	1	VR	0	-
Junonia iphita	Chocolate Pansy	8	R	21	VC	11	C
Junonia lemonias	Lemon Pansy	0	-	2	VR	0	-
Junonia orithya	Blue Pansy	0	-	2	VR	0	-
Tirumala limniace	Blue Tiger	8	R	21	VC	12	C
Family: Pieridae							
Catopsilia pomona	Common Emigrant	12	C	24	VC	26	VC
Catopsilia pyranthe	Mottled Emigrant	27	VC	18	C	21	VC
Cepora nerissa	Common Gull	10	R	20	C	8	R
Colotis amata	Small Salmon Arab	19	C	27	VC	7	R
Delias eucharis	Common Jezebel	9	R	24	VC	12	C
Eurema brigittia	Small Grass Yellow	21	VC	41	VC	26	VC
Eurema hecabe	Common Grass Yellow	16	C	43	VC	12	C
Leptosia nina	Psyche	12	C	26	VC	23	VC
Pareronia valeria	Common wanderer	0	-	9	R	10	R
Family: Hesperiidae							
Ampittia dioscorides	Bush hopper	0	-	9	R	0	-
Borbo cinnara	Rice Swift	18	C	2	VR	0	-
Pelopidas mathias	Rice skipper	21	VC	3	VR	0	-
Erionota thrax	Banana skipper	0	-	2	VR	0	-
Potanthus nesta	The Dart	0	-	2	VR	0	-
Psuedocoladenia dan	Fulvous Pied Flat	7	R	11	C	2	VR
Suastus gremius	Indian Palm Bob	0	-	1	VR	0	-

* n- numbers observed; SD- Status of Dominance; As per Treadaway's checklist for the status of dominance, <3: Very Rare (VR); 4-10: Rare (R); 11-20: Common (C); >20: Very Common (VC)

the lowest values were observed in the plantation habitat. However, Evenness_e^H/S (0.805), and Equitability- J (0.941) were recorded maximum, which indicate that the large number of species shared the same distribution proportion in the semi-urban ecosystem and also it shows the stability of the ecosystem (Table 2). Shannon's and Simpson's diversity indices were appropriate for conservation planning when selecting priority sites for protection by ranking them by their level of diversity (Magurran and Dornelas 2010). Berger Parker index (0.076) was maximum in agro-ecosystem and this indicates that the community is dominated by the most common species (*i.e.,* not evenly distributed) *Melanitis leda* (Common evening brown/ rice green horned caterpillar) and *Pelopidas mathias* (Rice skipper) in rice ecosystem (Table 1, 2). Elanchezhyan and Balakrishnan (2020) documented the butterfly pests, *M. leda* and *P. mathias* were found abundant in the vegetative stage of rice fields.

Table 2. Diversity indices of butterfly species in Cuddalore district, Tamil Nadu during 2022-23

Diversity Indices	Agricultural ecosystem	Horticultural ecosystem	Semi-urban Ecosystem
Taxa_S	38	59	40
Individuals	406	750	432
Dominance (D)	0.039	0.029	0.037
Simpson (λ)	0.961	0.971	0.963
Shannon-Weiner (H1)	3.395	3.713	3.446
Evenness_e^H/S	0.784	0.707	0.805
Brillouin	3.220	3.566	3.275
Menhinick	1.886	2.118	1.876
Margalef	6.160	8.610	6.262
Equitability_J	0.933	0.914	0.941
Fisher_alpha	10.26	14.67	10.40
Berger-Parker	0.076	0.057	0.067
Chao-1	38.25	59.88	39.25

CONCLUSION

Butterfly communities in different ecosystems of Cuddalore district, Tamil Nadu, India are well supported by abundant crop, floral and weed diversity in horticultural and semi-urban ecosystems than the agro-ecosystem. The number of species of butterflies observed in horticultural ecosystem was consistently greater than both the semi-urban and Farmland habitat. The family Nymphalidae was the most abundant species and had the highest individual species, and the family Hesperiidae recorded the least number of species. Long term monitoring is needed for analysis of butterfly population trends in the coastal area. Furthermore, additional work is needed to compare butterfly beta diversity among general categories of vegetation types within and among different ecosystems, to provide better baseline data.

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Life Cycle of Dried-fruit Beetle, *Carpophilus hemipterus* (L.) (Coleoptera: Nitidulidae) on Peanut and Population Development on Different Processed Nuts

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Abstract: Studies on the biology of dried-fruit beetle *Carpophilus hemipterus* (L.) on peanut and its preference among five different nut kernels were conducted at Post Harvest Technology Centre, Bapatla, Andhra Pradesh, India. The adult is a slightly flattened oblong beetle measures 2 to 5 mm in length. The elytra are short, leaving distal portion of the abdomen exposed. The average time period from egg to adult emergence is 33.6 days during winter and 41.17 days in summer. Pistachios and cashewnuts attracted significantly more insects (9.33 and 8.67, respectively) of dried-fruit beetle adults and the total adult progeny was the highest in pistachios (125.0) which was at par with cashewnuts (114.83). The order of preference of *C. hemipterus* to the processed nuts tested was; pistachios > cashewnuts > walnuts > peanuts > almonds. *C. hemipterus* is a pest of quarantine importance, knowledge on insect biology and its preferences to various nuts is useful to take necessary preventive measures in storage and processing units.

Keywords: Edible nuts, Storage product insects, Nitidulidae, Preference, Quality

Nuts have become an important part of healthy diet as they are rich in proteins, dietary fibres, vitamins, minerals, mono- and poly-unsaturated fatty acids, antioxidants, carotenoids, phytosterols and phenolic compounds (De Souza et al 2015, Tas and Gokmen 2017) and are known to improve metabolic biomarkers (Leila et al 2022). With high calorific value and several nutritional and health benefits, nuts play a very significant role as immunity boosters in prevention of many diseases including cardiovascular risks, arterial pressure, oxidative stress, inflammation and insulin resistance (De Souza et al 2017, Kim et al 2017). Popular edible nuts viz., almonds, hazels, pecans, macadamias, pistachios, walnuts, cashew nuts, peanuts, etc. are traded in the international market. India is the major producer, processor, consumer and exporter of cashew which is the most important commercial crop grown in the coastal belt of India (Karthickumar et al 2014). In India, cashew was cultivated over an area of 1.16 million hectares during 2021-22 with an estimated kernel production of 7.74 lakh metric tonnes (FAOSTAT 2022). India ranks second with 22% of the world's production next to the African countries sharing 45% (ICAR-DCR Annual Report 2021). Walnut and pistachios are grown in temperate regions of northern India. However, nuts like almonds either in the form of raw or kernels are imported from other countries for processing, and marketing within the country. Peanut is another economically important crop grown for edible oil as well as table purposes. During post-harvest processing of nuts, stored product pest problems are becoming major concern. Common pests observed in nut processing industries are insects, mites, rats, microbes, birds, etc., while the insects include, red flour beetle *Tribolium castaneum* (Herbst), red-legged ham beetle *Necrobia rufipes* (De Geer), saw-toothed beetle *Oryzaephilus surinamensis* (L.), dried-fruit beetle *Carpophilus hemipterus* (L.), cadelle *Tenebroides mauritanicus* (L.), almond moth *Ephestia cautella* (Walker), Indian meal moth *Plodia interpunctella* (Hubner), lesser meal worm *Alphitobius piceus* (Olivier), etc (Rajat et al 2020).

Approximately 200 species have been reported under the genus *Carpophilus* which are distributed in tropical and temperate regions mainly by international trade. Many cryptic species like *C. hemipterus*, *C. mutilatus* Erichson, *C. obsoletus* Erichson, *C. ligneous* Murray and *C. dimidiatus* (Fabricius) cause considerable damage to processed and un-processed dried fruits and stored products (Leschen and Marris 2005). The adults and larvae of *Carpophilus* spp. cause damage on poorly dried cereal grains, cocoa, copra, oilseeds, dried fruits, vegetables, herbs and mouldy produce. Louw et al (2009) documented that the dried-fruit beetle breeds prolifically in fermenting fruit, with the adults sheltering under the decaying, moist cladodes those dropped from the cactus pear plant. An event of rain triggered hull rot, *Carpophilus* beetle trap catches, and nut damage in almonds with higher damage levels in wetter areas of Australia (Hossain 2018). Thus, moisture and humidity are very important for the development of dried fruit beetles (Mason

2018). Though the dired-fruit beetle is regarded as a pest of minor importance as it feeds predominantly on rotten, fermented or over ripened fruits in the field, the beetles pose a significant risk to export markets because the infested nuts are difficult to identify and reject during processing and sorting. Moreover, *C. hemipterus* is capable of thriving well even at higher temperatures compared to other species of *Carpophilus* (James and Vogele 2000).

Andhra Pradesh is located in the coastal region of India and there are several industries involved in the processing of various nuts. Volatiles from food products in combination with aggregation pheromones produced by male adults of *C. hemipterus* play a major role in attracting the insects. Abiotic and host-associated factors such as nutritive values, moisture, temperature, processing methods, storage conditions and control measures determine the survival and development of insect pests on dried fruits and nuts and their economic impact. Since these are high-valued food items and traded in international market, a very low or zero tolerance of live insects is allowed. Particularly during certain processing activities, such as, partial rehydration normally done before packing to avoid breakage, nuts are prone to oviposition by dried-fruit beetle and results in returns of shipments. With this in view, studies on life cycle of *C. hemipterus* and its preference among different nuts were taken up which can help in formulation of necessary preventive measures during processing and storage of various nuts.

MATERIAL AND METHODS

Detailed biology of *C. hemipterus* on peanut and its preference among five different nut kernels was studied in ambient conditions at Post Harvest Technology Centre, Bapatla, Andhra Pradesh, India during 2021 and 2022.

Insect rearing: The *C. hemipterus* insects were cultured on disinfested fresh peanut substrate in the laboratory using few adult insects collected from the peanut samples of local processing units. For this purpose, more than 1 kg of freshly shelled peanut kernels were procured and sterilized in a hot air oven for 3 h maintained at 60 ºC to kill all the insects at different stages, if any. After cooling, the kernels were made into four parts of 250 g each and placed in culture jars (500 ml). Then, 50 adults of *C. hemipterus* were introduced into each jar with the aid of an aspirator. The jars were covered tightly with a perforated lid which was covered with fine mesh to allow aeration and were kept in the laboratory at ambient conditions. After allowing oviposition by females for three days, the introduced insects were removed and the cultures were retained until the emergence of adult progeny. After completion of two generations, freshly emerged adult insects were used for the studies on biology and preference.

Life cycle of *C. hemipterus* on peanut: Insects comprising of both sexes were released into fresh peanut kernels and left overnight for oviposition by female insects. All the insects were removed to ensure that the eggs laid are fresh and of same age. The egg laden individual kernels were observed with the help of an illuminated magnifying lens and isolated into small diet cups. They were observed individually till the emergence of adult while the duration of different stages i.e., egg, larva, pupa, and longevity of adult insects were recorded. Thus, total developmental period from egg to adult emergence was worked out. The mean duration of each stage was calculated based on 30 insect individuals. This study was carried out both during summer and winter months.

Preference of *C. hemipterus* to different nut kernels: The relative preference of *C. hemipterus* for five different nut kernels namely; peanut (*Arachis hypogaea* L.), cashewnut (*Anacardium occidentale* L.), pistachio (*Pistacia vera* L.), almond (*Prunus dulcis* [Mill] D.A. Webb), and walnut (*Juglans regia* L.) was assessed under free-choice conditions. Nut kernels of premium quality were procured from the local market of Bapatla. All five types of nuts (20 g each) were taken in separate polythene paper discs (10 cm diameter) and arranged in a circle in a steel container (45 cm diameter and 10 cm depth) having a lid. The mixed population of twenty four *C. hemipterus* adults was released in the centre so that each individual insect can move into the host material according to its preference. Thus, there were five treatments with three replications arranged in completely randomized design. At five days after release of insects (DAR), the nuts were collected in to individual plastic containers (capacity: 200 ml) along with insects and the number of insects moved into each type of nuts was recorded. Observations on subsequent progeny adult emergence from each nut species were recorded at 40 and 80 DAR and the total progeny adults were worked out. The mean population emerged from the nut samples were suitably transformed and analysed for ANOVA using web based agricultural statistics software package WASP 2.0.

RESULTS AND DISCUSSION

Life cycle of *C. hemipterus* on peanut: The dried-fruit beetle adult is a slightly flattened oblong beetle measures 2 to 5 mm in length. The elytra are short, leaving distal portion of the abdomen exposed (Fig. 1). They are light brown in color with yellow markings on the wing cases. On peanut kernels, the adults prefer to lay eggs beneath the seed coat at points where it is ruptured or damaged. They explore to find out such places on the nuts for egg laying. During winter, the egg period of *C. hemipterus* is 5.25 days ranging from 4 to 6 days

(Table 1). The larval period is 19.3 days and the pupal period is 9.05 days. During summer, the period of the egg stage is 4.93 days and the larval period is 29.93 days followed by the pupal stage which lasted for 8.7 days. Thus, the average time period from egg to adult emergence is 33.6 days during winter and 41.17 days in summer. The adults that emerged during the winter months survived for more than 120 days, whereas, those emerged during summer lived only for about one month. Similarly, an extension in larval duration for about 10 days during the dry-weather period also indicated that this pest prefers high humidity.

Gautam et al (2014) observed that eggs of *C. hemipterus* are white in color and cylindrical in shape with bluntly pointed anterior and posterior ends**.** Burks and Johnson, (2012) described that *C. hemipterus* adult has a distinct yellow colored patches on elytra; the antennomeres 2 and 3 subequal in length; prosternal process expanded laterally behind coxae; mesoventrite with discal carinae; and metaventrite with axillary space very small, reaching to 1/5 the length of metepisternum. Adults feed, and live longer than the larvae. Larvae and adults of *C. hemipterus* beetles cause extensive damage by feeding on the product and contaminate it with frass, cadavers, and cast skins; ultimately causing increased moisture which leads to product spoilage with undesirable mold and bacterial growth (Luttfullah and Hussain 2011).

Table 1. Biology of *C. hemipterus* on peanut

Stage of the insect	Development period (Days)	
	During winter	During summer
	Mean± SD (Range)	Mean± SD (Range)
Egg	5.25 ± 0.79 (4-6)	4.93 ± 0.78 (4-6)
Larva	19.3 ± 1.22 (17-21)	29.93 ± 1.93 (27-33)
Pupa	9.05 ± 1.45 (7-11)	8.7 ± 1.09 (7-11)
Egg to adult emergence	33.6 ± 2.26 (31-37)	41.17 ± 2.02 (36-46)
Adult life span	>120	30

Preference of *C. hemipterus* to different nut kernels: Preference of an insect for some food substrate can be determined by the rate at which the insect multiplies on it. Pistachios and cashewnuts attracted significantly more insects (9.33 and 8.67, respectively) of dried-fruit beetle adults, followed by walnuts (4.50), whereas peanuts and almonds received the minimum numbers (0.67 and 0.50) at 5 DAR (Table 2). At 40 DAR, the highest number of progeny of adults were found in pistachios (40.83) followed by cashewnuts (17.83). Walnuts supported the mean population of 5.0 adults while the peanuts (1.50) and almonds (0.83) supported very negligible population. At 80 DAR, the highest adult progeny buildup was in cashewnuts (97.0) followed by pistachios (84.17). In walnuts, as many as 19.67 adults were observed. Peanut and almonds recorded 3.33 and 1.0 adults of progeny, respectively. Overall, the total adult progeny was the highest in pistachios (125.0) which was at par with cashewnuts (114.83). They were followed by walnuts (24.67), while peanuts and almonds registered the total progeny adults at 4.83 and 1.83, respectively. Among the nuts offered to dried-fruit beetle, pistachios and cashews were highly preferred, whereas, almonds were the least preferred, probably they were hard and possessed intact testa. Thus, the order of preference of *C. hemipterus* to the processed nuts tested was; pistachios > cashewnuts > walnuts > peanuts > almonds. Among peanuts, cashewnuts, pistachios, almonds, and walnuts, *C. hemipterus* affected pistachios heavily producing 125 progeny adults in 80 days. Oladipupo et al. (2018) observed that the peanut supported the highest adult emergence and suffered the greatest damage by the *C. hemipterus* compared to other food materials (cocoa, rice and cowpea) and also highlighted the

Table 2. Preference and progeny development of *C. hemipterus* on different processed nuts

Nuts	Insects moved into (No.)	Progeny adult emergence (No.)		
	5 DAR	40 DAR	80 DAR	Total
Peanuts	0.67 (1.05)[c]	1.50 (1.28)[d]	3.33 (1.95)[d]	4.83 (2.31)[c]
Cashewnuts	8.67 (3.0)[a]	17.83 (4.27)[b]	97.0 (9.85)[a]	114.83 (10.72)[a]
Pistachios	9.33 (3.12)[a]	40.83 (6.42)[a]	84.17 (9.19)[b]	125.0 (11.19)[a]
Almonds	0.50 (0.97)[c]	0.83 (1.12)[d]	1.0 (1.18)[e]	1.83 (1.42)[d]
Walnuts	4.50 (2.19)[b]	5.0 (2.32)[c]	19.67 (4.47)[c]	24.67 (5.01)[b]
CD (p=0.05)	0.43	0.33	0.65	0.58

Values in parentheses are square root transformed values; DAR: Days after insect release. In each column values with similar letter do not vary significantly at P=0.05

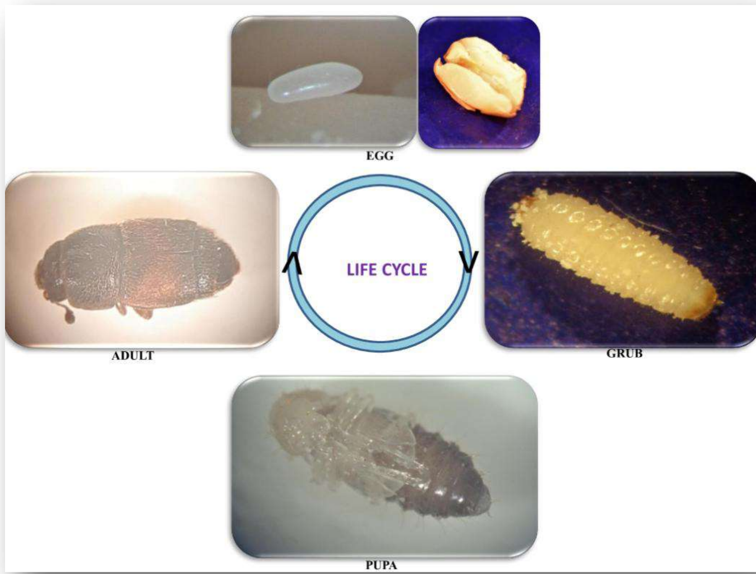

Fig. 1. Biology of dried-fruit beetle *C. hemipterus* on peanut

innate ability of *C. hemipterus* to survive even on less preferred food materials. Despite the strict quarantine and preventive measures, introduced invasive insect species challenge the sustainable pest management due to their fast acclimatization and establishment in new areas. Benedetta et al (2022) reported the invasiveness of *C. truncatus* which is capable of acclimatizing to the walnut and almond production areas of the world and also opined that it is to be considered as a quarantine pest. Thus, their presence itself is of a great concern for those involved in nut processing. Nagaraju et al (2022) reported that some exotic storage pests including *Carpophilus* sp. were intercepted in raw cashew nuts shipments imported into India. Moreover, Carpophiline species are known to tolerate high tropical temperatures. Thus, any sort of poor management and negligence in this regard involves huge costs in terms of salvage as well as exporting country's reputation.

CONCLUSION

Insect infestations at nut processing units are of particular concern as they interfere with international trade and pest-free conditions in the processing and storage facilities should be given much more importance. The dried-fruit beetle preferred processed pistachios and cashews compared to peanuts, walnuts and almonds. Since *C. hemipterus* has been found associated with several nut processing centers, the information on its preference to various nuts is of much relevance in management of this quarantine pest. By adopting simple practices and regular sanitation of process equipment and the premises, the populations of stored-product insects can be prevented from reaching unacceptable levels.

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Characterization and Etiolgy of Pathogen(S) Associated with Wilt Complex Disease of *Lagenaria siceraria* in Himachal Pradesh

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***Abstract*:** The microscopic examination of the diseased plant parts of bottle gourd revealed the association of three pathogens of the wilt complex namely, *Colletotrichum orbiculare*, *Fusarium oxysporum* and *Didymella bryoniae.* Pathogenicity test with each of the three isolated pathogens was conducted on the highly susceptible bottlegourd variety MHBG 8 and the Koch's postulates were proved by *Didymella bryoniae* thereby, confirming the pathogenicity of the test pathogen.*D. bryoniae*exhibited white cottony aerial mycelium and olive green to dark green or black substrate mycelium. Pycnidia were brown coloured and contained hyaline, cylindrical conidia having rounded ends with two guttules, non or mono septate, measuring 3-5 x 2-3 µm. Pseudothecia expressed as dark brown with hyaline pseudoparaphyses protruding from ostiole and contained numerous asci with 8 ascospores each. Ascospores were hyaline, oval, monoseptate and measured 5-8 x 3-5 µm in size. Blast results of the ITS sequences obtained through PCR amplification of the fungal DNA using ITS1 and ITS4 primers were 99 per cent coinciding with that of *Stagnosporopsis cucurbitcearum*. Thus, on the basis of, morpho-cultural characteristics and molecular characterization, the test pathogen is identified and confirmed as *Didymella bryoniae* (*Stagnosporopsis cucurbitcearum*) to be the cause of wilt disease of bottle gourd.

***Keywords*:** Wilt complex, Bottle gourd, *Didymella bryoniae*, Pycnidia, Molecular characterization

The occurrence of wilt complex disease in bottle gourd, grown in Himachal Pradesh, resulted in sudden drying or wilting of the vines leading to complete failure of the crop resulting in huge losses to the farmers. Many pathogens like *Erwinia* spp., *Xanthomonas* spp., *Rhizoctonia* spp., *Colletotrichum* spp., *Fusarium* spp., *Didymella* spp., and an insect pest squash bug (*Anasa tristis*) are associated with the disease, but the exact cause of disease is not known. The pathogen is a newly discovered threat to bottle gourd production in Himachal Pradesh, therefore its correct identification was necessary to establish an effective management strategy.*Didymella bryoniae* (Auersw.) Rehm [anamorph *Stagonosporopsis* cucurbitacearum (Fr.)Aveskamp, Gruyter & Verkley.] is a major fungal pathogen with a widehost range within the family Cucurbitaceae. The pathogen has been reported to occur naturally on *Lagenaria siceraria* in Southeast Asia (Thaung 2008).

Basim et al (2016) observed that *D. bryoniae* isolate under *in vitro* conditions showed white aerial and olivaceous mycelium in the initial stages of growth, whereas olive to dark green or black substrate mycelium in the latter part. The colony surface in the Petri dish was rough and undulated.PCR based technique has more recently been applied for the successful identification of *Didymella bryoniae* (Keinath and Dean 2001). The internal transcribed spacers (ITS) gene of the nuclear ribosomal DNA operon ITS region (Druzhinina et al 2005), has been proposed as standard loci for use in DNA barcoding in fungi. The use of ITS as fungal barcode locus is most popular (Seifert 2009) because ITS is more specific region for distinction at the species level (Singh et al 2005).

Rajkumar et al (2016) carried out the PCR reactions using the cycling conditions of an initial denaturation step at 94°C for 3 min followed by 35 cycles with a denaturation step at 94°C for 15 sec, annealing at 52°C for 40 sec, extension at 72°C for 1 min, followed by a final extension at 72°C for 5 min. Basım et al (2016) and Choi et al (2010) separated the amplified PCR products by gel electrophoresis in 2% agarose gel with 0.5X TAE buffer, stained by keeping the gel in the ethidium bromide (0.5 µg/ml) for 10 min, and then visualized under an ultraviolet (UV) light imaging system which produced fragment sizes of approximately 560 bp (Basım et al 2016). Tsai and Chen (2012) observed that PCR products amplified using primers ITS1 and ITS4 had 98 to 99% nucleotide sequence identity with *Didymella bryoniae*.Keeping in view the economic importance of the disease, a comprehensive study was designed to ascertain the causal agent of the sudden wilt malady of bottle gourd based on morphological and molecular identification.

MATERIAL AND METHODS

Sterilization of glass ware/plastic ware/soil: The glass ware was dry sterilized at 160-180^{0}C for 2 hr in a hot air oven. Growth media were sterilized in autoclave at 1.1 kg/cm^{2} pressure for 20 min, whereas plastic ware was surface sterilized with 100 per cent alcohol.

Isolation and purification: Isolation of the fungal pathogen(s) was conducted from symptomatic fresh plant tissues observed microscopically. Small pieces of tissue (approximately 1 × 1 cm) were cut aseptically from the margin of the lesions. The pieces were disinfested in 1.0 per cent sodium hypochlorite for 15-20 sec, followed by rinsing three times with sterile distilled water, and finally blotted on sterilized filter papers to remove the excess moisture. The bits were then transferred to potato dextrose agar (PDA) and quarter strength potato dextrose agar (QPDA) medium slants under aseptic conditions and were incubated in BOD incubator at 25°C under 24 hr continuous photoperiod produced from cool white fluorescent bulbs. Precautions were taken to avoid contamination of culture from time to time. To obtain a pure culture from a single conidium, a small piece was cut from an area of the colony, taking care to avoid other microorganisms. The piece was put into 10 ml sterile water in a test tube, and was agitated for 20 to 30 sec to release conidia. The spore suspension was serial diluted and 1 ml spore suspension was poured in Petri plates containing 2 per cent water agar. Then after 1 day the Petri plates were examined under microscope, a single spore was marked and transferred to another petri plate containing potato dextrose agar or one quarter strength potato dextrose agar using fine tip needle. Fungal colony arising from single spore was multiplied on PDA or QPDA medium and used for further studies.

Pathogenicity Test

Preparation of inoculum: Inoculum was prepared by flooding a Petri dish of the 15 days old isolate growing on PDA or QPDA with sterilized distilled water and gently scraped to release conidia. The suspension was filtered through four layers of sterile cheese cloth to remove mycelial bits and media. Spore concentration/inoculum load was determined by counting the number of spores in a haemocytometer and adjusted to 1x10^{5} conidia/ml.

Pathogen inoculation: To confirm the identity of isolated pathogen(s) obtained from bottle gourd plants, pathogenicity test was performed by inoculating the isolated pathogen on highly susceptible bottle gourd variety MHBG 8. Healthy plants of susceptible variety were raised in plastic pots (15 cm dia) filled with sterilized soil. Fully established 30 days old plants were inoculated by spray method using spore suspension of test pathogen. Sterile, distilled water was sprayed on corresponding control plants. The inoculated and control plants were placed in net-house at 25-30^{o}C temperature and covered with plastic bags for 96 hr to maintain 100 per cent relative humidity and thereafter the pots were watered daily till the development of disease symptoms. The data on incubation and latent period was recorded. The pathogen was reisolated from the diseased plants to prove Koch's postulates.

Morpho-cultural studies: The pathogen was identified on the basis of morpho-cultural characteristics. Sterilized Petri plates containing equal quantity (20 ml) of PDA/QPDA medium were inoculated with 5 mm culture disc of 10-15 days old culture of pathogen and incubated at 25±1^{o}C. Various morphological traits both, macroscopic (colony colour, colony type, colony growth, pigmentation) and microscopic (size, shape and colour of fruiting bodies and spores) were recorded. Fruiting bodies were placed on a droplet of sterile water on a microscopic slide and crushed to release the contents. The length × width of the spores from the pathogen was measured at 400X magnification and was examined for the presence of septa.

Molecular Characterization

Raising mycelium mass: Five mm bits of the pure culture of the fungus were incubated in liquid potato dextrose broth and kept at 25°C for 8-10 days in orbital shaking incubators. Mycelia (10-15 g) and liquid media were separated by pouring the culture through a funnel lined with filter paper. The mycelia was dried between paper towels and stored at 4°C for further use.

Protocol for DNA extraction: The dried mycelium was ground into fine powder using liquid nitrogen in sterilized pestle mortar. The 50 mg of this powder was taken in 1.5 ml eppendorf tubes and 750 µl of SDS buffer was added to it and incubated at room temperature for 15 min. After incubation 750 µl of Chloroform: Isoethyl alcohol (24:1) is added to it and centrifuged at 14000 rpm for 10 min. The aqueous phase was taken into a fresh eppendorf tube and 400 µl of isopropyl alcohol was added to it and incubated overnight at -20°C.Next morning the tubes were subjected to centrifuge action at 10000 rpm at 4 °C. The supernatant thus obtained was discarded and pellets formed were washed with 200 µl of 70 per cent ethanol and dried for two hr by inverting the tubes over paper towel/tissue paper. At the end, pellet was dissolved in 50 µl of TE buffer centrifuged for one min and stored at -80°C.temperature.

Preparation of agarose gel electrophoresis: The DNA extracted was checked for its quality and quantity using agrose gel electrophoresis. 1.2 per cent agrose gel was prepared by adding 1.2 gms of agrose in 100 ml of TAE buffer (0.5 X) and heated gently till the agrose gets completely dissolved and the mixture becomes transparent. Ethidium di bromide (3 µl/100 ml TAE buffer) was added to the mixture and cooled down before pouring in gel electrophoresis plate on which combs were fixed to make wells. The gel was left undisturbed for 30 min for solidification.3 µl of extracted DNA was mixed with 1 µl of gel loading dye and loaded in the wells of electrophoresis plate that were submerged in 0.5 X TAE buffer.Gel was run at 180 V for one hour and then visualized in ultraviolet (UV) transminator.

PCR amplification and DNA sequencing: Amplification and sequencing of the pathogen DNA was performed using a pair of universal primers ITS1 (5'TCCGTAGGTGAACCTGCGG3') and ITS4 (5'TCCTCCGCTTATTGATATGC3'). PCR reactions were carried out in a total volume of 50 µl. Reaction components included 5 µl of 10X PCR buffer, 2 µl dNTPs, 2 µl of 10 µM forward and reverse primers (ITS1/ITS4), 0.8 µl ExTaq, 3 µl of $MgCl_2$, 2 µl DNA template and 33.2 µl of water. Cycling conditions included an initial denaturation step at 94°C for 3 min followed by 35 cycles with a denaturation step at 94°C for 15 sec, annealing at 52°C for 40 sec, extension at 72°C for 1 min, followed by a final extension at 72°C for 5 min**.**The amplified PCR products were separated by gel electrophoresis in 1.2 per cent agarose gel with 0.5X TAE buffer as described above plus 3 µl of 1 kb plus ladder and water as negative control were also loaded in the adjacent empty wells for comparison and then visualized in ultraviolet (UV) transminator. The amplified PCR products were sent for custom sequencing.

RESULTS AND DISCUSSION

Isolation of the pathogen: Microscopic examination of the fresh samples of diseasedbottle gourd plants collected from different locations of the districts surveyed during cropping season 2020, exhibited presence of *Colletotrichum orbiculare, Fusarium oxysporum* and *Didymella bryoniae*. *Colletotrichum orbiculare* and *Fusarium oxysporum* were isolated on PDA and *Didymella bryoniae* on QPDA. The typical colony of *Didymella* developed on QPDA expressed as white aerial mycelium and olive to dark green or black subsrate mycelium. The results on the description of fungal growth culture of *Didymella bryoniae* are similar to those described by Jensen et al (2011), Keinath (2013) and Rajkumar et al (2016).

Pathogenicity: Data on pathogenicity test with each of the three isolated pathogens *viz., Colletotrichum orbiculare, Fusarium oxysporum* and *Didymella bryoniae* on the highly susceptible bottlegourd variety MHBG 8 reveals the expression of variable disease symptoms (Table 1, Fig. 1). *Colletotrichum orbiculare* produced water-soaked lesions on leaves that later turn into dark brown or black spots with an incubation period of 3 days and latent period of 5 days. *Fusarium oxysporum* caused vascular browning, root rot, main stem browning and wilting with 6 days of incubation period and 11 days of latent period. *Didymella bryoniae* caused water-soaked lesions on leaf margins, stem canker, gummy exudation from vines and leaf wilting with an incubation period of 3 days and a latent period of 10 days.The symptoms produced by *Didymella bryoniae* on inoculated bottlegourd plants were similar to those of the wilt disease under study and the pathogen was reisolated from diseased plants thereby proving Koch's postulates. Hence, confirming the pathogenicity of the test pathogen. Symptoms produced by *Didymella* on bottlegourd plants possessed marked appearance of the characteristic symptoms following lesion formation, canker production, gummy exudation, stem cracking and finally wilting of the vines. Similar observations have been described by Keinath (2013) giving an account of variation in symptomatology on the basis of their prevailing weather conditions.

Morphological identification of the pathogen: The test pathogen exhibited white cottony aerial mycelium and olive green to dark green or black substrate mycelium (Table 3, Fig. 3). Pycnidia was brown coloured and contained hyaline, cylindrical conidia having rounded ends with two guttules, non or mono septate, measuring 3-5 x 2-3 µm. Pseudothecia was of dark brown colour having hyaline pseudoparaphyses protruding from ostiole. Pseudothecia measured 100-120 x 40-80 µm and contained numerous asci with 8 ascospores each. Ascospores were hyaline, oval, monoseptate and

Table 1. Pathogenicity of pathogen(s) associated with wilt complex disease of bottlegourd

Pathogen	Symptom development	Incubation period (days)	Latent period (days)
Colletotrichum orbiculare	Water-soaked lesions on leaves that later turn into dark brown or black spots	3	5
Fusarium oxysporum	Vascular browning, root rot, main stem browning and wilting	6	11
Didymella bryoniae (Stagnosporopsis cucurbitacearum)	Water-soaked lesions on leaf margins, stem canker, gummy exudation from vines, leaf wilting	3	10

appear as two unequally sized triangles joined at the bases, pointing in opposite directions. They measured 5-8 x 3-5 µm in size. Basim et al (2016) observed that *Didymella bryoniae* isolate *in vitro* possess white aerial and olivaceous mycelium in the initial stages of growth and olive to dark green or black substrate mycelium in the latter part.Rajkumar et al (2016) observed hyaline and cylindrical conidia with rounded ends, non or mono septate and measuring 6-13x3-4 µm in size and hyaline ascospores measuring 15-21x5-8 µm in size that are monoseptate with two cells of differing sizes. Keinath (2013) mentioned dark brown to black coloured pseudothecia containing hyaline pseudoparaphyses protruding from the ostiole which are in accordance to the studies with respect to the test pathogen. Thus, the characteristic features of the test pathogen related, revealed its identity as *Didymella bryoniae*.

Molecular characterization of the pathogen: DNA was

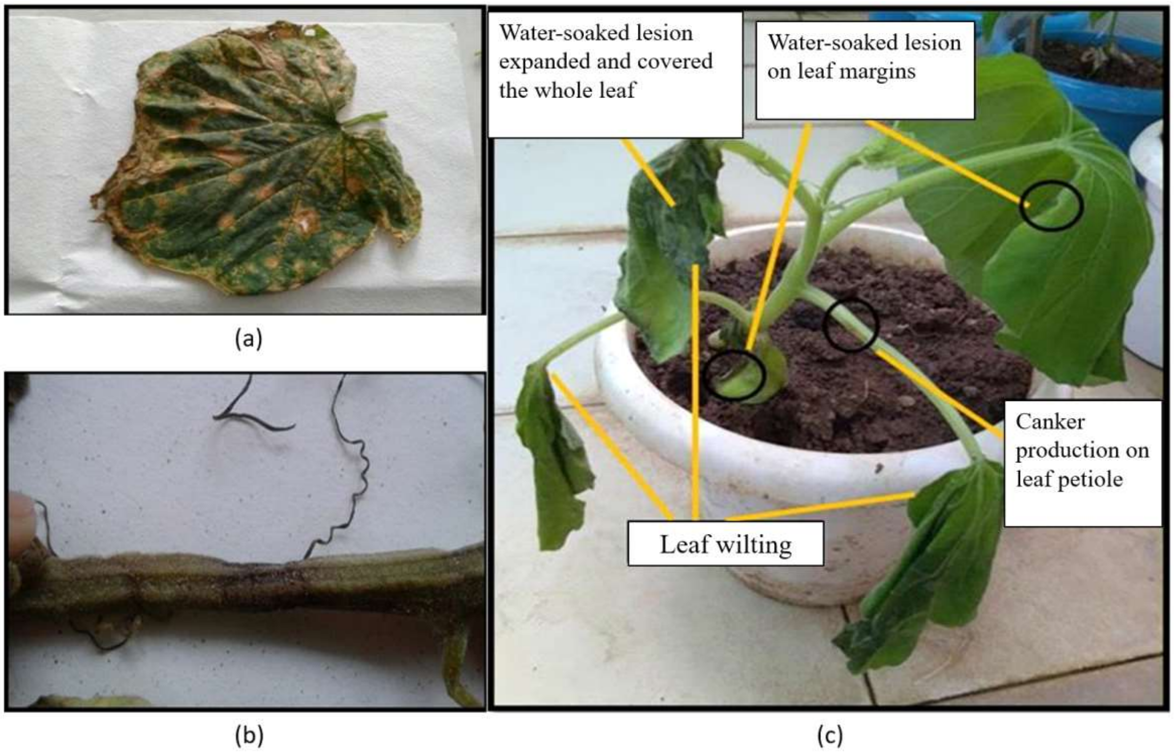

Fig. 1. Pathogenicity test of the isolated pathogen(s); (a) *Colletotrichum orbiculare* (b) *Fusarium oxysporum* (c) *Didymella bryoniae*

Table 2. Pathogen (s) associated with wilt complex disease of bottle gourd in different districts of Himachal Pradesh

District	Plant parts observed	Microscopic observations	Pathogen associated	Frequency of occurrence (%)
Kangra	Leaves	Acervuli and conidia	*Colletotrichum orbiculare*	30.0
	Leaves and roots	Macro and micro conidia	*Fusarium oxysporum*	10.0
	Leaves and stem	Conidia	*Didymella bryoniae (Stagnosporopsis cucurbitacearum)*	60.0
Hamirpur	Fruits	Acervuli and conidia	*Colletotrichum orbiculare*	10.0
	Stem	Macro and micro conidia	*Fusarium oxysporum*	25.0
	Stem and fruits	Pseudothecia and ascospores	*Didymella bryoniae*	65.0
Bilaspur	Fruits and leaves	Conidia	*Colletotrichum orbiculare*	25.0
	Stem and leaves	Macro and micro conidia	*Fusarium oxysporum*	15.0
	Fruit and stem	Conidia and ascospores	*Didymella bryoniae*	60.0
Una	Stem and leaves	Macro and micro conidia	*Fusarium oxysporum*	20.0
	Leaves, stem and fruit	*Pycnidia and conidia, pseudothecia and ascus*	*Didymella bryoniae*	80.0

extracted using SDS extraction buffer and checked for its quality in 1.2% agarose gel (Fig. 4). The amplified product using ITS1 and ITS4 primers were electrophoresed in 1.2% agarose gel and visualized in UV transamination (Plate 4.6). Amplification of 550 bp was obtained. Then the amplified product was sent for custom sequencing. The sequences obtained were as:

CAATACAATCCTTGGTATTCCATGGGGCATGCCTGT
TCGAGCGTCATTTGTACCTTCAAGCTTTGCTTGGTGTT
GGGTGTTTGTCTCGCCTCTGCGCGCAGACTCGCCTCA
AAACGATTGGCAGCCGGCGTATTGATTTCGGAGCGCA
GTACATCTCGCGCTTTGCACTCACAACGACGACGTCC
AAAAAGTACATTTTTTACACTCTGACCTCGATCATGATG
TGCCGCGTCCAGCCTCAAACCG

The sequence analysis using NCBI blast program showed 99% homology with the reference sequences of

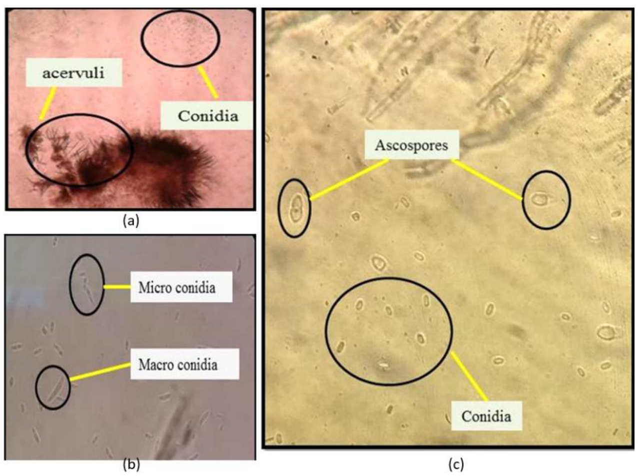

Fig. 2. Microscopic examination of the diseased plant samples; (a) *Colletotrichu orbiculare* (b) *Fusarium oxysporum* (c) *Didymella bryoniae*

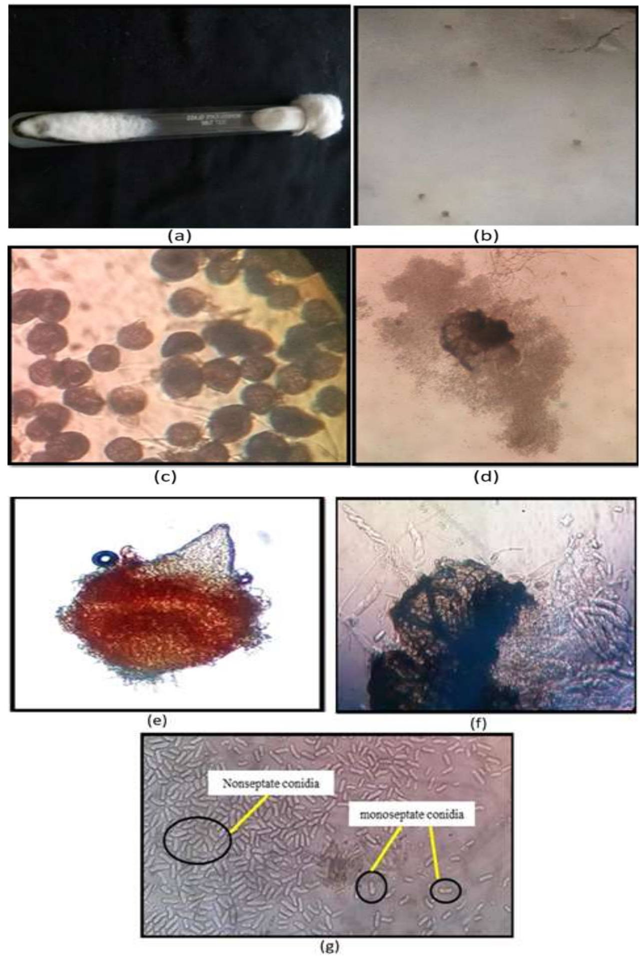

Fig. 3. Morpho-cultural features of the test pathogen causing wilt disease of bottle gourd; (a) pure culture of test pathogen, (b) fruiting bodies on culture, (c) brown coloured pycnidia, (d) pycnidia liberating conidia (e) pseudothecia with hyaline pseudoparaphyses, (f) pseudothecia liberating asci, (g) mono septate and non septate conidia

Table 3. Morpho-cultural features of the test pathogen causing wilt disease of bottle gourd

Character	Isolated test pathogen	*Didymella bryoniae**
Aerial mycelium	White coloured aerial mycelium	White aerial mycelium
Substrate mycelium	Olive to dark green or black coloured substrate mycelium	Olive to dark green or black substrate mycelium
Pycnidia	Brown coloured	Tan or brown coloured with a dark ring of cells around the ostiole
Conidia	Hyaline, cylindrical, rounded ends with two guttules, non or monoseptate, 3-5 x 2-3 µm	Hyaline, oblong to cylindrical with rounded ends,mainly with two guttules, and non or monoseptate, 6-13 x 3-5 µm
Pseudothecia	Dark brown, hyaline pseudoparaphyses protruding from ostiole, asci with eight ascospores, 100-120 x 40-80 µm	Dark brown to black, slightly immersed in the host tissue, hyaline pseudoparaphyses are present, protruding from the ostiole. Contain numerous asci with eight ascospores each, pseudothecia ranged from 195-205 µm in diameter
Ascospores	Hyaline, monoseptate, oval, appear as two unequally sized triangles joined at the bases, pointing in opposite directions, 5-8 x 3-5 µm	Hyaline and monoseptate, 13-21 µm in length and 5-8 µm in width, they are oval and appear as two unequally sized triangles joined at the bases, pointing in opposite directions

*Keinath et al 1995

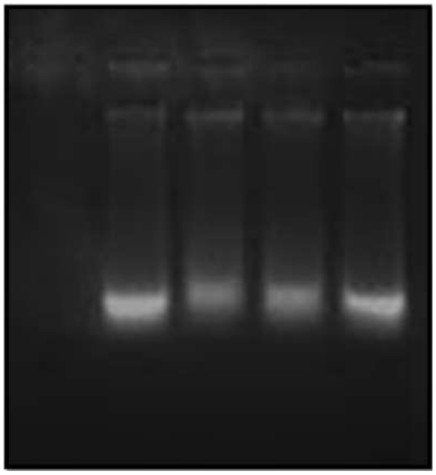

Fig. 4. DNA check of *Didymella bryoniae*

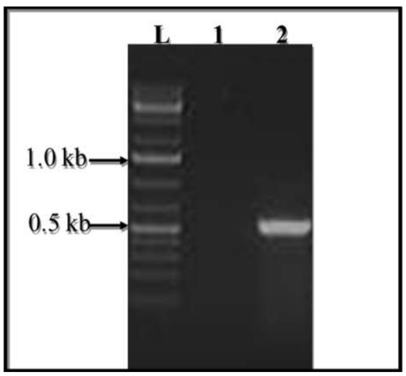

Plate 4.6. PCR amplification of ITS region using ITS 1 and ITS 4 primers.

L: 1 kb plus ladder, 1: Negative control, 2: PCR with fungal DNA

Stagnosporopsis cucurbitcearum. Thus the identity of the test pathogen was established as *Didymella bryoniae* (*Stagnosporopsis cucurbitcearum*). Based on the morpho-cultural characteristics and molecular characterization, the test pathogen is identified and confirmed as *Didymella bryoniae* (*Stagnosporopsis cucurbitcearum*) to be the cause of the disease.

CONCLUSION

Out of the three pathogens associated with wilt complex of bottle gourd, *Didymella bryoniae* proved to be the causal agent of the disease. It produces the characteristics symptoms of the disease when inoculated into healthy plants. It exhibits white cottony aerial myceliuma produces brown pycnidia and hyaline conidia with rounded edges. Pseudothecia produced are dark brown in color. The BLAST results of ITS sequences showed 99 per cent similarity with *Stagnosporopsis cucurbitcearum.* Therefore, based on morphological and molecular characters we were able to identify and confirm the *Didymella bryoniae* as the causal agent of wilt disease of bottle gourd.

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Disease Scenario and Virulence Pattern of Major Wheat Pathogens Occurring in Indo-Gangetic Plains of West Bengal, India

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Abstract: Owing to climate change, the disease dynamics have been altered across important wheat growing belts of our country. Considering the importance of wheat in West Bengal, a survey was conducted across different districts of the state in the year 2019-20 and 2020-21 for monitoring the present status of foliar diseases of wheat. In the year 2019-20, seven locations across two districts, Nadia and Murshidabad, were surveyed while twenty locations across six districts were surveyed in the following year. In 2019-20, high spot blotch severity (43.21%) was observed in four locations of Nadia district, while Karimpur of Nadia (24.69%) and Jalangi in Murshidabad district recorded lower severity (24.69). Highest leaf rust severity score was recorded in Jalangi, Murshidabad (100 S), while lowest severity was observed in Karimpur Parisha in Nadia district (20 S). In 2020-21, highest spot blotch severity (59.26%) was recorded in two locations (Jalangi, Dhanirpur-Bhaduripara) of Murshidabad district, while lowest disease severity (9.88%) was observed in Bara Aduliya (Krishnanagar) of Nadia. Highest rust severity (80 S) was observed in Nadia District while lowest severity (20 S) was recorded in four locations of Nadia (Bara Aduliya, Krishnanagar, Magurakhod, Bhajanghat), one in Birbhum (Tarapith) and Murshidabad (Raninagar). Pathogen identification revealed rust pathotype 77-9 (121R60-1) was most abundant in both the consecutive years, while isolate WB7 of *Bipolaris sorokiniana (*Accession no. MT804348) was most aggressive among the isolates collected. The identified pathotypes can be used further for screening of genotypes.

Keywords: Leaf rust, Spot blotch, Survey, Variability, Wheat

Wheat (*Triticum aestivum* L.) is one of the most significant cereal crops and is the staple for almost 2.5 billion people worldwide. Being blessed and equipped with a diverse agro-ecological environment, India is the world's second-largest producer of wheat, providing food and nutrition security to the majority of its population through production and consistent supply, notably in the recent past (Sharma and Sendhil 2015). With a share of 13.53% in the global total production of wheat, India is the world's second-largest producer behind China (PIB 2021). Approximately 32 million hectares of wheat were cultivated in India, yielding 110 million tonnes at productivity of 3467 kg per hectare (FAOSTAT 2021). By reaching record and surplus wheat output, coordinated research and multiple food security and development-based programmes in various stages have brought the country closer to realising "food and nutrition for everyone." However, wheat is susceptible to a plethora of biotic stresses, which includes rust and spot blotch.

Spot blotch disease of wheat (caused by *Bipolaris sorokiniana*), and leaf rust (caused by *Puccinia triticina*), are common in warm, humid regions of the world where wheat is grown (Joshi et al 2007 Kumar et al 2020). It causes significant yield loss in warm and humid regions of the world such as China, Africa, Eastern India, Bangladesh, Latin America and Nepal (Devi et al 2018, Gupta et al 2018). Typically, *B. sorokiniana* causes symptoms on the stem, sheath, and leaf (Roy et al 2023). Severe infection may also penetrate the spikes, producing low weight, shrivelled grains with a black tip at the embryo end of kernels (Gupta et al 2018). The pathogen heavily relies on favourable environmental factors for disease development (Devi et al 2018, Tamang et al 2021). Extensive research has been conducted to identify and develop resistant and tolerant genotypes against the disease (Kumar et al 2019, Mahapatra et al 2020). Leaf rust solely affects foliage, in the form of dusty, reddish-orange to reddish-brown fruiting structures that emerge on the surface of the leaf are indicative symptoms. In case of severe infection, numerous spores from these lesions can almost completely cover the upper leaf surface, which leads to defoliation and yield reduction. There is a 15-20% estimated annual yield loss of wheat in South Asia as a result of this disease (Duveiller and Sharma 2009). Early infection may cause plants to become weak and have poor root and tiller growth (Heidarian et al 2020). For assessing the disease severity, survey is a foremost tool. With an alteration in climatic conditions, the disease dynamics have changed (Debnath et al 2021), which necessitates the conduction of surveys. Further, the variability study of a fungus and its aggressiveness are important to determine a wholesome picture of pathogen. Hence, the present investigation was carried out to develop a comprehensive idea of the disease severity and variability of associated pathogen in the Indo-Gangetic plains of West Bengal.

MATERIAL AND METHODS

Survey and data recording: For the present investigation, the disease severity of spot blotch and leaf rust across different districts of West Bengal were recorded from 2019-20 to 2020-21. Regular visits to farmers' fields as well as trial nurseries were conducted to assess the severity of the diseases and identify the disease hotspots. Monitoring for leaf rust and spot blotch was conducted during crop season as well as off-season to examine the survival of the pathogen on collateral hosts. The surveys were conducted from November in Nadia, Birbhum, Murshidabad, Malda and Hooghly districts of West Bengal. For assessing the severity of leaf rust, the infected plants were evaluated using modified Cobb's scale by using 0-9 scale (Kaur et al 2018). For spot blotch, the disease severity was assessed by visually scoring the flag (F) and penultimate (F-1) leaves, as per the double digit scale (00-99), Disease severity (Diseased leaf area DLA%) was calculated using the following Osman et al (2015). Here, D1 indicates the disease scored in F leaf and D2 indicates the diseases scored in F-1 leaf.

Disease Severity (DLA %) = $(D1/9) \times (D2/9) \times 100$,

Pathogen identification: The collected rust samples were sent to Rust laboratory, Flowerdale, Shimla for identification of the collected pathotype (Nayer et al 1997). The recorded disease severity for the consecutive years were further analysed to determine their dependence on weather parameters and shift in prevalent pathotype. For isolation of *Bipolaris sorokiniana* isolates, naturally infected wheat leaves exhibiting characteristic symptoms of *Bipolaris sorokiniana* were collected from 10 different locations of West Bengal, which exhibited high disease severity (Table 1). Fragments of infected leaves were then surface sterilized and incubated for 3 d (12 h photoperiod, 25°C). After the growth of mycelia on the incubated fragments, the pathogen was isolated using single spore technique (Aregbesola et al 2020). The morphological and microscopic characteristics, described by Mew and Gonzales (2002) were used to identify the pathogen. The culture was then multiplied on Potato Dextrose Agar media and incubated in BOD incubator at 26±1°C.

For molecular characterization of the pathogen, amplification of ITS genomic region was done using primer pair ITS1/ITS4.The PCR cycle included initial denaturation at 94 °C for 1 min, followed by 35 cycles of denaturation, annealing and extension at 94 °C for 30 s, at 55 °C for 30 s, and 72 °C for 1 min, respectively, and final extension at 72 °C for 10 min. The amplicon was subjected to a 1.2% gel electrophoresis. A 100bp ladder was used for confirming the amplicon size and the product was visualized using Gel Doc XR System (Bio-Rad Laboratories). The sequence homology was conducted by BLAST analysis at NCBI. The identified sequences were aligned using Clustal W multiple alignment software. The generated amplicons were freez dried and then sent to Eurofins Genomics, India for sequencsing.

Virulence assessment of *Bipolaris sorokiniana* isolates: K-4015, a popularly grown genotype was used for virulence assessment of the isolates. For the assessment under greenhouse conditions, the pure culture of pathogen, was harvested by flooding the plates with sterilized distilled water,

Table 1. Prevalence of foliar diseases of wheat in different districts of West Bengal during 2019-20

Location	Geographical location (GPS)	Spot blotch (Disease severity)(%)	Leaf rust (Cobbs Scale)
Nadia district			
Bara Anduliya, Krishnanagar	23.62° N, 88.53° E	24.69 (29.79)	20 S
Thana rd. Chapra	23.54°N, 88.55°E	43.21 (41.10)	30 S
Chhitka Daspara	23.84°N, 88.49° E	43.21 (41.10)	40 S
Karimur cha	23.97° N, 88.62° E	43.21 (41.10)	80 S
Jamtala	22.11°N, 88.57° E	43.21 (41.10)	80 S
Karimpur, Parisha	23.97° N, 88.62° E	24.69 (29.79)	20 S
Murshidabad district			
Jalangi, Domkol	24.13° N, 88.69° E	24.69 (29.79)	100 S

and rubbing the culture with a sterilized glass rod. 1% TWEEN®20 solution was added to the suspension to aid in emulsification of the spores. The obtained suspension was filtered through three-layered muslin cloth, to obtain a dirt free, uniform suspension of fungal spores/mycelial bits. Three weeks old plants were sprayed with a pathogen solution. The concentration of the inoculum was adjusted at 2 × 10^5 spores/ml with the aid of hemocytometer prior to inoculation. After inoculation, the plants were covered with clear plastic bags for 24 h, to help in pathogen establishment. The pots were arranged in completely randomized block design, with 3 replications. The average temperature of the greenhouse was 25°C, with RH >95%. Irrigation was provided on a regular basis to maintain the humid microclimate.

RESULTS AND DISCUSSION

Disease scenario: For identifying the major diseases of wheat, a survey was conducted across different districts of West Bengal in the year 2019-20 and 2020-21 (Fig. 1). While recording spot blotch severity, characteristic spot blotch symptoms in the form of elongated brown elliptical to oval lesions were observed on the leaves, sheath, glumes and nodes (Fig. 2). In the year 2019-20, seven locations across two districts, Nadia and Murshidabad, were conducted. The wheat varieties mostly cultivated were HD2967, HD 3086, PBW 343 and in few places still growing Sonalika. The size of the farmers field are mostly very small 2-3 bighas and farmers were mostly growing wheat for their own consumption only. But when survey were conducted in Murshidabad district then few farmers were growing wheat for commercial perpus and overall crop health were good enough. They were mostly growing HD 2967, DBW187, HD 3086 etc. and few farmers even don't had knowledge about variety they were using. Spot blotch and leaf rust was reported in all the locations surveyed, with varying severity (Table 1). High spot blotch severity (43.21%) was observed in four locations of Nadia district (Thana rd. Chapra, Chhika Daspara, Karimur cha, Jamtala), while Karimpur of Nadia (24.69%) and Jalangi in Murshidabad district recorded lower severity (24.69%). The rust severity, in the year 2019-20, ranged between 20S to 100 S across varying locations. The highest leaf rust severity score was recorded in Jalangi, Murshidabad (100 S), while the lowest severity was observed in Karimpur, Parisha and Bara Anduliya, Krishnanagar in Nadia district (20 S). In Nadia, the highest severity (80S) was observed in Karimur cha and Jamtala. In the following year, twenty locations across six districts were surveyed (Table 2). Among the locations surveyed, highest spot blotch severity (59.26%) was recorded in two locations (Jalangi, Dhanirpur-Bhaduripara) of Murshidabad district, followed by Raninagar (51.85%) in Murshidabad. In Nadia district, spot blotch disease severity ranged from 9.88-51.85%, with Bara Aduliya (Krishnanagar) and Magurakhod recording lowest and highest disease severity respectively. A disease severity of 43.21% was recorded in Kalyani, Shukpukuria, Chhitka (Krishnanagar-Karimpur road side) and Jamtala, while relatively lower scores were recorded in Bhajanghat (37.04%), followed by Chhika-Daspara, Karimur cha and Thana rd. Chapra .The disease severity was maximum in in Malda (43.21%) followed by Birbhum , Hooghly and North 24 Parganas. Lowest disease severity (9.88%) was observed in Bara Aduliya (Krishnanagar) of Nadia district. In both the year diseases severity data not varied much as the prevailing weather and it is a good indication that diseases were under control due to use of tolerant newly recommended varieties used by the farmers of survey locations (Table 3). Among the locations surveyed for leaf rust severity, highest severity (80 S) was observed in Karimur cha and Jamtala of Nadia District while lowest severity (20 S) was in four locations of Nadia (Bara Aduliya, Krishnanagar, Magurakhod, Bhajanghat), one in Birbhum (Tarapith) and Murshidabad (Raninagar). No rust incidence was recorded in North 24 Parganas and Hooghly Districts. Among the twelve locations of Nadia highest leaf rust severity (80S) was in Karimur cha and Jamtala followed by Kalyani, Shukpukuria, Chhika-Daspara. Among the four districts of Murshidabad highest leaf rust incidence in Domkol-taraf (60 S) followed by Dhanirpur-Bhaduripara, Jalangi and Raninagar .

Identification of samples: Following survey of disease prevalence across different districts of West Bengal, the samples were kept for further identification. The collected rust samples were sent to Rust laboratory, Flowerdale, Shimla for identification of the collected pathotype (Table 4). In 2019-20, the occurrence of Pathotype 77-9 (121R60-1) was highest in the collected samples (21), followed by 77-5 and 77-9+Raj1555. The pathotypes 12-3 (49R37) and 12-4 (69R13) were identified in one sample each. In the following year, pathotype 77-9 (121R60-1) was most abundant (11 samples) followed by 77-9+Raj1555 (121R60-1,7), 77-5 (121R63-1) and 12-3 (49R37). During the cropping season 2019-20 and 2020-21, ten isolates of *B. sorokiniana* were collected from different fields of West Bengal (Table 5). The isolates were subjected to molecular identification by conducting PCR, using primer pairs ITS1/ITS4. Species specific bands were observed at around 600 bp, which was measured using the representative ladder (Fig. 3). The DNA sequences were sent to NCBI to get the accession numbers (Table 5). The sequences were searched in NCBI-BLAST and their identity percentage with reported ITS sequences was obtained (Table 6). While determining the aggressiveness among the isolates of *Bipolaris sorokiniana*, isolate WB7 (Accession no. MT804348) was the found to be the most aggressive among the ten isolates when evaluated on DBW 90 (70.99%). Among the 10 isolates highest severity was noticed in WB7 (70.99%), while lowest severity was observed in WB3 and WB4 (7.02 and 7.86%, respectively). The disease severity in the isolates WB1 (39.88%), WB2 (39.24%) and WB5 (41.69%) were observed to be statistically at par with each other. Similarly, the difference in disease severity between WB8 (25.02%) and WB9 (24.24%) were statistically at par with each other. Different disease severity was observed in WB10 (55.18%) and in WB6 (36.28%), though they were not significantly different. The

Table 2. Prevalence of foliar diseases of wheat in different districts of West Bengal during 2020-21

District	Location	Geographical location (GPS)	Spot Blotch (Disease severity %)	Leaf rust (Cobbs Scale)
North 24 Parganas	Bagda	23.21° N, 88.89° E	14.81 (22.63)	No rust
	Jaypur, Chandanpukur	23.38°N, 88.56°E	24.69 (29.79)	No rust
Nadia	Bhajanghat	23.38° N, 88.74° E	37.04 (37.49)	20s
	Kalyani	22.97° N, 88.43° E	43.21 (41.10)	40s
	Shukpukuria	23.61° N, 88.36°E	43.21 (41.10)	40s
	Magurakhod	25.25°N, 88.08°E	51.85 (46.06)	20s
	Chhitka (Krishnanagar-Karimpur road side)	23.84°N, 88.49°E	43.21 (41.10)	No rust
	Chhika-Daspara	23.84°N, 88.49°E	24.69 (29.79)	40 S
	Karimur-cha	23.97°N, 88.62°E	24.69 (29.79)	80 S
	Bara Aduliya, Krishnanagar	23.62° N, 88.53° E	9.88 (18.32)	20 S
	Thana rd. Chapra	23.54°N, 88.55°E	24.69 (29.79)	30 S
	Jamtala	22.11°N, 88.57°E	43.21 (41.10)	80 S
Malda	Sultanganj	24.85° N, 88° E	43.21 (41.10)	40s
Birbhum	Tarapith	24.11° N, 87.79° E	29.63 (32.98)	20s
	Mallarapar	24.08° N, 87.71° E	24.69 (29.79)	40s
Hooghly	Bhedia, Sekampur	23.58°N, 87.74°E	43.21 (41.10)	No rust
Murshidabad	Raninagar	24.22° N, 88.55° E	51.85 (46.06)	20s
	Jalangi	24.13°N, 88.69°E	59.26 (50.34)	40s
	Domkol-Taraf	24.12° N, 88.54° E	43.21 (41.10)	60s
	Dhanirpur-Bhaduripara	24.88° N, 88.56°E	59.26 (50.34)	40s

Table 3. Weather parameters of the districts surveyed during February-March of 2019-20 and 2020-21

Year	T max (°C)	Tmin (°C)	Rainfall (mm)	RH max (%)	RH min (%)	DLA (%)
2019-20	27.09	11.81	0.18	87.37	66.93	35.27
2020-21	29.46	14.99	0.00	85.58	60.00	38.14

result therefore indicated that most aggressive isolate which produced maximum disease severity was WB7 followed by WB10 whereas WB3 and WB4 were least virulent with respect to their symptom development in host.

In this era of changing climatic conditions, an array of new pathotypes has emerged in different wheat growing zones of the world. Although North-Eastern Plain Zone is a major wheat growing belt in the country, the disease dynamics have changed drastically, owing to a drastic climate change, occasional drizzles and warm temperature during winter (Debnath et al 2021). Considering the importance of wheat in the eastern zone of the country, it becomes imperative to identify the prevalent diseases in the wheat belts of NEPZ. Hence the present study was conducted to identify the major foliar diseases of wheat across different districts of West Bengal, as well as to identify the pathotypes of the brown rust collected during the survey. In the present study, spot blotch and leaf rust have been observed to be the most prevalent in the districts surveyed. Different frequencies of *Bipolaris sorokiniana* have been found throughout the wheat-growing regions in India as well as in neighboring nations. Devi et al (2021) already established the variability among the isolates collected from the same study area. Iftikhar et al (2010) discovered that in Pakistan, the Sindh zone had the highest prevalence of spot blotches (75% in 2005) followed by Foot hill areas of Gilgit and Sukardu (62.5%), and central Punjab area (60%). A minimum yield loss of 30% has been reported under favourable conditions in susceptible varieties in India (Sharma-Poudyal et al 2016), while 18-50% yield loss was

Table 4. Pathotype distribution of brown rust (*Puccinia triticina*) in West Bengal during 2019-20 and 2020-21

Pathotype observed		No. of samples
2019-20	12-3 (49R37)	1
	12-4 (69R13)	1
	77-5 (121R63-1)	5
	77-9 (121R60-1)	21
	77-9+Raj1555	3
2020-21	12-3 (49R37)	1
	77-5 (121R63-1)	3
	77-9 (121R60-1)	11
	77-9+Raj1555 (121R60-1,7)	9

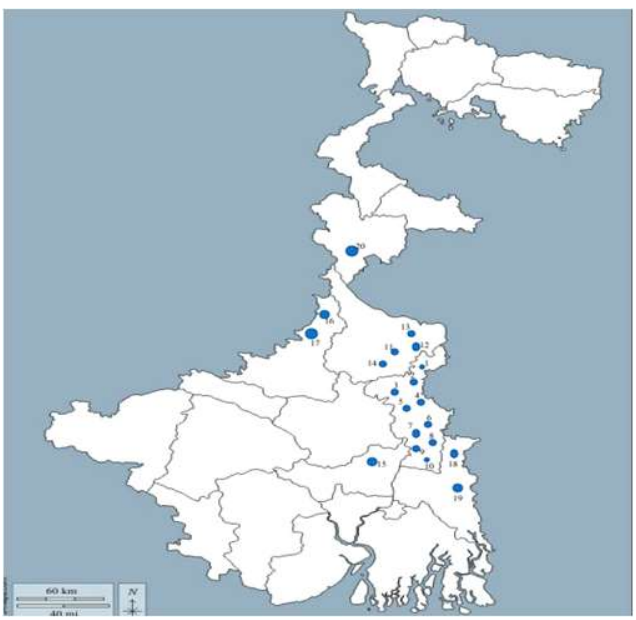

Fig. 1. Locations surveyed during 2019-20 and 2020-21. 1-Karimur Cha, 2- Karimur, Parisha, 3- Jamtala, 4- Bara Anduliya, 5-ChikkaDaspara, 6-Thana Rd., 7-Mungrakhod, 8-Shukpukuria, 9-Bhajanghat, 10-Kalyani, 11- Domkol, 12- Jalangi, 13- Raninagar, 14-Bhaduripara, 15-BhediaSekampur, 16-Mullarpur, 17-Tarapith, 18-Bagda, 19-Chandanpukur, 20-Sultanganj

Fig. 2. Characteristic disease symptoms observed during field survey A. Rust B. Spot blotch

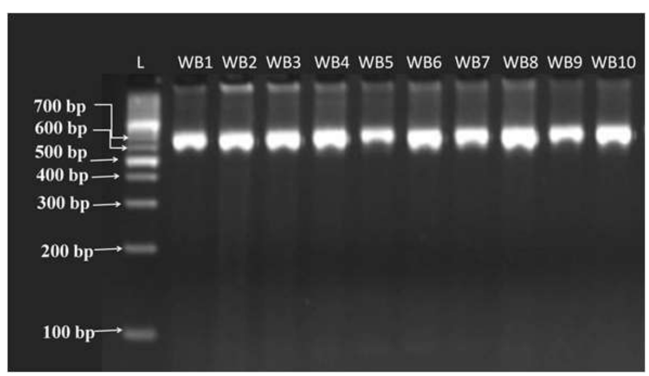

Fig. 3. PCR amplification products from the ITS region (ITS1, 5·8S, ITS2) of 10 *Bipolaris sorokiniana* isolates. Lane L, DNA ladder (100 bp); WB(1-10): Amplicons of *Bipolaris* isolates

observed in warm and humid regions of the world (Gurung et al 2014). In study, high spot blotch severity (43.21%) was observed in four locations of Nadia district (Thana rd. Chapra, Chhika Daspara, Karimur cha, Jamtala), while Karimpur of Nadia and Jalangi in Murshidabad district recorded lower severity (24.69%) in 2019-20. In the following year, the highest spot blotch severity was recorded in two locations of Murshidabad district, followed by Raninagar in Murshidabad. The variations in disease severity might be due to varying weather conditions and differences in pathogen inoculum density across different districts. Leaf rust has been considered as the most severe and widely distributed among the three rusts of wheat (Huerta-Espino et al 2011). In study, the highest leaf rust severity score was recorded in Jalangi, Murshidabad in 2019-20, while highest leaf rust severity was d in Karimur cha and Jamtala of Nadia District in the following year. The difference of intensity might be due to difference in degree of resistance among cultivars, as well as prevalent weather conditions (Pasquini et al 2003). In both the year except few locations diseases data of both spot and leaf rust were under control as because of the farmers using the recent NEPZ recommended varieties. Except HD 3086 showed high leaf rust score as it susceptible to leaf rust. Even in both the years winter season not received must rain so disease severity were low. Overall diseases status of the both year were food along with good crop health.

The collected samples of leaf rust were sent to Rust laboratory, Flowerdale, Simla for identification of the collected pathotype, which revealed the prevalence of Pathotype 77-9, 77-5 77-9+Raj1555, 12-3 and 12-4 in the year 2019-20. In the following year, the collected pathotypes were identified as 77-9, 77-9+Raj1555. 77-5) and 12-3. In the same year, the pathotype 77-5 was identified in two samples from Tamil Nadu, while the pathotype 77-9 was identified in four samples from Himachal Pradesh and one sample from Tamil Nadu (Prasad et al 2020). In a subsequent survey conducted in India in 2020, the pathotype 77-5 was discovered in five samples each from West Bengal and Gujarat, two samples each from Himachal Pradesh, Punjab, and Uttar Pradesh, one sample each from Jammu & Kashmir and Bihar, six samples each from Uttarakhand, seventeen samples each from Madhya Pradesh, eleven samples from Maharashtra, and twelve samples each from Karnataka and sixty two samples of Tamil Nadu. The same pathotype was identified in multiple samples from Himachal Pradesh, Punjab, and Uttar Pradesh, as well as three samples each from West Bengal, Maharastra, Karnataka, Tamil Nadu, and Madhya Pradesh in 2021 (Prasad et al 2021). The pathotype 77-9 was identified in West Bengal, Himachal Pradesh, Jammu & Kashmir, Punjab, Uttar Pradesh, Uttarakhand, Madhya Pradesh, Bihar, Gujrat, Maharastra, Karnataka, and Tamil Nadu in 2020. In 2021, the pathotype 77-9in a number was observed from Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, Uttarakhand, Maharastra, Madhya Pradesh, Bihar, Maharastra, Karnataka, and Tamil Nadu in addition to eleven samples from West Bengal. The pathotype 77-9+Raj1555 was identified from Uttar Pradesh (3 samples) and from Punjab (1 sample) in 2020 (Prasad et al 2020), while it was

Table 5. Details about the isolates of *Bipolaris sorokiniana* collected from survey locations

Isolates	NCBI accession No.	Location	Geographical location (GPS)	Mean disease severity (%)
WB1	MT804342	Sultanganj	24.85° N, 88° E	39.88 ± 1.89[c]
WB2	MT804343	Bhajanghat	23.38° N, 88.74° E	39.24± 1.55[c]
WB3	MT804344	Tarapith	24.11° N, 87.79° E	7.02± 1.67[a]
WB4	MT804345	Mallarapar	24.08° N, 87.71° E	7.86± 1.01[a]
WB5	MT804346	Domkol-Taraf	24.12° N, 88.54° E	41.69± 1.82[c]
WB6	MT804347	Shukpukuria	23.61° N, 88.36°E	36.28± 1.10[bc]
WB7	MT804348	Jalangi	24.13°N, 88.69°E	70.99 ± 1.99[e]
WB8	MT804349	Jamtala	22.11°N, 88.57°E	25.02± 1.43[b]
WB9	MT804350	Chhitka (Krishnanagar-Karimpur road side)	23.84°N, 88.49°E	24.24 ± 1.93[b]
WB10	MT804351	Raninagar	24.22° N, 88.55° E	55.18 ± 1.16[d]

Means with the same letter are not significantly different according to DMRT's significant difference test (α=0.05)

Table 6. Identification of *Bipolaris sorokiniana* isolates of ITS region

Sample	BLAST match	NCBI accession no.	Query coverage (%)	Max identity (%)
WB1	*Bipolaris sorokiniana* strain WH.PBW.IP.04	KM066949.1	100	100
WB2	*Bipolaris sorokiniana* isolate PJC5	OM419194.1	100	100
WB3	*Bipolaris sorokiniana* strain BS-47	DQ367884.1	100	100
WB4	*Bipolaris sorokiniana* isolate WLB-18-10	MK809557.1	100	100
WB5	*Bipolaris sorokiniana* isolate WLB-18-13	MK809551.1	100	100
WB6	*Bipolaris sorokiniana* isolate A35	OQ225221.1	100	100
WB7	*Bipolaris sorokiniana* isolate 01	MT254730.1	100	100
WB8	*Bipolaris sorokiniana* isolate WLB-18-22	MK809565.1	100	100
WB9	Bipolaris sorokiniana isolate WB9	MT804350.1	100	100
WB10	*Bipolaris sorokiniana* isolate WLB-17-47	MN535889.1	100	100

identified from Himachal Pradesh, Punjab, Uttar Pradesh, Uttarakhand, Madhya Pradesh, and Maharashtra in 2021 (Prasad et al 2021). Pathotypes 77-5 , 77-9 and 77-9+Raj1555 were discovered in nearby countries like Nepal in two, twenty seven, and twelve samples, respectively (Prasad et al 2021). Upon conduction of molecular studies, ten different isolates of *Bipolaris sorokiniana* were identified. Verma et al. (2020) had identified different isolates of *Bipolaris sorokiniana* based on Two Internal transcribed spacer (ITS) region, from Maharashtra. In the present study, the isolates were also observed to vary based on the aggressiveness. Isolate BS7 (Accession no. MT804348) was most aggressive among the ten isolates when evaluated on wheat genotype DBW 90 (70.99%), while BS3 was least virulent. Both morphological and pathological variations among *B. sorokiniana* isolates have been documented (Jaiswal et al 2007). Previously, Bandopadhyay et al. (2016) and Devi et al. (2021) collected 10 isolates from different parts of India, which varied significantly in aggressiveness among themselves. Kashyap et al. (2022) had identified a moderate to low haplotype diversity among 528 isolates of *Bipolaris sorokiniana* collected from different parts of the country.

CONCLUSION

The disease prevalence of wheat has been changing due to changes in weather parameters and emergence of new virulent pathotypes in the pathogens. In the present study, the prevalence of spot blotch and leaf rust has been assessed in different districts of West Bengal. The prevalent virulent pathotypes have also been identified. Hence, the results of this study will help the plant pathologists and breeders for screening genotypes against existing virulent pathotypes.

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First Record of Grey Bamboo Shark, *Chiloscyllium griseum* (Müller & Henle 1838) from Dholai Port, Southwest Coast of Gujarat, India

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***Abstract*:** This study focused on *Chiloscyllium griseum*, also known as the Grey bamboo shark, which inhabits the Indian coastal waters. The main objective of this study was to identify and describe the Grey bamboo shark species in the region and assess its conservation status. A female specimen was collected from a trawler operating near the southwest coast of Gujarat. Detailed morphometric parameters were meticulously observed and recorded for taxonomic identification. Subsequently, the specimen was transferred to the College of Fisheries Science, Navsari for further analysis and preservation. The results reveal that *C. griseum* was first time documented at Dholai port and along the Arabian Sea coast of south Gujarat. This paper provides comprehensive details about the morphometric parameters observed of adult specimens of *C. griseum*. This research significantly contributes to the understanding of the Grey bamboo shark in Gujarat, shedding light on its distribution and providing a comprehensive description of its morphological traits.

***Keywords*:** Bottom Trawler, Dholai Port, Gujarat coast

The Indian coastal waters contain total of 88 shark species, encompassing 6 orders, 21 families, and 44 genera (Kizhakudan et al 2015). According to global data, quarter of sharks and ray species are currently facing the risk of extinction. This is primarily caused by unsustainable fishing practices, significant incidental catches, the destruction of their habitats, and the presence of illegal, unreported, and unregulated (IUU) activities (Clarke et al 2006 and Camhi et al 2009). The Indo-Pacific shark family Hemiscyllidae contains the genera *Hemiscyllium* and *Chiloscyllium* (Whitley 1967 and Compagno 1973). The Grey bamboo shark, *Chiloscyllium griseum* is commonly encountered in the Indo-West Pacific region, specifically in rocky regions and lagoons. It inhabits depths between 5 to 80 meters. Its distribution spans across several countries including Pakistan, India, Sri Lanka, Malaysia, and Thailand. Additionally, this species can be found in Indonesia, China, Japan, the Philippines, and Papua New Guinea. (Compagno 2001). The bamboo shark, known as *Chiloscyllium griseum*, is a type of shark that resides near the ocean floor and is characterized by its slow and lethargic movements. Its preferred habitat is in the waters of the Indian region, and during the period of December to May is commonly caught as bycatch. Due to limited research conducted on this species in Gujarat, there is a lack of available literature pertaining to *Chiloscyllium griseum.*

Dholai Port, located in the Navsari district of Gujarat, serves as a significant landing centre in south Gujarat coast of Arabian Sea. The majority of the boats registered at the port are mechanized trawlers, while a portion of the fleet consists of small vessels that utilize gill nets. The port facility is spread over 23 hectares of land and includes auction halls, net mending sheds, and a non-operational diesel pump. There is no evidence of this species being found in Gujarat, but based on the current study, it has been documented that *C. grisuem* is found along the south Gujarat Coast.

MATERIAL AND METHODS

On February 10, 2023 a trawler boat operating near the southwest coast of Gujarat landed a female specimen of Grey bamboo shark at Dholai port (Fig. 1). Total 109 morphometric parameters were closely observed and recorded for taxonomic identification and confirmation of *C. griseum.* The taxonomic identification was verified using reputable resources such as the FAO species catalogue, Vol 4, Part 1 Sharks of the world, an annotated and illustrated catalogue of shark species known to date by Compagno (2001).

The fishermen provided information about the fishing location, operating depth, and the gear used to catch *C. griseum*. Photographs of various important characteristics of the specimen were captured for documentation and future publication, confirming its identification. The specimen was preserved in a 5% formalin solution and display in the museum of the College of Fisheries Science, Kamdhenu University, Navsari.

Conservation status: The conservation status of *C. griseum* was determined using information from the IUCN red list and fish base websites. According to the IUCN, this species was categorized as Vulnerable in 2020, with a global scope of assessment (IUCN 2020).

RESULTS AND DISCUSSION

During the present study, *C. griseum* was first reported from Dholai port and the Arabian Sea coast of the south Gujarat region. According to the information obtained from the fishermen, it came to light that the specimens were caught from a bottom trawler operating at a depth of 30-32 meters near the south Gujarat coast of Arabian Sea. The total of 109 morphometric parameters were observed as standardized procedure of FAO for taxonomic identification of sharks (Table 1).

Species description: The mouth of the species is situated significantly ahead of the eyes, and the dorsal fins are devoid of spines and positioned towards the rear end of the tail, which is marked by a thick and notably elongated structure located before the caudal fin. The anal fin is also long and positioned anterior to the caudal fin, while the trunk lacks lateral ridges. The dorsal fins are characterized by straight or outwardly curved posterior margins, with the first dorsal fins origin positioned roughly opposite the rear halves of the pelvic fin bases. The adult specimens of the species do not generally display any distinct patterns of coloration, whereas juvenile specimens exhibit transverse dark bands without any black borders.

The pre-pectoral length is 18.63% of the total length. The snout is rounded at the front. The eyes are moderately large, measuring 1.66% of the total length (Fig. 5). There are no lateral ridges on the sides of the trunk, and the ridges between the dorsal fins are not prominent (8.12% TL). The

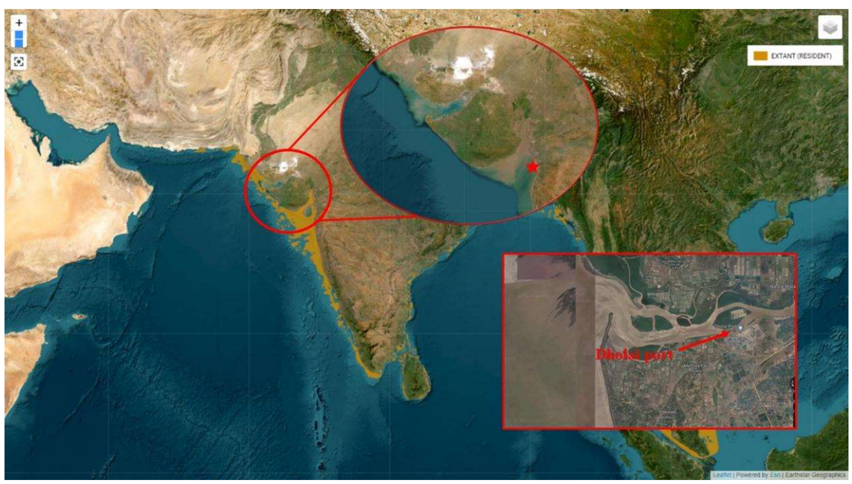


Fig. 1. Location of sample collection along with the species occurrence on the Arabian sea coast

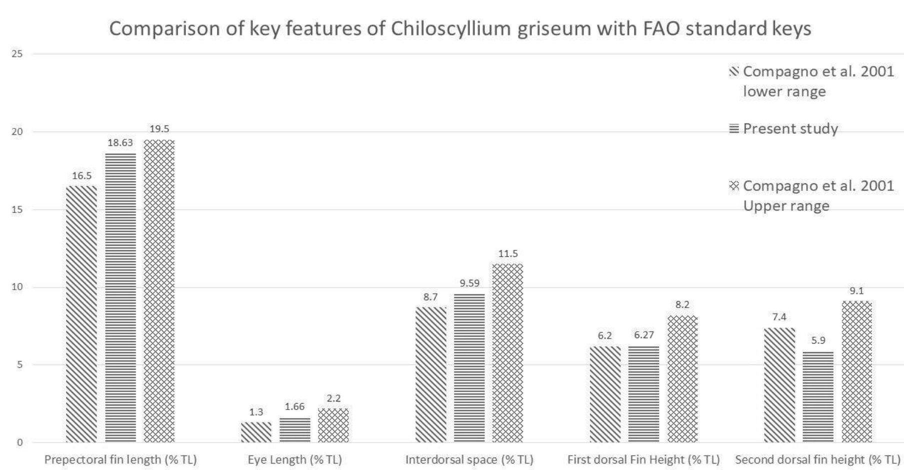
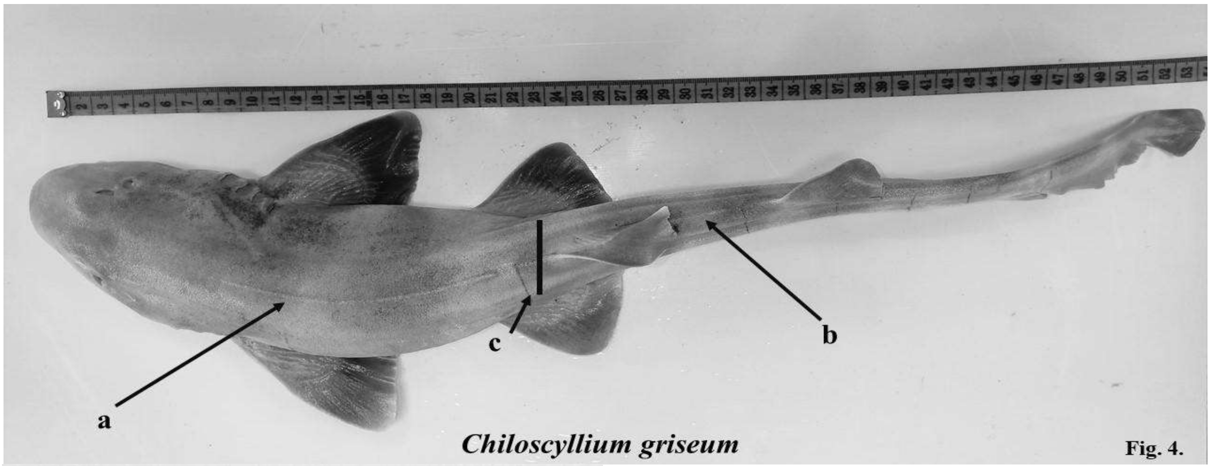
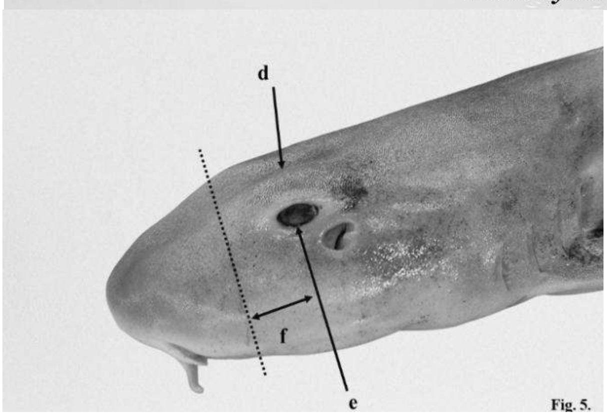
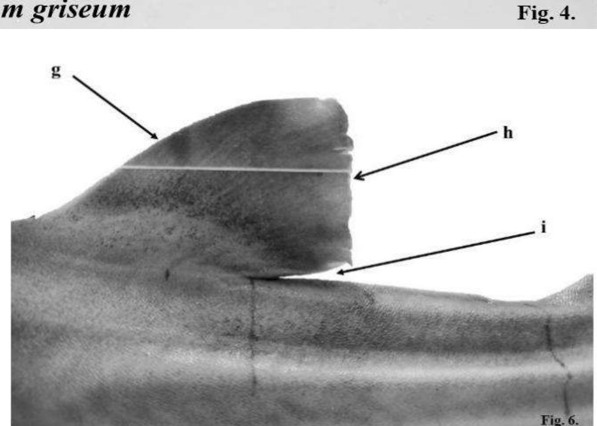


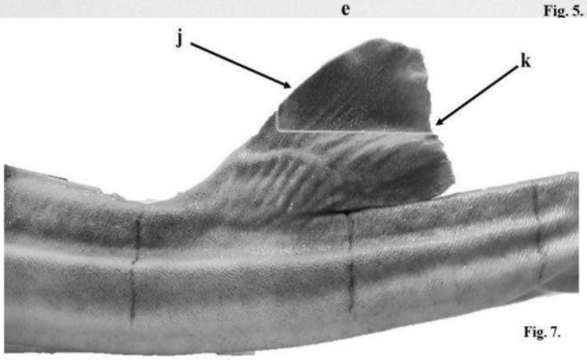
Fig. 2. Comparison of key features of *Chiloscyllium griseum* with FAO standard key

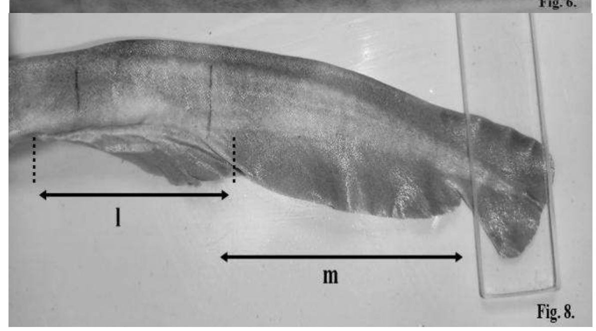
Plates











- **Fig. 4.**
  - a: Pre-dorsal ridge
  - b: Inter-orbital ridge
  - c: Origin of first dorsal fin on rear half of pelvic fin
- **Fig. 5.**
  - d: Supra-orbital ridge
  - e: Large eyes
  - f: Mouth well in front of eyes
- **Fig. 6.**
  - g: First dorsal fin well rounded and spineless
  - h: Posterior margins of dorsal fins straight rather than concave
  - i: Both dorsal fins projects free rear tips
- **Fig. 7.**
  - j: Second dorsal fin anteriorly rounded without any spines
  - k: Straight posterior margin
- **Fig. 8.**
  - l: Anal fin length (origin to free rear tip) smaller than hypural caudal lobe
  - m: Hypural caudal lobe

Table 1. Morphometric parameters of *Chiloscyllium griseum*

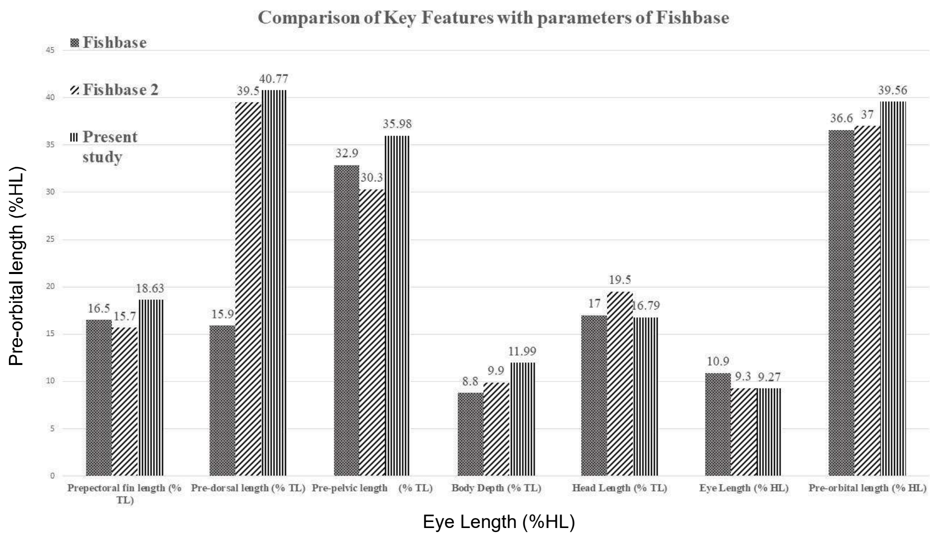
Morphometric parameters	TL* (%)	Cm
Total length	100	54.20
Fork length	-	-
Pre-caudal fin length	76.75	41.60
Pre-second dorsal fin length	58.49	31.70
Pre-first dorsal fin length	40.77	22.10
Head length	16.79	9.10
Pre-brachial length	16.05	8.70
Pre-spiracular length	8.12	4.40
Pre-orbital length	6.64	3.60
Pre-pectoral fin length	18.63	10.10
Pre-pelvic fin length	35.98	19.50
Snout vent length	43.36	23.50
Pre-anal fin length	71.22	38.60
Inter dorsal length	9.59	5.20
Dorsal caudal fin space	9.96	5.40
Pectoral pelvic space	13.65	7.40
Pelvic fin anal fin space	35.42	19.20
Anal fin caudal fin space	0.00	-
Pelvic fin caudal fin space	31.92	17.30
Vent caudal fin length	59.23	32.10
Prenarial length	2.77	1.50
Pre-oral length	4.43	2.40
Eye length	1.66	0.90
Eye height	0.74	0.40
Intergill length	6.64	3.60
1st gill slit height	2.21	1.20
2nd gill slit height	2.21	1.20
3rd gill slit height	2.58	1.40
4th gill slit height	2.03	1.10
5th gill slit height	2.03	1.10
6th gill slit height	-	-
7th gill slit height	-	-
Pectoral fin anterior margin	16.79	9.10
Pectoral fin radial length	8.30	4.50
Pectoral fin base	8.30	4.50
Pectoral fin inner margin	8.30	4.50
Pectoral fin posterior margin	10.33	5.60
Pectoral fin height	11.25	6.10
Pectoral fin length	15.31	8.30
Sub terminal caudal fin margin	3.69	2.00
Sub terminal caudal fin width	1.48	0.80
Terminal caudal fin margin	4.43	2.40
Terminal caudal fin lobe	4.98	2.70
First dorsal fin length	12.92	7.00
First dorsal fin anterior margin	12.73	6.90
First dorsal fin base	8.86	4.80

Cont...

Table 1. Morphometric parameters of *Chiloscyllium griseum*

Morphometric parameters	TL* (%)	Cm
First dorsal fin height	6.27	3.40
First dorsal fin inner margin	3.69	2.00
First dorsal fin posterior margin	5.90	3.20
Second dorsal fin length	11.25	6.10
Second dorsal fin anterior margin	11.25	6.10
Second dorsal fin base	7.20	3.90
Second dorsal fin height	5.90	9.20
Second dorsal fin inner margin	4.06	2.20
Second dorsal fin posterior margin	5.90	3.20
Pelvic fin length	12.73	6.90
Pelvic fin anterior margin	11.62	6.30
Pelvic fin base	9.04	4.90
Pelvic fin height	6.83	3.70
Pelvic fin inner margin	5.72	3.10
Pelvic fin posterior margin	9.04	4.90
Anal fin length	12.55	6.80
Anal fin anterior margin	7.75	4.20
Anal fin base	10.52	5.70
Anal fin height	3.14	1.70
Anal fin inner margin	1.29	0.70
Anal fin posterior margin	5.54	3.0
Head height	10.70	5.80
Trunk height	11.99	6.50
Abdominal height	7.75	4.20
Tail height	9.59	5.20
Caudal peduncle height	2.77	1.50
Caudal peduncle width	1.48	0.80
Second dorsal fin insertion anal fin insertion	16.24	8.80
Second dorsal fin origin anal fin origin	13.10	7.10
First dorsal fin midpoint pectoral fin insertion	24.35	13.20
First dorsal fin midpoint pelvic fin origin	11.81	6.40
Pelvic fin midpoint first dorsal fin insertion	7.20	3.90
Pelvic fin midpoint second dorsal fin origin	16.79	9.10
Pre-caudal tail	33.39	18.10
Snout to mouth length	4.43	2.40
Head	16.79	9.10
Trunk	26.75	14.50
Tail	56.46	30.60
Mouth length	0.37	0.20
Mouth width	2.12	4.40
Upper labial furrow length	1.29	0.70
Lower labial furrow length	1.29	0.70
Nostril width	0.50	0.30

Cont...



*Measurements are calculated against the head length (HL).

Fig. 3. Comparison of key features of *Chiloscyllium griseum* with Fish base

Table 1. Morphometric parameters of *Chiloscyllium griseum*

Morphometric parameters	TL* (%)	Cm
Inter narial space	4.80	2.60
Anterior nasal flap length	0.18	0.10
Nasal barbel length	2.95	1.60
Nostril snout tip distance	-	-
Mouth eye distance	2.03	1.10
Pre-orbital space	6.09	3.30
Inter orbital space	5.90	3.20
Spiracle length	1.48	0.80
Eye-spiracle space	0.74	0.40
Head width	13.65	7.40
Trunk width	10.89	5.90
Abdominal width	5.72	3.10
Tail width	5.72	3.10
Girth at trunk	42.44	23.00
Girth at abdomen	20.66	11.20
Girth at tail	25.46	13.80
Pre-dorsal ridge	22.88	12.40
Inter dorsal ridge	8.12	4.40
Origin of the anal fin to free rear tip of 2^{nd} dorsal fin	13.09	7.10
Hypural caudal lobe	16.05	8.70

*All the percentage calculation in above have been done against total length of fish

space between the dorsal fins is relatively short, slightly larger than the base of the first dorsal fin, and it represents 9.59% of the total length. The distance from the snout to the vent is 43.36% of the total length, while the distance from the vent to the tip of the tail is 59.23% of the total length. The dorsal fins are fairly large and rounded (12.92% TL), approximately the same size as or larger than the pelvic fins (12.73% TL). They do not have concave posterior margins or protruding free rear tips (Fig. 6). The origin of the first dorsal fin is positioned over the rear halves of the pelvic fin bases (Fig 4.). The base of the first dorsal fin is slightly longer (8.86% TL) than the base of the second dorsal fin (7.20% TL). The height of the first dorsal fin represents 6.27% of the total length, while the height of the second dorsal fin represents 5.90% of the total length. The anal fin originates slightly behind the free rear tip of the second dorsal fin. The length of the anal fin, from its origin to the free rear tip (13.10% TL), is slightly smaller than the length of the hypural caudal lobe (16.05% TL). The base of the anal fin (10.52 % TL) is less than six times the height of the anal fin 3.14% of total length (Fig. 8). Similar observations were reported by Compagno (2001).

The information obtained in this research has been compared to Compagno, 2001 (Fig. 2) and Fish base (Fig. 3.) which indicated percentage of all-important characteristics falls within the range of both the FAO standard and Fish base standard. Therefore, it can be inferred that the species under investigation is *C. griseum.* The present investigation revealed that *C. griseum* was first time documented at the Dholai port and along the Arabian Sea coastline in the south Gujarat area.

CONCLUSION

The species was caught from Dholai port, situated on the southwest coast of Gujarat. Further identification of the specimen was done using a standardized procedure, and the recorded data was compared to previous studies by FAO and Fish base. The species in this study was indeed *Chiloscyllium griseum*, commonly known as the Grey bamboo shark, which according to the IUCN, is a vulnerable species. This study reports the occurrence of *C. griseum* from the southwest coast of Gujarat.

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Geospatial Analysis for Sustainable Aquaculture Expansion: A Case Study on Water Spread Area Mapping and Fish Production Potential in Dimbhe

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Abstract: Indian reservoirs with an area of 3.91 million hectares, possess immense potential for fisheries that offer economic and social security. Planning fisheries and aquaculture activities in a reservoir require knowledge of water spread dynamics and potential fish culture areas. Geospatial technologies in inland water resource management and decision-making have been widely used worldwide. The current study assessed the water spread dynamics and map potential areas for enclosed fish culture in Dimbhe reservoir, Maharashtra, India using Sentinel-2 Multi Spectral Instrument (MSI) images during the period 2019-22. Mapping of the spatial extent of the Water Spread Area (WSA) for identifying the potential sites and area for scientific ranching and fish culture using Normalized Difference Water Index (NDWI) and Water Presence Frequency (WPF) along with bathymetry was performed. The results showed that the WSA declines from Rabi season to summer season, with 70.44 percent (1445.39 ha) of the area covered with water for at least 8 months and 39.60 percent (812.45 ha) retaining water for at least 11 months, respectively. The calculated average number of fingerlings required to utilize the available water area in Dimbhe reservoir is 0.56 million with a production potential of 112.88 metric tonnes. The perennial WSA available in the Dimbhe reservoir is 551.22 ha which is most suitable for permanent cage culture practices. The study shall help in planning out scientific ranching and the improvement of enclosed fish culture locations with other water resource applications and to plan appropriate interventions for reducing the fish yield gap.

Keywords: Normalized difference water index, Water spread dynamics, Water presence frequency, Bathymetry, Fish culture, Reservoir

Indian reservoirs with 3.91 million hectares (ha) area offer immense potential for fisheries and provide economic and social security, especially in rural areas (DoF 2022, Sarkar et al 2015). Fish yield from reservoirs is low to the tune of 49.9 kg $ha^{-1}yr^{-1}$ in small, 12.3 kg $ha^{-1}yr^{-1}$ in medium, and 11.4 kg $ha^{-1}yr^{-1}$ in large reservoirs despite their high production potential (Sarkar et al 2018). Inland fisheries provided 12.5 million tonnes (70%) of India's total fish production in 2017–18 (Yadav et al 2021) among which reservoir fish cage culture accounts for only about 3.81 percent (DoF 2022). The Department of Fisheries (DoF), India intends to increase current cage culture fish production from 2.44 lakh metric tonnes to 6.29 lakh metric tonnes by 2024-25 (DoF 2022). It is revealed that climate change is a major factor influencing global production of fisheries (Yadav et al 2022), whereas poor stocking and lack of insight into periodic water availability for aquaculture systems are reasons for low productivity in Indian reservoirs (Sugunan 2015, Kumar 2018). Regular stocking or annual stocking is recommended if auto stocking is not achievable for medium and large reservoirs until a mass breeding population is developed to provide stock replenishment throughout the reservoir's water-spread region (Mane et al 2014, Kiran et al 2015, NFDB 2016). The use of geospatial technologies in the management of inland water resources and decision-making for fish culture purposes have been well recognized as they can monitor large areas easily (Ingole et al 2015). Satellite-based Remote Sensing (RS) imagery provides applications for assessing and monitoring aquaculture sites and leverages sustainable development (Ottinger 2018). Mapping of waterbodies, their dynamics, periodicity, and their management by using high-resolution panchromatic and multispectral satellite data has been widely accepted (Ottinger et al 2018, Kumar et al 2021) also; the water resource use in different seasons can demonstrate the actual situation of the annual water availability in reservoir. Comprehensive databases of waterbody resources and their dynamics are required for planning fish culture practices. Based on satellite data, developing of spatiotemporal resource inventory for reservoirs can be used for sustainable fisheries management and optimizing fish productivity (Anand et al 2019). Adoption of enclosed fish culture methods in reservoirs have the high potential to increase the present fish production in Indian reservoirs (Sarkar et al 2018). Increasing trend in cage farming in reservoirs demand a very precise understanding of the dynamic water spread of reservoirs in order to develop and perform an economically viable enclosure fish culture activity (Kumar et al 2018, Anand et al 2019). Bathymetric information is also crucial for understanding reservoir environment and planning aquaculture activities (Hollister 2011, NFDB 2016).

In this context, this study has been taken up in Dimbhe reservoir, Maharashtra to analyze the water dynamics, assess effective Water Spread Area (WSA), stocking density, production potential and to map the potential areas for enclosed fish culture. This reservoir plays a major role in livelihood security of 19 villages and has a great potential for fisheries and aquaculture (Iyer 2014, Khanolkar et al 2018). As the yield potential and optimum stocking capacity of the reservoir is unknown, estimation of WSA and Water Presence Frequency (WPF) at different depths at different locations can aid in determination of the same. The information will be beneficial in identifying viable fish culture areas, and ultimately lead to the sustainable utilization of large-scale resources (Ghatge et al 2008). The water spread dynamics and potential fish culture area identification in inland water bodies is crucial for intensive aquaculture practices and water uses.

MATERIAL AND METHODS

Study area: The study was conducted in Dimbhe reservoir, which lies between 19° 05′ 52.82″ N, and 73° 43′ 19.56″ E on Ghod river basin near Ambegaon Taluka, Maharashtra (India). The basin is situated at an elevation of 717- 719 m surrounded by tropical forest, grassland and agricultural land. The reservoir is associated with Ghod river and water inflow is from the rainfall in Sahyadri hills, Western Ghat. It is the part of Kukadi project, a gravity dam made in 1992-1993 by the Government of Maharashtra, for irrigation in 19 villages (covering 34000 ha area) (Sehgal et al 2013, Theurkar et al 2015). The reservoir plays a major role as the water and power supply sources for the surrounding villages.

Study period and data set: The present study used satellite data of Sentinel-2 MSI cloud-free imageries were obtained from the Sci-Hub Copernicus open access website (https://scihub.copernicus.eu/dhus/#/home) with spatial resolution of 10 m for the visible bands, i.e. Blue (Band 2), Green (Band 3), Red (Band 4), and Near InfraRed (Band 8). Individually, a total of 64 images were downloaded and processed through Quantum GIS (QGIS) Software. Four years of seasonal water variation from the years 2019 to 2022 were featured in the study. Two satellite images were taken in 1st and 2nd quarter of each month to get the average water surface area value for a month. Based on seasonal water availability, time period was divided into two phases. The amount of water accessible in February (Rabi season) was deemed to represent the minimum amount required for fish culture, which is water available for at least 8 months (FAO 1992, NFDB 2016). Similarly, May (Zaid/summer season) represents the minimal amount of water that is present in a water body for at least 11 months, when all the irrigation demand has been fulfilled (FAO 1992, NFDB 2016, Anand et al 2019). For WPF analysis, 100% water pixel value areas were considered as consistent water availability zone suitable for enclosed fish culture. Outer boundary layer of reservoir is taken as the farthest waterbody mark area during the monsoon season where water is filled at full reservoir level (Sarda and Das 2018, Anand et al 2019).

Extraction of WSA for fish culture: An overview of the methodological framework used in the current for estimating the WSA (Fig. 2). NDWI was used for discriminating and mapping water pixels of the sites under the study (Borro et al 2014, Khattab et al 2014)

$$NDWI = \frac{DN_{Green} - DN_{NIR}}{DN_{Green} + DN_{NIR}} \qquad [-1 \text{ to } +1]$$

Water features are indicated by positive values while the vegetation and soil features have values between – 1 and 0. DN_{Green} and DN_{NIR} are the digital number value of green and near-infra-red (NIR) bands of the satellite imageries.

A composite seasonal WSA map was generated by integrating the two annual aggregate maps. As a single-year image does not justify the exact value of water presence area in water bodies, particularly in areas where annual and seasonal water level fluctuation is higher due to heavy water uses for irrigation, hydroelectric power generation and asymmetric rainfall pattern. Thus, NDWI for the month of Feb (Rabi season) and May (summer season) from 2019-2022

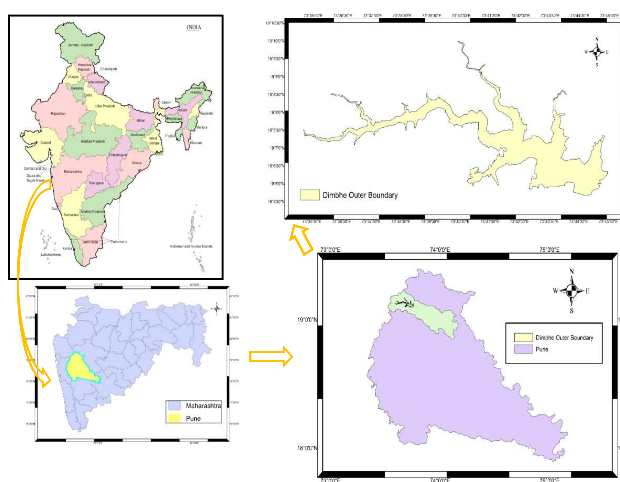

Fig. 1. Map of the study area

has been aggregated into a final composite image. From two annual aggregate maps, the WSA was estimated by geo-referencing.

Fingerlings requirement estimation: The fingerlings requirement and yield potential has been calculated (NFDB 2016, Anand et al 2019). Areas under the two water availability zones (8 or 11 months) were determined for calculating the total number of fingerlings required for stocking using the following Eq.

$$F = A * SD$$

F = Total number of fingerlings required for stocking in reservoir

A = Area of water availability zone (ha)

SD = Stocking density of particular water availability zone (numbers/ha) as per topography of the reservoir and guidelines for stocking in medium-large reservoir.

$$AF = \frac{\Sigma_n F_R + \Sigma_n F_z}{n}$$

A_F = Average number of fingerlings required for a waterbody

F_R = Fingerlings required for 8 month water availability zone

F_Z = Fingerlings required for 11month water availability zone

n = Number of years taken for preparation of a composite map

Y = F * AW * SR

Y = Potential fish yield in reservoir (kg/year)

F = Total number of fingerlings required for stocking in reservoir

AW = Average weight of individual fish at harvesting (kg)

SR = Survival rate of fish (%)

The total minimum potential fish yield of a specific waterbody can then be calculated (kg/ha/year)

Fish culture yield potential estimation:

A_Y = Average yield required for a waterbody

Y_R = Average yield in 8-month water availability zone

Y_Z = Average yield in 11-month water availability zone

n = Number of years taken for preparation of a WSA composite map

$$AY = \frac{\Sigma_n Y_R + \Sigma_n Y_z}{n}$$

Assessment of seasonal WPF: Reclassified NDWI images were merged seasonally using the WPF approach to determine the seasonal WPF for pre-monsoon (March to May, 24 Sentinel-2 MSI images) and Post-monsoon (October to February, 40 Sentinel -2 MSI Images). To investigate the phase-wise pre-monsoon and post-monsoon spatiotemporal fluctuations in the WPF of Dimbhe reservoir, images from 2019 and 2022 were individually combined into a vector image. WPF method was adopted (Sarda and Das 2018) to create the seasonal composite image of water presence as demonstrated in Figure 3 using the following Eq.

$$WPF_j = \frac{\Sigma_{i=1}^{n} I_j}{n} \times 100$$

WPF_j = WPF of jth pixels in a time period; I_j = jth pixel having water in the selected NDWI images; n = number of images.

The value of WPF image pixels ranges from 0 to 100%. A

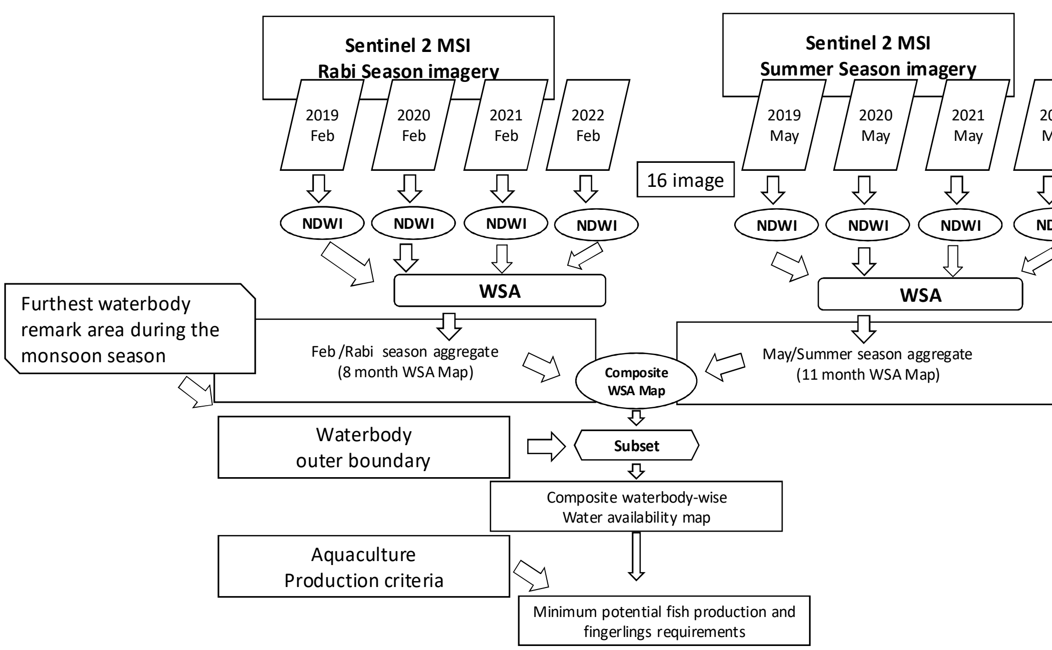

Fig. 2. Methodological framework for assessing WSA and fisheries potential area

higher WPF value indicates the frequent or regular appearance of water in the pixel, lower value or tending to zero indicates irregularity in the water presence. 100% indicates the presence of water in all the years. Based on the WPF value, the composite map was reclassified into three classes viz. Low WPF (<33%); Moderate WPF (33 -66%) and High WPF (>66%), pixels with zero value are classified as "No water". Pre and post-monsoon season WPF composite maps of 2019-2022 were used. Pixels with 100% frequency values in these composite maps were considered for identifying areas suitable for enclosure-based fish culture.

WSA in Dimbhe reservoir is divided into two section viz. perennial and seasonal based on the following criteria:

Seasonal WSA: 100% frequency pixels of post-monsoon season composite maps were first recorded to generate seasonal WSA maps that could only hold water from monsoon to post-monsoon.

Perennial WSA: Pixels with 100% frequency WPF composite maps generated from both pre and post-monsoon of 2019-22 represented parts that retained water year-round in the reservoir. Permanent enclosed fish culture installations require the availability of perennial water area.

Bathymetry Mapping of Dimbhe Reservoir: The selected site for cage installation and composite fish culture in the reservoir should have a minimum depth of 10 m and 1 m, respectively throughout the year (NFDB 2016). Integrating depth profile data with water availability area will help in meeting more accurate cage site selection and area requirements during installation (Anand et al 2019). Hence, a bathymetric model of the reservoir was generated using satellite dataset with a resolution of 10 m (Fig. 4).

The model was validated and corrected using field data surveys and topographic maps. The detailed methodological framework for bathymetric model was given in Figure 4. Path maps for perennial and seasonal water bodies were extracted from shape files prepared for estimating the WSA in

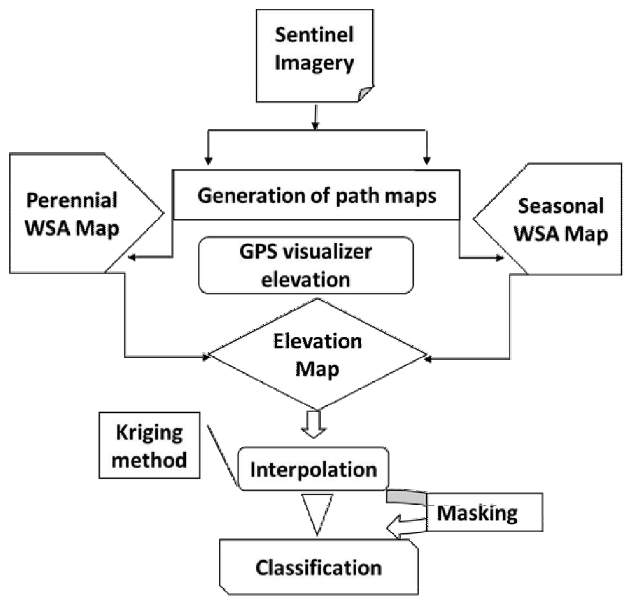

Fig. 4. Methodology framework for bathymetric mapping

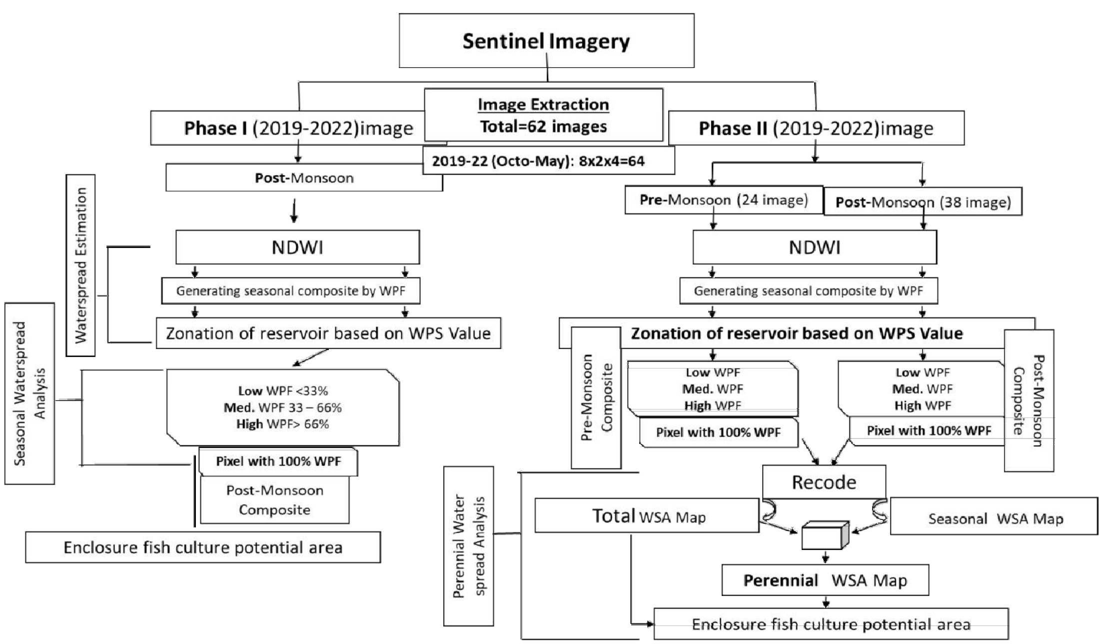

Fig. 3. Flowchart of methodological framework used for assessing water presence area mapping and potential area for enclosed culture

Google Earth Pro. Using an open-access GPS visualizer elevation (https://www.gpsvisualizer.com/elevation), an elevation GPX file was created and converted into to features class. Elevation data of precise position were obtained by adding the location (Latitude-Longitude) to the attribute table with field observation. The interpolation tool was used to get the unknown values in geographic coordinates for elevation using Kriging method which is a sophisticated geo-statistical tool that generates an estimated surface from scattering of z-valued points. Extracted Kriging file, based on the minimum and maximum depth, is classified into 10 m intervals and the plotted minimum value was chosen as surface values against the elevation map observed points (Khattab et al 2017). The estimated values of selected bathymetric models were compared with observed field survey data to ensure accuracy and to monitor the development of lake bottom throughout reservoir operation. The estimated perennial water availability zone with >10 m depth profile area was found to be suitable for cage culture (NFDB 2016). Ground truthing was performed to comprehend the dynamics of the waterbodies and usage patterns. Information on fish culture system, species cultured, duration of culture, stocking density, survival rate (%), yield per unit area, and types of culture systems were collected from Dimbhe Cooperative Society members. Water quality parameters such as dissolved oxygen (DO), chlorophyll content, turbidity, and depth were measured in different locations of the reservoir.

RESULTS AND DISCUSSION

Reservoir seasonal WSA estimation and mapping: WSA in Dimbhe reservoir shrinks dynamically from the end of monsoon to the end of summer season. The total WSA in Dimbhe reservoir was found to be 2051.48 ha, which is in par with the recorded result of 2202 ha at FRL (Waghmare et al 2022). Figure 5 depicts the dynamics of the average spatial watershed distribution for 8 months and 11 months in the Dimbhe reservoir. 70.44 percent (1445.39 ha) of the reservoir area remains covered by water for at least 8 months (Feb month composite WSA) and 39.60 percent (812.45 ha) retains water for at least 11 months (May month composite WSA), respectively (Table 1). Availability of water in the reservoir between February (8^{th} month) and May (11^{th} month) is very significant in terms of extending the fish culture period to the 11^{th} month, thereby increasing the fish yields.

NDWI was used in this study and the outcomes were consistent with the findings of Sarda and Das (2018) where Massanjore dam presence area dropped from 44.13 to 23.54 km^2 in pre-monsoon and from 63.37 to 37.57 km^2 in post-monsoon. Anand et al (2020) observed that estimation of seasonal water availability in terms of seasonal changes in WSA to be necessary for assessment of fish production potential from available water resources.

Estimation of fingerling requirement and enclosed fish culture potential: As per "Guidelines for Fisheries Development in Reservoirs" by NFDB, stocking rate for medium and large reservoirs should not be <500 fingerlings per hectare with a survival rate of 10 percent and average harvest size of 2 Kg. An average of 0.56 million fingerlings were estimated to utilize the available water of Dimbhe reservoir. Total annual average fish production potential conservatively estimated from the available WSA for the reservoir were 112.88 tonnes (Table 2).

Production in Dimbhe was between 27 to 32 tonnes in the last few years, which is much less than the estimated production potential of 112.88 tonnes. Dimbhe reservoir, with 70 % water availability in 8 months, can provide further opportunities for greater intensive aquaculture adoption. For enclosed fish culture purposes, estimated perennial WSA was 551.22 ha in and seasonal WSA was 1199 ha (Fig. 6).

Available perennial area in Dimbhe reservoirs is 551.22 ha that comprised 26.9% of their maximum WSA suitable for permanent cages (Fig. 7). Identification of enclosed fish culture regions based on reservoir perennial and seasonal WSA aids in the effective facility installation by preventing

Table 1. Seasonal WSA in Dimbhe Reservoir

Year	February (ha)	%	May (ha)	%
2019	1122.21	54.69	377.10	18.38
2020	1536.17	74.87	982.88	47.90
2021	1555.91	75.83	1161.66	56.62
2022	1452.28	70.78	816.17	39.78
Average	1445.39	70.44	812.45	39.60

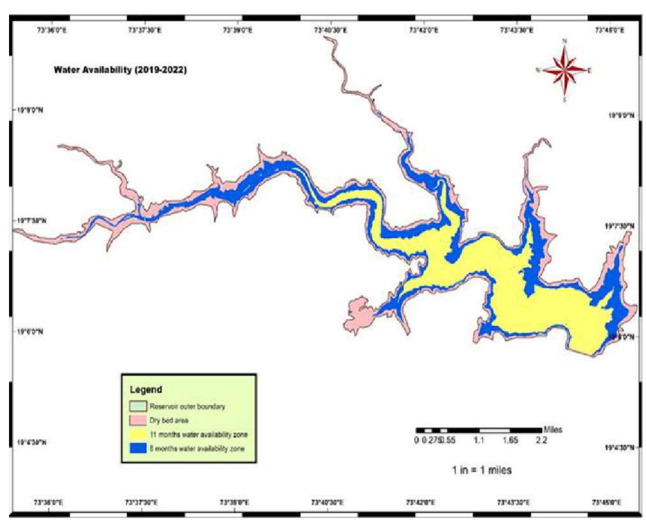

Fig. 5. Water spread dynamics in the Dimbhe reservoir

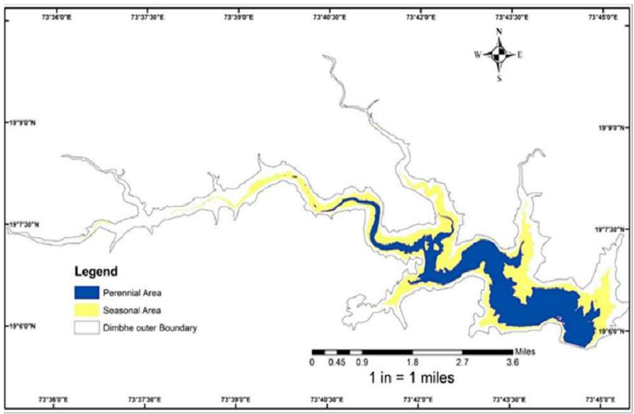

Fig. 6. Seasonal and perennial water area of Dimbhe reservoir

overcrowding and maximizing the use of water resources, thereby, facilitating effective fisheries management. Furthermore, WPF estimate was related to the findings of Deoli et al (2021) for WSA dynamics at Sattal Lake where a decreasing trend was observed during post-monsoon to February and also in summer season.

Bathymetry assessment: The highest water depth point of the reservoir in seasonal area is 69.7 m and its average depth is around 36 meters, i.e., 4 m deeper than that of the perennial area (Fig. 6). There is >66% water availability in the seasonal area and 20-36 m depth is concluded to be appropriate for cage culture. In India, the source of water for the reservoirs is usually precipitation.

Table 2. Standardized culture parameters used to estimate the expected fish production from the reservoir (Sugunan and Katiha 2004, NFDB 2016)

11 months (February)			8 months (May)			Average	
Area available (ha)	Stocking density (million fry)	Potential fish production (Tonnes)	Area available (ha)	Stocking density (million fry)	Potential fish production (Tonnes)	Stocking density (million fry)	Potential fish production (Tonnes)
1445.39	0.72	144.53	812.45	0.41	81.24	0.56	112.88

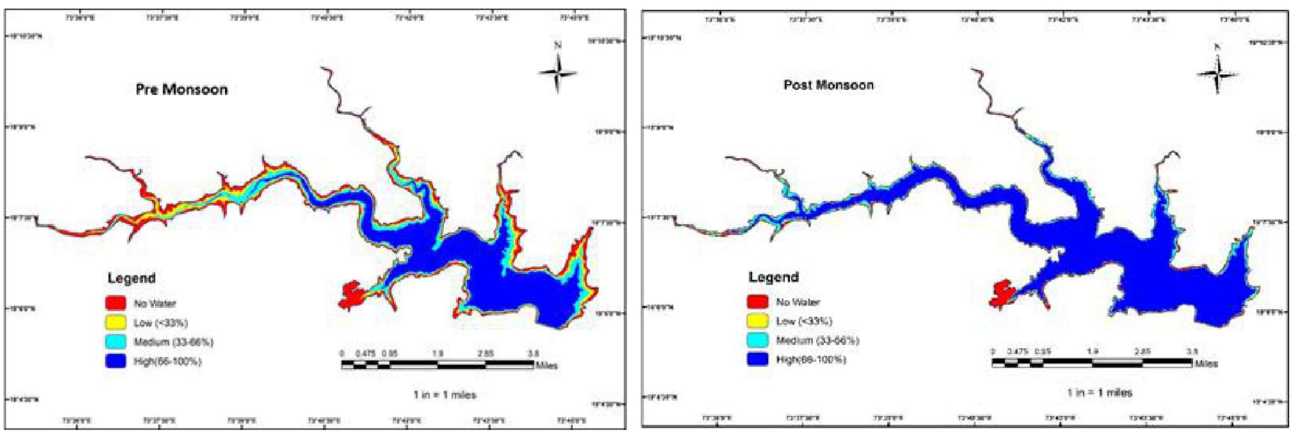

Fig. 7. Comparison between post-monsoon and pre-monsoon WPF dynamics

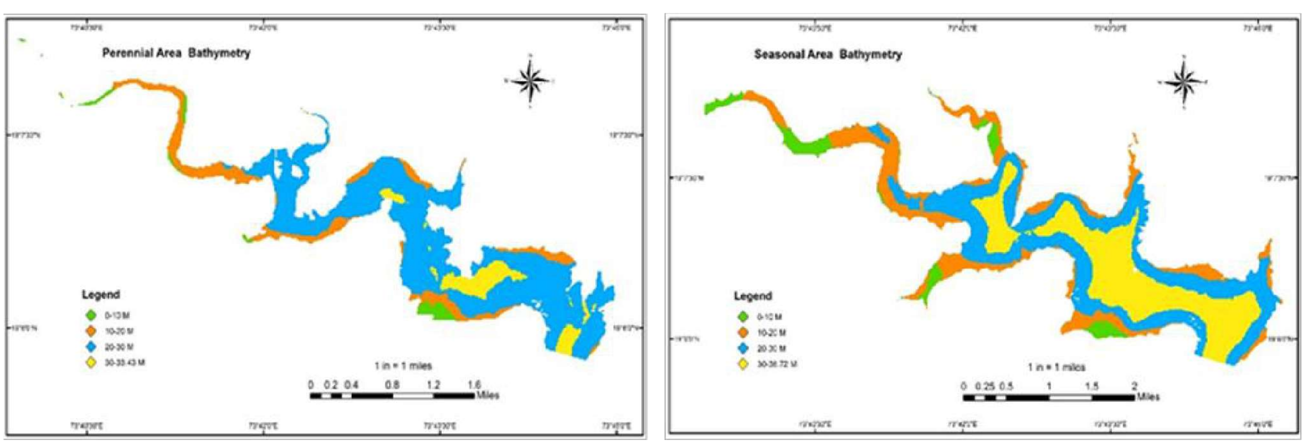

Fig. 8. Bathymetry map of seasonal and perennial area

After addressing the requirements for irrigation, hydroelectric projects and other activities; the retained water available year-round with a depth of >10 m is ideal for intensive fish culture practices. Incorporation of bathymetric analysis is effective for cage culture practice (NFDB 2016).

Based on the spatiotemporal water distribution and depth profile, a proposed model adopted from Anand et al (2019) for selecting an appropriate cage and pen fish culture method and candidate species in the Dimbhe reservoir (Fig. 9). The water pH varied seasonally from 6.7 to 7.6 and water surface temperature fluctuated between 20°-27° C. Species diversity in Dimbhe reservoir was high which included *Catla, Labeo rohita, Puntius ticto, Puntius sophore, Salmostoma bacaila, Garra mullya, Cyprinus carpio, Ompok bimaculatus, Chanda nama, Oreochromis mossambica*. These indigenous species are suitable for ranching and cage culture. For grow-out fish culture, pens and permanent cages can be utilized to locate perennial water regions with low depth (1-3 m) and high depth (10 m) respectively (NFDB, 2016). Indian Major and Minor Carp and ornamental breeding can be farmed in pens located on the reservoir's rim comprising at least 10 m of water. Because of high evaporation and low rainfall, usage of reservoir water for irrigation, water treatment plans, hydroelectric generation and other uses led to a decrease the water column depth and WSA from February (Rabi season) to May, which correlates the findings of Waghmare et al (2022). This study has been supported by the results of Anand et al (2019) who found WSA of the Nizamsagar reservoir in pre-monsoon season decline from 108.11 to 99.34 km^2 by using NDWI and WPF. Remote sensing generated results were verified through in-situ survey multiple times which further strengthened this study. Therefore NDWI, WSA, WPF and all the parameters used are beneficial in sustainable reservoir fisheries management.

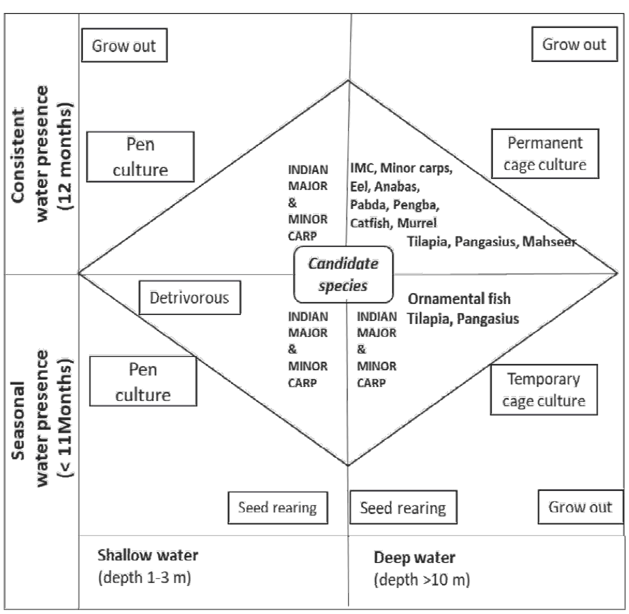

Fig. 9. Appropriate enclosing fish culture technique and potential species in a reservoir based on the depths and spatial water spread area (Das et al 2014)

CONCLUSION

WSA and WPF suggest an appropriate place for enclosed intensive culture at seasonal WSA (54.46% of the total reservoir) and perennial WSA (26.9%). Majority of the perennial and seasonal WSA have respective depths of 20-27 m and 20-30 m which are highly suitable for cage culture as per the NFDB (NFDB, 2016). Bathymetry analysis of perennial and seasonal WSA is performed to identify the precise depth of locations for fish culture activities. Estimation of water spread dynamics and bathymetry analysis is essential for fishery managers, policymakers to build and execute knowledge-based management methods for sustainable development. Enclosure culture facilities, considering the seasonal water availability (pre-monsoon and post-monsoon) trends, will help to achieve economic sustainability of the production system as it involves huge initial investment. This study will be helpful in planning out scientific ranching and enclosed fish culture practices for reducing the fish yield gap.

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Assessment of Bird Diversity along Yamuna River, Haryana, India

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Abstract: The avian diversity status of selected sites of Yamuna Riverine area in Haryana was studied from September 2021 to April 2022. A total of 59 birds were observed and recorded from studied sites (Yamunanagar, Panipat and Faridabad riverine area), which belongs to 8 orders and14 families. The dominant Order was Anseriformes with 15 species, followed by the order Charadriiformes with 13 species and order Gruiformes with 09 species. Fifty-nine bird species belonging to 14 families and eight orders have been recorded from the Yamuna Riverine area in Haryana. The family Anatidae was dominant (25 %), followed by Scolopacidae (14%), Ardeidae (13 %), Charadriidae (7%), Rallidae (7%) and Motacilidae (7%). Phalacrocoracide, Ciconiidae and Laridae had only five per cent of the total reported bird species. The number of species in Segment I (Yamuna Nagar riverine area), segment II (Panipat riverine area)) and segment III (Faridabad riverine area) were 48,41 and 44 respectively. Out of 59 reported bird species, 33 species (56 %) were winter migrants, 16 species (27 %) were residents and 10 species (17 %) were local migrants.

Keywords: Avifaunal, Biodiversity, Yamuna, Riverine area

Avian diversity plays a vital role in ecological assessment, serving as a significant indicator for both qualitative and quantitative evaluation of various habitats. Birds are integral components of natural ecosystems, occupying a crucial position in the food chain. They are closely tied to ecosystem services, such as acting as pollinators, facilitating seed dispersal, regulating pollution, providing sustenance for other animal predators, and contributing to nutrient recycling processes (Padmavathy et al 2010, Jatav et al 2022). Global bird diversity is steadily declining, primarily due to human-induced disruptions and the impact of climate change (Chen et al 2011, Sekercioglu et al 2012). IUCN Red List of endangered birds has identified 1,226 bird species as globally threatened, with India having 88 threatened bird species and ranking seventh in this regard (BLI 2010, Roy et al 2012). India, with an estimated 1,340 bird species within the Indian subcontinent, harbors more than 13% of the world's bird species, out of a global total of over 9,500 (Grimmett et al 1998, Mistry 2015 and Choudhury et al 2016). In Haryana, approximately 450 bird species have been documented in water bodies, whether they are flowing or stagnant. These play a crucial role in various ecosystems and attract a significant number of birds by meeting their feeding and other essential requirements (Singh et al 2020). Haryana, with a wetland area covering 42,480 hectares (Panigrahy et al 2012), serves as a habitat for a diverse range of wildlife, including various bird species (Singh et al 2020). The Yamuna River, one of India's most significant and revered waterways, has nurtured a diverse range of plant and animal life (Priyanka 2012). The river, along with its adjacent wetlands, floodplains, and riparian environments, constitutes a crucial ecosystem for numerous bird species, establishing a vital route for both migratory and resident birds. Birds diversity also plays a pivotal role in evaluating the overall health of natural habitats (Gregory et al 2003). The present study analyzes the bird diversity of selected sites along the Yamuna River and understands their ecological and conservation status.

MATERIAL AND METHODS

Study area: The present studies were conducted in three sampling sites, namely, Yamunanagar, Panipat and Faridabad along the Yamuna River (latitude 28°55'42.8664" N and longitude 77°5'29.3712"E). The samples were collected monthly from September 2021 to April 2022.

Sampling methods: From September 2021 to April 2022, frequent fortnightly trips to the study site were made along selected sites of the Yamuna River (Yamunanagar, Panipat, and Faridabad) to perform avifaunal surveys. Using the Line Transect approach, data were gathered by walking along five fixed transects (Gaston 1975). From six in the morning until six in the evening, birds were seen constantly. Nikon Action

10x50 mm binoculars were used to observe the birds, and whenever it was practical, pictures were made with the Canon PowerShot SX50HS and the Nikon D300s DSLR with the Nikon AF 80-400mm f/4.5-5.6D VR telephoto lens. Field guides were used to identify birds (Ali et al 1987, Grimmett et al 1998).

RESULTS AND DISCUSSION

Fifty-nine bird species belonging to 14 families and 8 orders were observed during the study period along the selected sites of Yamuna River and the maximum species were in site1 (Yamuna Nagar) (48 species), followed by 44 species in site 3 (Faridabad) and minimum 41 species in site 2 (Panipat) (Table 1). The most dominant order was Anseriformes (15 species), followed by the Charadriiformes (13 species) and Gruiformes (09 species). Anatidae was the dominant family containing 25 percent of bird species, followed by Scolopacidae 14 percent family Ardeidae, 13 percent and Charadriidae, Rallidae, and Motacilidae with 7 percent of bird species. Phalacrocoracidae, Ciconiidae and Laridae have only 5 percent of the total reported bird species (Fig. 2). Out of 59 reported species, 24 % were very common, 20% common, 08% rare, and 07% were less common. The percentage contribution of abundance status in total bird diversity of Yamuna River was Least concern 50%, Near-threatened 5%, Vulnerable 2% and critically endangered 2%. Out of fifty-nine bird species, 33 species (56 %) were winter migrants, 16 species (27 %) were residents, and 10 species (17 %) were local migrants. The difference in bird diversity across different habitats might be associated with the availability of food, roosting and nesting sites, predation

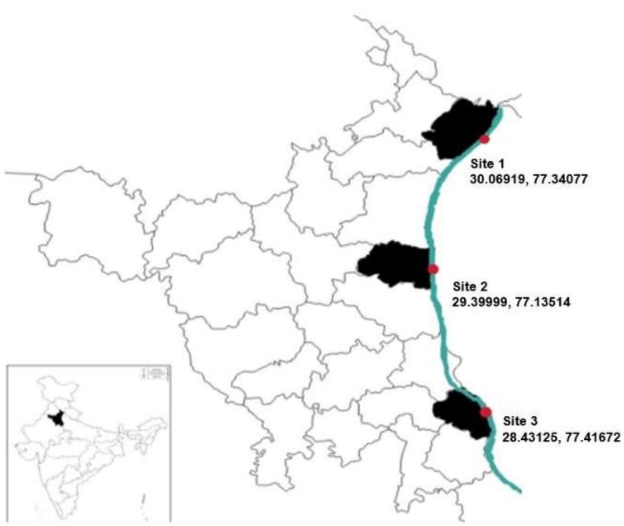

Fig. 1. Studied sites: Site 1: Yamunanagar, Sites2: Panipat and Sites 3: Faridabad riverine area of Yamuna River

Table 1. Bird species in the selected sites

Family	Common name	Residential status	Abundance status
Podicipediformes			
Podicipedidae	Little grebe	R	Common
Pelecaniformes			
Phalacrocoracidae	Little cormorant	R	Very common
	Indian shag	LM	Very common
	Great cormorant	LM	Less common
Ciconiiformes			
Ardeidae	Little egret	LM	Common
	Grey heron	WM	Rare
	Purple heron	LM	Rare
	Large egret	LM	Lees common
	Median egret	LM	Very common
	Cattle egret	R	Very common
	Indian pond-heron	R	Very common
	Black-crowned Night Heron	LM	Rare
Ciconiidae	Painted stork	LM	Rare
	White-necked Stork	LM	Rare
	Asian openbill stork	LM	Rare
Threskiornithidae	Eurasian spoonbill	WM	Less common
Anseriformes			
Anatidae	Greylag goose	WM	Common
	Bar-headed Goose	WM	Common
	Brahminy shelduck	WM	Common
	Mallard	WM	Very common
	Eurasian wigeon	WM	Common
	Spot-billed Duck	WM	Very common
	Northern shovelle	WM	Very common
	Northern pintail	WM	Very common
	Garganey	WM	Less common
	Common teal	WM	Very common
	Common pochard	WM	Very common
	Red-crested Pochard	WM	Common
	Ferruginous pochard	WM	Common
	Greater scaup	WM	Common
	Tufted pochard	WM	Common
Gruiformes			
Rallidae	White-breasted Waterhen	R	Very common
	Purple moorhen	R	Common
	Common moorhen	R	Very common

Cont...

Table 1. Bird species in the selected sites

Family	Common name	Residential status	Abundance status
	Common coot	WM	Very common
Jacanidae	Bronze-winged Jacana	R	Rare
Charadriidae	Little ringed plover	WM	Common
	Red-wattled Lapwing	R	Very common
	White-tailed Lapwing	WM	Rare
	River lapwing	R	Common
Charadriiformes			
Scolopacidae	Spotted redshank	WM	Very common
	Common redshank	WM	Very common
	Ruff	WM	Common
	Little stint	WM	Very common
	Black-tailed godwit	WM	Common
	Common sandpiper	WM	Very common
	Common greenshank	WM	Very common
	Wood sandpiper	WM	Very common
Recurvirostridae	Black-winged Stilt	R	Very common
	Pied avocet	WM	Less common
Laridae	River tern	R	Common
	Black-headed Gull	WM	Common
	Pallas's gull	WM	Common
Coraciiformes			
Alcedinidae	Lesser pied kingfisher	R	Less common
	White-breasted Kingfisher	R	Very common
Passeriformes			
Motacilidae	White wagtail	WM	Very common
	Large pied wagtail	R	Less common
	Citrine wagtail	WM	Common
	Yellow wagtail	WM	Common

R= Resident, WM= Winter migratory, LM= Local migratory

pressure and disturbance (Hossain and Aditya 2016). Trees along riverbanks also influence the species richness and abundance of bird species (Mistry 2015). The highest number of species was recorded in site 1 Yamunanagar compared to the other two sites due to some habitat heterogeneity. The patches of tall wooded trees, scrub and bushy type stumpy vegetation, grasses and wetlands augmented resource variety to sustain different bird species (Kumar and Sahu 2019). The quality and quantity of food available is the key factor that determines the distribution and abundance of birds in a given habitat same as in the selected

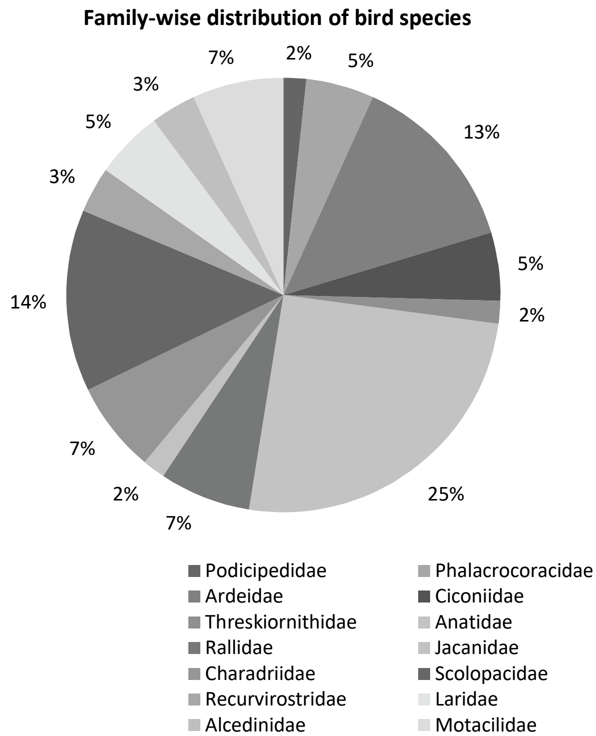

Fig. 2. Family-wise distribution of bird species

sites of the Yamuna River (Mukhopadhyay and Mazumdar 2017).

CONCLUSION

The study highlights significant bird diversity along the Yamuna River, documenting 59 bird species spanning 14 families and 8 orders. This diversity underscores the Yamuna River ecosystem's importance as a habitat for diverse bird species. Dominant orders include Anseriformes, Charadriiformes, and Gruiformes, with Anatidae being the dominant family, housing a quarter of the observed species. Insights into conservation status reveal a substantial proportion of winter migrant birds, emphasizing the need to preserve these habitats. Additionally, the study brings attention to rare and less common species, warranting specialized conservation efforts. Habitat heterogeneity across different sites along the river contributes to varied bird species.

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Optimal Crop Planning for Economic and Ecological Sustainability of Punjab Agriculture

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Abstract: The use of natural resources in Punjab, especially irrigation water for agriculture, is facing a crisis. A proper and sustainable plan is needed for reasonable use. Therefore, the current study has been conducted to develop optimal crop plans by incorporating technologies such as wheat sown by using happy seeder (HS), direct-seeded rice (DSR), and short-duration varieties (SDVs) of paddy. The result revealed that for optimum utilization of available resources, the area under paddy, guar, and potato crops needs to be reduced while the area under basmati, sugarcane, cotton, barley, sunflower, and peas needs to be increased. By adopting the optimal plan with existing resource use and technologies the returns can be increased by 2.52%, while adoption of the optimal plan with technologies (HS, DSR, and SDVs) increased returns ranging from 3.38 to 8.63%, along with saving in irrigation water use ranging from 4.65 to 4.96%. Further, the optimal plans will help in increasing the use of underutilized human labour, and reducing the use of chemical fertilizers with presently much higher use than the recommended levels.

Keywords: Resources, Agriculture, Sustainability, Technology, Optimal plan, Returns

Resources including water, soil, plants, animal diversity, renewable energy, climate, vegetation, ecosystem, etc. are the most important affective factors in the agricultural production. Due to overexploitation, these resources are diminishing continuously. Sustainable agriculture focus on long-term production, with the least impact on the environment (Pagliarino et al 2020). The situation demands food security and improvement in agriculture. Development must guarantee both the growth of agricultural production and the conservation of natural resources (Robertson 2015). This means that the natural resources should be managed in such a way that food production is secured now as well as in the future. Therefore, food security is not an easy task based on quantity as well as in the continuity (Kielbasa et al 2018). Agriculture is forced to find a balance between conservation and development. Responsible use of natural resources is essential for agriculture. The most important of these natural sources on which existence depends are water and soil (Wrachien 2002). The future of living beings and agricultural production systems is at stake due to continuously depleting aquifers and increasing pressure on underground water under projected climate change scenarios (Kumawat et al 2020). Anthropogenic and adverse natural activities are the major factors for the deterioration of natural resources. Increased exploitation of groundwater results in depletion of groundwater level. Hence, the holistic management of water and soil resources is indispensable for agricultural sustainability as well as for the protection of the natural ecosystem. Development and adoption of improved technologies, judicious use of natural resources, and effective management practices are the need of the hour for the protection of water and soil from degradation (UNDP; FAO; WHO; WB, 2008).

India is the largest consumer of groundwater in the world, consuming more than 25% of the world's fresh water, and using 88% of it for irrigation. Much of its agricultural production depends on excessive water consumption, and production areas are likely to face water shortages in the long term. Currently, about 60% of the country's underground aquifers are under severe stress (World Bank 2009, 2010, and 2012) and the water table in the "Indus Basin" is the second most stressed in the world. Groundwater is used indiscriminately, and due to the overexploitation of water resources, the sustainability of existing agricultural systems becomes questionable and creates critical problems for the second generation (Vatta and Taneja 2018). Over-dependence and over-exploitation are particularly severe in Punjab state (North-West India) or the Green Revolution Belt (Hira 2009). The central government's policy played a key role in imitating the policy of the Green Revolution under which the pattern of agricultural production in Punjab shifted crucially towards a monoculture of paddy and wheat, the food items being important for the national goal of self-reliance in food availability (Singh 2012). Much of its agricultural production depends on excessive water consumption, and production areas are likely to face water shortages in the long term (Grover et al 2017). With a significant change in the pattern of cultivation over the last sixty years, the area devoted to the main crops increased from 3.79 in 1960-61 to 7.830 million hectares in 2020-21, an increase of over 100%. More importantly, the wheat area increased from 1.39 to 3.53 million hectares (Increase of 2.54 times). The rice area increased from 230 thousand to 3.149 million hectares (Increase of 13.7 times) during this period (Anonymous 2021). Therefore, these two crops dominated the state cultivation pattern. The mastering of paddy-wheat rotation has brought Punjab from excess water to a deficit water state. Although paddy was not the traditional crop of Punjab, oilseeds and pulses have been practically wiped out. The management of paddy straw raises significant human and soil health concerns. The studies show that the agricultural sector in Punjab has been overcapitalized and is at a stage where its inputs are being used more or less exclusively. As a result, agricultural production costs have grown and farmers now bear an extra financial burden which makes agriculture unsustainable. Therefore, a key objective of this study is to develop optimum crop plans under various technologies.

MATERIAL AND METHODS

Data: The current study is based on data collected under the 'Comprehensive scheme for studying the cost of cultivation of principal crops in Punjab' operational in the Department of Economics and Sociology at Punjab Agricultural University, Ludhiana. It is the most important database on the cost of cultivation of major crops in the state. For the present study, the data pertains to the year 2018-19. The plot-wise data were collected from the 300 farmers of 30 villages, from the three agro-climatic zones of the state, representing all the climatic conditions, farmer categories, and crops of Punjab. Besides, data from secondary published sources were also used to determine the resource use coefficients and availability levels in the state.

Analytical tools: The budgetary analysis has been performed to work out the economics of different crops. The optimum crop plans were developed using the linear programming technique. The various components in the cost of cultivation of crops under study were estimated in line with the methods provided in the manual of cost of cultivation like farm-produced and purchased seed, fertilizers and manures, plant protection chemicals, human labour, owned/hired machinery charges, and interest on working capital. Based on the cost concept used; the overall costs included the farmers' paid-out expenses in cash and kind for various items of cost of the cultivation (INR per hectare) taken in the present study. Variable cost: i) value of the seed, ii) value of fertilizer and manure, iii) value of plant protection chemicals, iv) value of human labour (family + hired), v) value of machine labour (owned + hired), vi) value of irrigation charges.

Mathematical specifications of the model: The mathematical technique of linear programming (LP) is frequently used to assist in decision-making when allocating areas under various crops and selecting various enterprise combinations. It is a simple and applicable tool for comparing various uses of scarce resources under changing goals and limitations. The program also enables to simulate the impact of different options. Using a quasi-dynamic LP model, various crop business strategies were created for the current study. The goal was to maximize returns while keeping in mind the limitations of arable land, human labour potential, irrigation water use, chemical fertilizers, and working capital. Equations 1-7, which are followed by an explanation of each, have been used to mathematically express the model explanation for optimizing.

Objective function:

$$Max\ Z = \sum_{c=1}^{n} (Y_c P_c - C_c) A_c \qquad (1)$$

Where:

Z = Returns over variable costs

Y_c = Yield of main product & by-product (per hectare) of crop species c

P_c = Price of crop output (main product & by-product) (INR per unit of crop produce)

C_c = Cost of cultivation (INR per hectare)

A_c = Area under crop species c

c = Crop species

n = Number of crop species

Area constraint:

$\Sigma_t \Sigma_c A_{tc} \leq NS_t - 0A_c$ (2)

Minimum area constraint:

$A_c \geq min_c$ (3)

Maximum area constraint:

$A_c \geq Max_c$ (4)

$A_c \geq 0$

Where:

A_{tc} Area occupied by crop species c in the tth month

NS_t Net sown area

OA_c Area under orchard and other perennial crops

c Crop species

t Time (months of the year)

A_c Area under crop species c

Labour constraint:

$\Sigma_t \Sigma_c HL_{tc} \leq THL_t$ (5)

Other input constraints:

$\Sigma_c X_c A_c \leq CUX$ (6)

$A_c \geq 0$ (7)

Where:

HL_{tc}	Monthly human labour use (per hectare)
THL_t	Total human labour use in the t^{th} month
X_c	Input use per crop (i.e. working capital, ground water, and fertilizers)
A_c	Area under crop
CUX	Availability of working capital, ground water, and fertilizers

Almost the entire cropped area in Punjab is under irrigation water use. Usually, crops in the state are grown in three seasons: (i) monsoon, also called *kharif* (Starts from July to October), (ii) winter, also called *rabi* (November to March), and (iii) summer (March to June). The principal crops grown during the *kharif* season are paddy, cotton, and maize, while other crops like like pigeon pea, cluster bean, green gram, groundnut, and black gram are also cultivated in a smaller area. In the *rabi* season, wheat, potato, and mustard are the major crops, whereas gram, sunflower, lentil, and barley are some of the traditional crops grown on a very small area in the state. Moong is also grown in the short window of 50-70 days during summer, also called zaid season. In this model, 20 crop activities were included. Crop and enterprise planning using LP primarily takes the supply-side behavior, more precisely, the area response based on net returns and resource constraints, ignoring the demand aspects. As a result, such models tend to overestimate or underestimate the area allocations for some crops. While the per-unit requirement coefficients of labour, working capital, farm power, and fertilizer were estimated using data from the cost of cultivation, the per ha requirement of irrigation water for various coefficients was calculated using the approach suggested in earlier studies (Cooper et al 2011, Srivastava et al 2015, Pojara and Shahid 2016, Pushpa et al 2017, Kaur et al 2018, Gill et al 2018, Anonymous 2019, Latif et al 2020, Singh et al 2022 and Bhatt et al 2022). The resource availability was mainly based on three different data sources. In the case of land, the net sown area (excluding area under perennial crops) was considered the total available land resource, whereas the number of cultivators and agricultural laborer was used to estimate the total labour availability in the state. Since the existing use of working capital and fertilizers in Punjab is already on the higher side, the use of these resources under the existing cropping pattern forms the right-hand side of the constraint equations. The minimum and maximum areas that should remain under different crops were determined based on experts' advice as well as previous area cultivation.

RESULTS AND DISCUSSION

The results of the optimal plan developed under existing resources use and technologies suggested that the total gross cropped area under wheat crop in the *rabi* season needs to be the same level 3.53 million hectares (Table 1). The area under paddy and guar in the *Kharif* season should be decreased to 2.25 million and 10 thousand hectares from 2.743 million and 33 thousand hectares and shifting to basmati, cotton, and sugarcane. The area under sunflowers, peas, and barley should be increased by decreasing the area under vegetable crops like potatoes from 107 to 60 thousand hectares, the reason is that will help to be self-sufficient for edible oils, however unforeseen rainstorms during harvest can occasionally cause problems, and peas increase from 43.9 to 50 thousand hectares. The model suggests increasing the gross cropped area (GCA) from 7.385 to 7.505 million hectares. The cropping intensity under the existing optimized model will increase to 196.83 from 193.68%. With the same level of irrigation water use, following this plan, the returns over variable cost would increase by 2.52%.

The optimized plan developed using technology wheat sown with Happy Seeder suggests sowing 741 thousand hectare of the current wheat area with Happy Seeder. The plan has suggested increasing the area under cash crops like cotton (Increased from 251 to 273 thousand hectares), and sugarcane as well as doubling the area under basmati paddy while decreasing the area under paddy by 12%. This is in line with the state's draft agricultural policy, which calls for switching 1.2 million hectares from rice to less water-intensive crops like maize, cotton, sugarcane, pulses, oilseeds, fruits, and vegetables (Vatta and Taneja 2018). The area under *kharif* and *rabi* pulses remains the same under the optimum plan. The area under *rabi* oilseeds; sunflower increased by 104% from the current area allocation and will be a good step towards making the state self-sufficient for edible oil. The area under peas and barley also increase by decreasing area under potato and with the existing irrigated water use, the returns over variable cost would increase by 3.38% in the state.

The optimum crop plan developed in wheat by introducing activity viz. sown with happy seeder (HS) and direct seeding of rice (DSR) recommend that 21% of wheat should be cultivated using Happy Seeder technology. Like other plans, this plan also suggests decreasing the area under paddy and guar while increasing the area under basmati and sugarcane during *kharif* season. The government should make arrangements for the export of basmati and ensure timely payment for sugarcane. Further, this plan suggests that out of the total recommended area for paddy cultivation, around 7% should be cultivated using DSR technology. The plan also advocates bringing more area under sunflower, which will be a good step towards self-sufficiency of the country for oilseeds and crop diversification. The government may further encourage the farmers to bring more area under oilseed crops by providing a competitive price. It can increase returns by 3.73% along with some saving in irrigation water use. The optimal plan developed with technology HS and short-duration varieties for paddy recommends beside same area under wheat with HS. As per the optimum plan the total area under paddy needs to be decreased from 2.743 to 2.430 million hectares and further out of the area 1.25 million hectares should be under short duration varieties (PR 121 and PR 121) developed by the Punjab agricultural University. The area under basmati paddy should be increased from 406 to 862 thousand hectares, while the area under sugarcane should be increased from 89 to 121 thousand hectares. This will help in saving the irrigation water to the tune of 4.65%. By adopting the recommendations of this plan, the returns can be increased by more than 8% and save 4.65% irrigation water along with saving on electricity used for running electric tube wells for irrigation. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture.

The developed optimal plan with all the technologies taken together (i.e. wheat sown with HS, paddy cultivation using DSR technology and SDVs) suggests 741 thousand

Table 1. Existing area vis-à-vis area under optimal plans, Punjab

(000'ha)

Crop category	Crops	Current area	Area under existing optimal plan	Optimum area under technology HS	Optimum area under technologies HS and DSR	Optimum area under technologies HS and SDVs	Optimum area under all technologies
Rabi Cereals	Wheat	3530	3530	2789.4	2789.4	2789.4	2789.4
	Wheat (HS)			740.6	740.6	740.6	740.6
	Wheat total	3530	3530	3530	3530	3530	3530
	Barley	5.9	12.6	12.6	12.6	12.6	12.6
Kharif Cereals	Paddy	2743	2251.4	2408.5	2265	1180	1015
	Paddy DSR				165*		165
	Paddy PR121					625	625
	Paddy PR126					625	625
	Paddy total	2743	2251.4	2408.5	2430	2430	2430
	Maize	108	108	108	108	108	108
	Basmati	406	862	862	862	862	862
Kharif pulses	Arhar	2.6	2.6	2.6	2.6	2.6	2.6
	Guar	33.3	10.2	10.2	10.2	10.2	10.2
	Moong	24.1	24.1	24.1	24.1	24.1	24.1
	Urad	2.0	2.0	2.0	2.0	2.0	2.0
Rabi pulses	Gram	2.0	2.0	2.0	2.0	2.0	2.0
	Lentil	0.6	0.6	0.6	0.6	0.6	0.6
*Rabi o*ilseeds	Rapeseed & Mustard	31.6	31.6	31.6	31.6	31.6	31.6
	Sunflower	2.5	5.1	5.1	5.1	5.1	5.1
Kharif oilseeds	Groundnut	1.5	1.5	1.5	1.5	1.5	1.5
Vegetables	Potato	107.1	60	60	60	60	60
	Peas	43.9	50	50	50	50	50
Cash Crops	Cotton-BT	251.6	430.2	273.1	251.6	251.6	251.6
	Sugarcane	89.3	121	121	121	121	121
Net Sown area (NSA)		4127	4127	4127	4127	4127	4127
Gross cropped area (GCA)		7385	7504.8	7504.8	7504.8	7504.8	7504.8
Irrigation water use (BCM)		29.06	29.06	29.06	29.03	27.71	27.62
Cropping Intensity (CI) (%)		193.7	196.8	196.8	196.8	196.8	196.8
Returns over variable cost (₹ Billion.)		483.7	495.9	500.0	501.7	523.9	525.4

hectares wheat area under the technology happy seeder in the rabi season. This plan recommends that the total area under paddy should be 2.430 in place of the current 2.743 million hectares. Further, out of these 2.430 million hectares 165 thousand hectares should be sown directly using DSR technology and for 1.250 million hectares short duration variety (PR 121 and PR 126) seed should be used. This will help in saving 4.96% of irrigation water. The optimum plan advocates increasing area under basmati, cotton, and sugarcane which is released from paddy cultivation. Also, the area under vegetables (potato) should be decreased from 107 to 60 thousand hectares and should increase the area of sunflower from 26 to 51 thousand hectares. Achieve cropping intensity of 196.83% and following the GCA to increase from 7.385 to 7.505 million hectares. This would result in increasing their returns over variable cost by 8.63% in the state.

Changes in resources use, and income: The optimum crop plans are capable of saving irrigation water ranging from 0.10 (0.03 billion cubic meters) to 4.96% (1.44 BCM) (Fig. 1) and will help in restricting the downward movement of groundwater level and ultimately helps in making agriculture sustainable. By encouraging the farmers to adopt these plans the government can save a significant amount of subsidy to be spent for providing free electricity to run the tube-wells. With the saved amount the farmers can be compensated either by providing subsidies on other inputs or by increasing the price of other competing crops. In terms of returns, the increase will be from 2.52 (INR. 495.87 billion) to 8.63% (INR. 525.42 billion) as compared to the current returns (INR. 483.69 billion) in existing resources use and technologies. Among the developed optimum plans, technologies of HS, DSR, and SDVs together were found to be more responsive to saving irrigation water use as well as the increase in returns over variable cost.

On the other hand, these plans use relatively higher human labour ranging from 0.3 to 8.57% as compared to their current usage level which is underutilized, and also working capital is increasing from 1.09 to 1.49% (Fig. 2).

These plans, if adopted, will also reduce the use of chemical fertilizers having current usage quite higher than the recommended levels. By adopting optimal crop plan

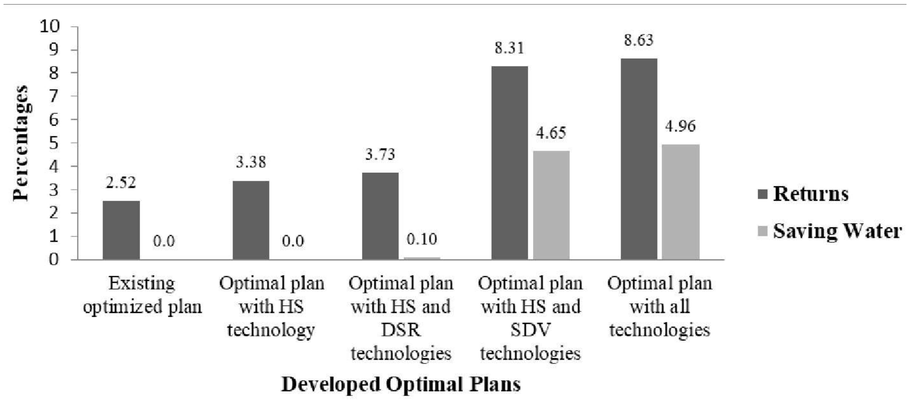

Fig. 1. Changes in existing irrigation water use and farmers' income under various developed optimal plans in Punjab

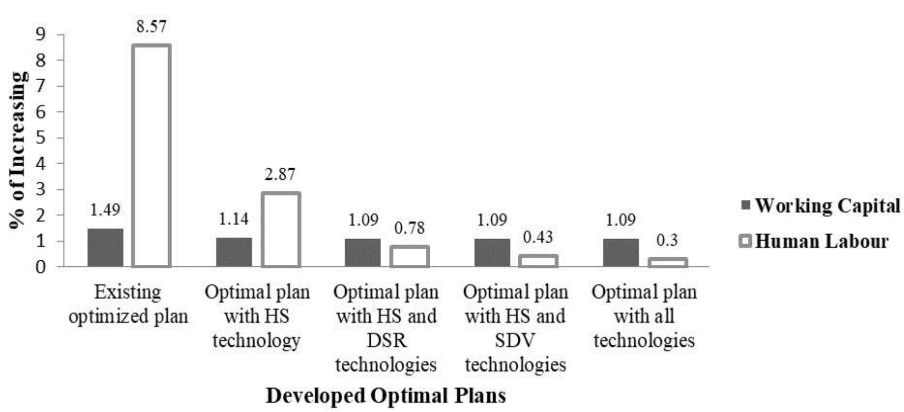

Fig. 2. Changes in existing human labour, and working capital under various developed optimal plans in Punjab

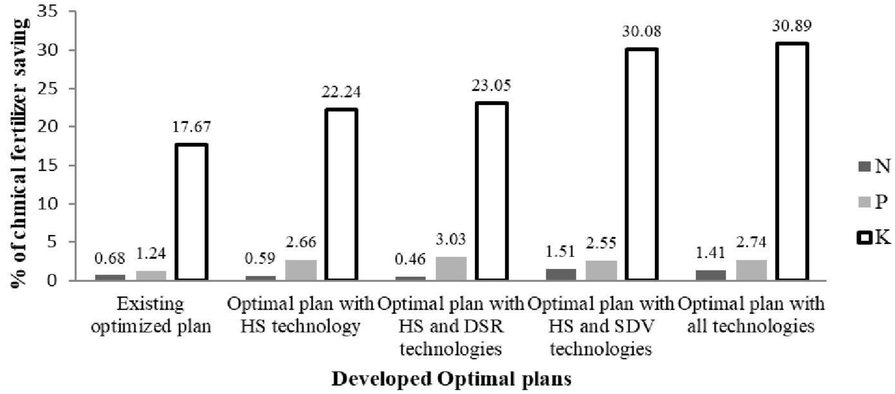

Fig. 3. Changes in the existing level of chemical fertilizer use under various developed optimal plans in Punjab

developed at existing technology level the use of N, P and K fertilizers can be lowered by 0.68, 1.24 and 17.67%, respectively from its existing use. Further, the optimum plan developed by incorporating technological interventions (happy seeder for wheat sowing, DSR and short duration varieties for paddy) the usage of N, P and K fertilizers can be reduce to the extent 1.41, 2.74 and 30.89%, respectively.

CONCLUSION

The natural resources the agriculturally advanced states of Punjab are declining at a fast rate due to intensive cultivation. In the alternative crop plan developed with existing resources use and technologies, for optimum utilization of available resources, the area under paddy, guar, and potato crops needs to be reduced while the area under basmati, sugarcane, cotton, barley, sunflower, and peas needs to be increased. Adopting the optimal plan with existing resource use and technology increases cropping intensity, and returns, while adoption of the optimal plan with technologies (HS, DSR, and SDVs) besides increasing the returns also saves irrigation water and ultimately saves electricity used for running electric tube wells. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture. Also, these plans advocate bringing more area under oilseed which will be a good step towards self-sufficiency of the country for oilseeds and crop diversification. The government may further encourage the farmers to bring more area under oilseed crops by providing competitive prices. So, if the Punjab farmers adopt these alternative crop plans, they can utilize more human labour which is largely underutilized. The crops in these optimum plans will require less quantity of chemical fertilizers that are presently having quite higher than the recommended levels, reducing the cost of cultivation along with a positive impact on the environment. These plans, if adopted by the farmers, along with saving precious groundwater will also help in increasing their income from farming.

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Evaluation of Physiochemical Factors in Saffia Nature Reserve, Southern Iraqi Marshes, using Geographic Information System Techniques

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Abstract: This survey was conducted during four seasons in nine stations representing the Saffia Nature Reserve (SNR) in Al-Hawizeh marsh, southern Iraq, which has 44 km^2. Physical and chemical parameters were monitored; including natural water quality parameters such as water temperature, pH, electric conductivity and dissolved oxygen in addition to levels of nutrients from September 2019 to August 2020. The current study discussed the possible use of spatial analysis techniques to characterize the temporal and spatial distribution of water prediction properties employing geographic information systems (GIS) to determine water quality parameters at SNR. In general, all parameters are within the acceptable limit of freshwater for aquatic life except electric conductivity. The current survey could serve as a basis for more monitoring and restoration of the marshland environment. The use of a geographic information system in evaluating the water quality depends on the laboratory result values of water samples and spatial analysis of these properties employing inverse interpolation of the weighted distance. It was possible to map water quality indicators along the study area for nine sites and six water quality indicators. The production of water quality maps will improve monitoring and enforcement of standards and regulations for better management and control. This study suggested that continuous monitoring of the physical and chemical characteristics of water marshes and water bodies, and the study of factors affecting the increase in the concentration of elements and nutrients and comparing them with environmental determinants.

Keywords: Physiochemical factors, Saffia Nature Reserve, Geographic Information System Techniques

Environmental studies occupy a vital space between basic, applied, and human sciences due to the occurrence of various processes between humans and ecological activities. Increasing pressure on natural resources raised great interest in evaluating, protecting, and maintaining ecosystems to become the foundations for future development processes (Al-Asadi and Maatouk 2013). With growing population growth and economic development, wetlands around the world are now decreasing and degrading (Davidson 2014, Dixon et al 2016). It is also reasonable to acknowledge wetlands as an indispensable resource for humans. In the Middle East and Western Europe, the Mesopotamian Marshlands are among the largest water bodies (Hussain et al 2012) as they occupied a wide area in southern Iraq, where the marshes of southern Iraq are considered to be the gardens of Aden on earth cos of their distinguishing characteristics and their beauty in a beautiful and picturesque environment. The marshes are considered a place for the emergence of the earth (Khalaf and Almukhtar 2005). The marshes of Mesopotamia are also classified as one of the largest bird and fish-rich natural reserves in the world, as there are reeds, sedge plants in the marshes but those plants in the marshes are considered to be among the most important areas for birds, their livelihoods, shelter and migration from different parts of the world (Kowais 2005). The Mesopotamian marshes consist of three large marsh complexes in Southwest Asia, including three main areas in the north, the Hawizeh Marsh, in the middle, the Central Marsh (Chibayish), and the Hammar Marshlands in the south, all of which are rich in natural resources and biodiversity. A unique wetland in the world during the forty sessions of the World Heritage Committee according to the third and fifth cultural criteria and the ninth and tenth natural standards in Istanbul in 2016. The conservation of invasive species, the most significant of which is the Convention on Biological Diversity, signed at the 1992 Earth Summit. The nature reserves are considered a natural center for researchers, university, and graduate students and exploit existing living organisms to conduct various scientific and medical studies and space for scientific experiments.

Water is the basic requirement of all species on the earth. Surface water tends to be an important water source because of the rise in its consumption for drinking, irrigation, water supply, and industrial uses, etc., a necessary resource is required. Rises in the agricultural and industrial sectors need more freshwater (Chen et al 2019). In order to assess the quality of water, it is necessary to specify the information on the state of water quality and to recognize factors that impact the effectiveness of water as well as the critical locations within the catchment. This can be accomplished by collecting water samples and then measuring the physical and chemical parameters at different sites in the research area (Ogbozige et al 2018).

GIS is necessary for the analysis of water bodies, to restore and manage water resources, including spatial and temporal data for all water sources, and to provide an effective database for a computer to store, manipulate and analyze data. For the past 30 years, GIS was used globally to obtain the requisite information to control different water bodies worldwide. Together with computer simulations, remote sensing and GIS software are effective tools to provide a solution for future management of the water sources, especially water quality control plans.

MATERIAL AND METHODS

Study Area: Al-Hawizeh Marsh is currently located within the southeastern part of the alluvial plain, precisely before the Tigris River meets the Euphrates River at Al-Qurna, and administratively it follows the northern part of the marsh to Maysan Governorate. In contrast, the southern part follows the Basrah Governorate. The total area of the marsh in the flood season is more than 3500 km^2, and this area decreases to 650 km^2 during the Drought season, and the site of the marsh on the Iraqi side is up to 2350 km^2. About 1900 km^2 were re-flooded after 2003. The capacity of the marsh is 5896 million cubic meters, with a surface area of 1800 km^2 for a level of 7 meters above sea level. SNR is one of the largest reserves in Iraq (E: 47° 40.413 ', N: 31° 10.887'), located within Al-Saffia marsh, east of Al-Dasim marsh, is rectangular with an area of 44 km^2, length 11 km^{2,} and width 4 km^2. A dam parallel to the border strip with the Iranian side and the west is a dam parallel to the border barrier, and it is connected with the Ajirda dam. SNR is one of the types of wetlands. It was established in 2006 by the Directorate of Agriculture in Basra Governorate to preserve biodiversity. Others, such as insects, crustaceans, and fish, especially during periods of migration, mating, and spawning as shown in Figure1. Locations of the sampling stations selected in the present study showed the most important sources of the Rivers, the source is the work of the researcher based on the administrative map of Iraq 1/1000000, the map of Basra Governorate 1/250000, and the USGS satellite map for the year 2021, using ArcMap Ver. 10.8.

Water sample collection and analysis: Water samples were collected from September 2019 to August 2020 from nine different stations in SNR, Al-Hawizeh Marsh (Fig. 1). The environmental variables, were recorded in the field, a standard thermometer for temperature within 10-100˚C, the potential of hydrogen ion (pH) and Electrical Conductivity (EC) (µs cm^{-1}) was measured by A Multiprobe type HANNA multimeter after calibrating the device before going to fieldwork with Buffer solutions, 4, 7 and 9, Milwaukee device to make the measurements of dissolved oxygen (mg L^{-1}). Water samples were taken from the field for the determination of NO_3 and PO_4 in the laboratory. Active nitrite NO_3 was measured according to American Public Health Association and active phosphate PO_4 by method of Strickland and Parsons (1976).

Data map: The base map of the study area is obtained by using ArcGIS 10.8 software. We pick WGS 1984 (Geographic Coordinate System) as a spatial reference map in the ArcGIS 10.8 program. Lastly, IDW was performed as an interpolation in spatial analyst. Interpolation is used to predict the value of attributes at un-sampled sites using values at locations within the same region

Statistical analysis: Data were statistically analyzed using Minitab ver.19, below the probability level of (0.05).

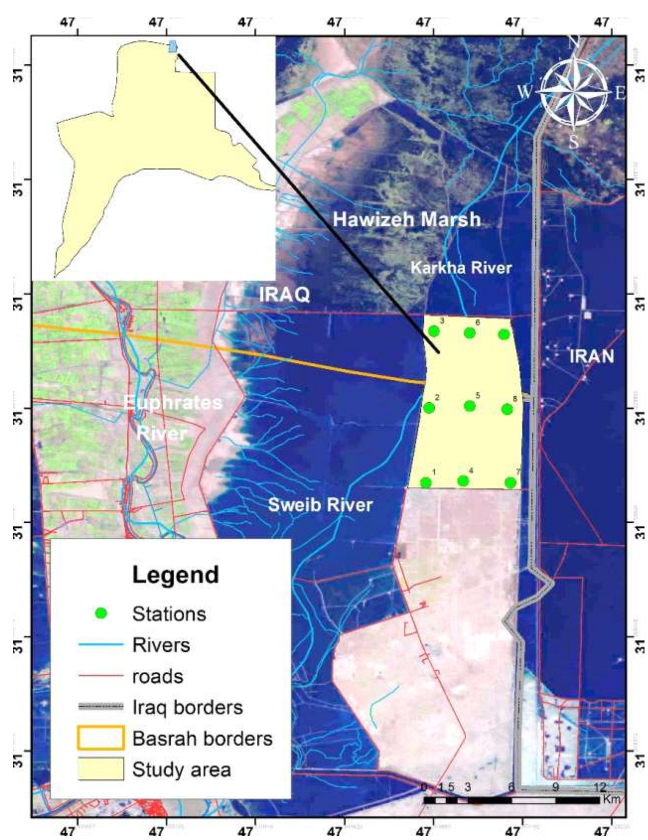

Fig. 1. Locations of the sampling stations selected in the present study and showing the most important sources of the Rivers

RESULTS AND DISCUSSIONS

Physical and Chemical Parameters

Water temperatures: The highest water temperature was 30.9°C in Station No.9 during the summer season, while the temperature decreased to its lowest levels in the winter season when it was 13.4°C in Station No. 3. Statistical analysis showed significant differences between seasons and no significant differences were observed between stations. This variation is due to the nature of the Iraqi climate in general, as thermal extremes characterize it, so it is hot and dry in the summer and cold and rainy in the winter may be to the intensity of solar radiation throughout the hours of the day, especially in the summer, slight differences or differences were recorded between the water temperatures on the surface and the lower layers inside the water column due to the shallow water in the marshes. This variation in water temperature helps in the abundance and growth of different species of organisms in the area (Douabul et al 2013). The local changes in water temperature may be due to the difference in the time of sampling, where the temperature is low in the early morning and then starts to rise as approach the middle of the day. In general, the waters of the marshes in southern Iraq are characterized by the difference in temperatures during the seasons of the year and this corresponds to the study of Al-Thahaibawi (2014) where the water temperature in the southern marshes ranged between 14.3 -35.6°C in winter and summer respectively (Fig. 4 a-d). Mohammed (2010) in Al-Hammar marsh in southern Iraq observed that the temperature ranged from 15°C in February to 31°C) in August.

Hydrogen ions (pH): The pH value is one of the important measurements that determine water bodies' suitability for different purposes. It also plays a vital role in rivers (Al-Hassani et al 2006, Yousry et al 2009). The pH recorded in the present study was within a narrow range. They tended to be alkaline as it is common in Iraqi inland water due to Iraqi natural waters' with relatively high content of calcium bicarbonate (Fig. 4). The lowest pH values in the study area reached 7.8 in No.2 and No.6 during the summer season, while the highest was 8.7) in station No. 5 during the winter. There were significant differences between the seasons at the probability level as well as the presence of significant differences between the stations (Fig. 6 a-d). In the present study alkalinity is the predominant characteristic of the water in the stations. These results are in agreement with the pH of freshwater in different regions of the world (Baudo and Beltrami 2001) as well as, with previous local studies on internal Iraqi waters (Hinton and Maulood 1980), The alkaline

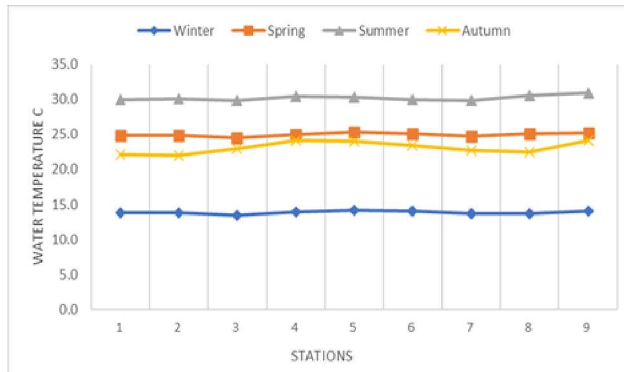

Fig. 3. Water temperature (°C) in SNR

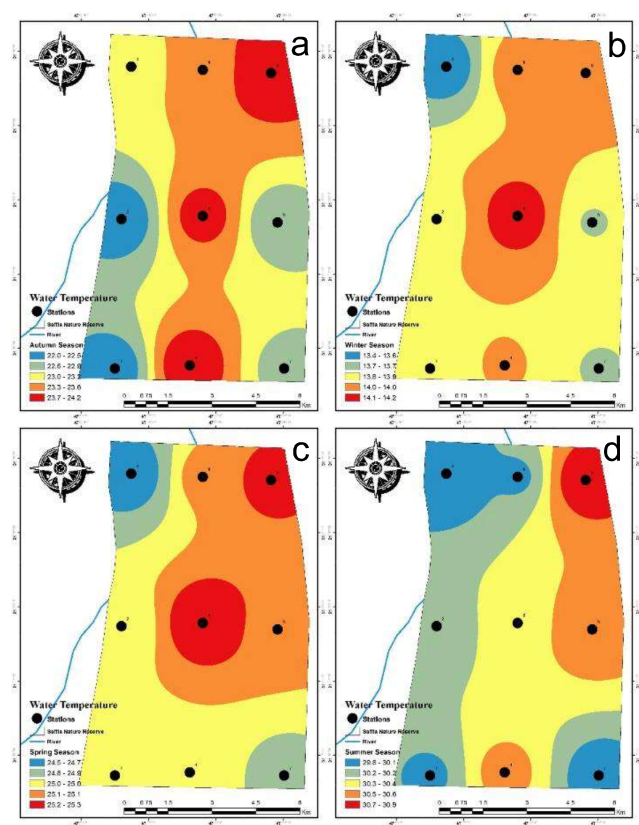

Fig. 4. Spatial distributions of WT using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

Fig. 2. Saffia nature reserve

characteristic of Iraqi waters is mainly due to the nature of lime sediments of the marsh, so the lower pH values may be due to the nature of acid or the increase in the concentration of dissolved carbon dioxide as a result of the organic decomposition of the materials. Bora and Goswami (2015) indicated that the pH value of rivers depends on several factors, including local geology, the environment, as well as human influences. The runoff of alkaline substances due to heavy rains is one of the factors affecting the high pH value of water (Rubio-Arias et al 2013), Higher temperatures lead to an increase in evaporation rates, which leads to an increase in the concentration of dissolved salts in water, which raised the pH value in the base direction (Odjadjare and Okoh 2010).In general, the waters of the Iraqi marshes are characterized by a low pH value in summer and high in winter, and this agrees with (Mohammed 2010, Al-Kenzawi et al 2011, Al-Saboonchi et al 2011, Al-Rikabi and Al-Kubaisi 2014, Al-Abbawy and Al-Zaidi 2018). The current study of the pH values at Station No.5 during the winter season recorded a value higher than the permissible limits according to the World Health Organization (6.5 - 8.5).

Electrical conductivity (EC): Electrical conductivity (EC) is a measure of the ability of an aqueous solution to carry an electric current, depending on the ions, their equivalence, total concentration, and their movement, as well as on the temperature at the time of measurement. The highest value of electrical conductivity was 7.1 μS cm^{-1} in station No.2 in the spring. The lowest value was 3.44 μS cm^{-1} in station No.5 in the autumn season (Fig. 7). The statistical analysis showed that there was significant differences between the seasons and was noticed that there were no significant differences between the stations (Fig. 8 a-d). The seasonal and monthly differences in the electrical conductivity values is attributed to the fact that it is associated with a decrease in water levels and an increase in the rate of evaporation in the summer, which leads to the dissolved ions being more concentrated and this leads to an increase in the electrical conductivity values in the water (Al-Kenzawi et al 2011), and the reason for the low values of electrical conductivity in the marshes water may be due to the dilution of salts by precipitation (Al-Saad et al 2010). The electrical conductivity value is also clearly related to the total soluble solids, as it reflects the water content of salts, nutrients, and organic materials (Parmar and Parmar 2010). It is well known that the Iraqi marshes were exposed to years of drought, which led to an increase in the concentration of salts in the sediments (Al-Abbawy and Al-Mayah 2010, Al-Abbawy et al 2011).

Dissolved oxygen (DO): Dissolved oxygen in water is the first evidence to prove the purity of natural water since most aquatic organisms depend on the presence of dissolved

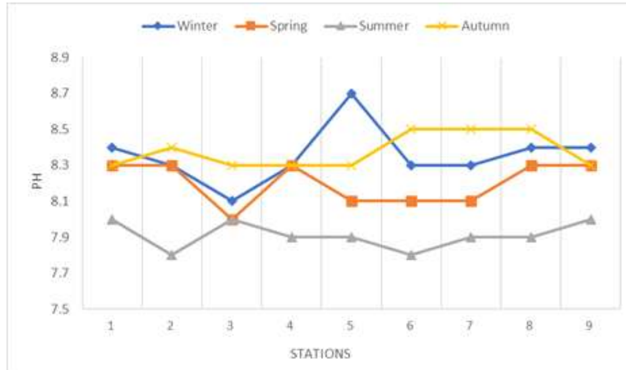

Fig. 5. Hydrogen ion concentration (pH) in SNR

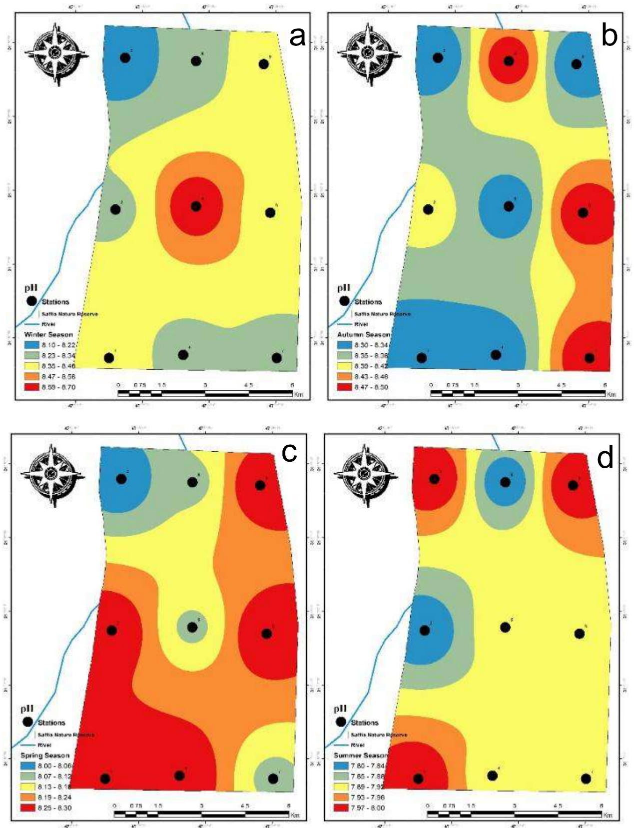

Fig. 6. Spatial distributions of pH values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

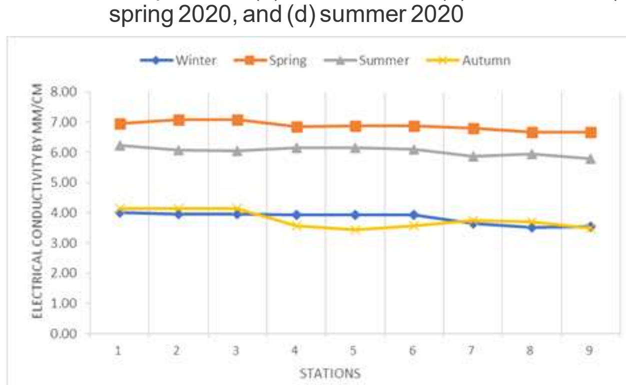

Fig. 7. Electrical Conductivity (EC) μm cm^{-1} in SNR

oxygen to survive (Singanan et al 2008). For that reason, dissolved oxygen is one of the most critical factors that affect the quality and degree of water bodies of water-pollution in it (Yang et al 2007). The results of dissolved oxygen in the current study showed that the highest dissolved oxygen was (10.1 mg l^{-1}) in station No. 8 during the winter season (Fig. 9). The lowest value was in the summer season (5.5 mg l^{-1}) in stations No. 4 and 5. The statistical analysis showed the presence of significant differences between the seasons and no significant differences were observed between the stations. There is a significant correlation relationship. Negative between dissolved oxygen and temperature (Fig. 10 a-d). In general, the low value of dissolved oxygen concentrations recorded during the summer season and the highest values represented in the winter season (Mohammed 2010, Al-Kenzawi et al 2011, Al-Saboonchi et al 2011, Al-Zuwar et al 2012, Douabul et al 2013, Al-Rikabi and Al-Kubaisi 2014, Al-Asadi 2014, Al-Abbawy and Al-Zaidi 2018). The presence of dissolved oxygen in the aquatic environment is affected by many factors, including the amount of rain, water temperature, salinity, the decomposition of organic matter in the water, the presence of aquatic plants, and the presence of pollutants from 4 mg l^{-1} (Cameron et al 2013). Most of the study results were for dissolved oxygen concentrations in the waters of SNR above the permissible limits according to the World Health Organization (6 mg l^{-1}).

Nutrients

Active Nitrate (NO_3^-): The nitrate anion is one of the inorganic nitrogen forms in water and nitrate, and ammonia. It is also a significant nutrient that contributes to building the vital activities of most living organisms. The high nitrate value

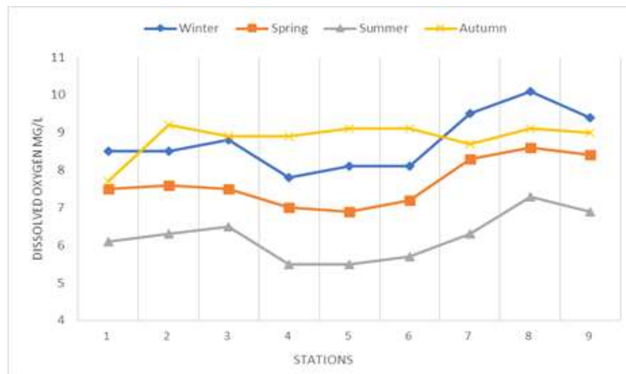

Fig. 9. Dissolved Oxygen (EC) mg L^{-1} in SNR

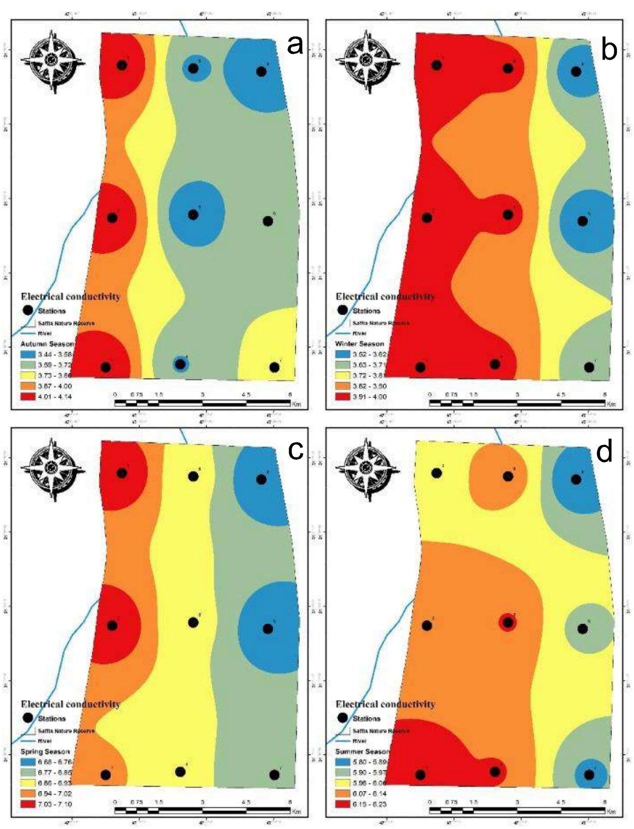

Fig. 8. Spatial distributions of E.C. values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

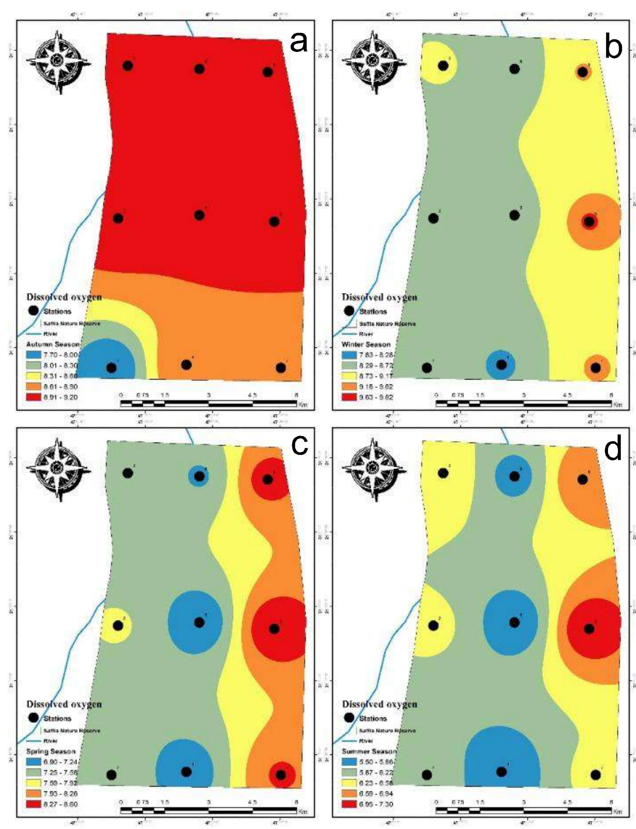

Fig. 10. Spatial distributions of DO mg L^{-1} values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

is due to the flow of nitrogen-rich floodwaters that bring in large quantities of contaminated wastewater (Pradeep et al 2012). The nitrate concentration reached the highest value (8.04 mg L^{-1}) in station No.1 in the winter season and the lowest was in station No.6 (0.53 mg L^{-1}) during the same season (Fig. 11). During the seasons, the sufficient nitrate concentrations were in the winter and spring seasons and the lowest were in the summer and autumn seasons. There was significant difference between the seasons. In contrast, no significant differences were between the stations and there is a significant negative correlation between nitrate concentrations and water temperatures. The reason for the high nitrate concentrations during the winter season may be to the rains, which in turn dissolve the organic compounds and nitrogen fertilizers on the banks of the rivers (Lomoljo et al 2009), as well as the low nitrate consumption by phytoplankton and aquatic plants (Twomey and John 2001, Al-Saadi et al 2008). The increase in oxidation of nitrite to nitrate as a result of the decrease in water temperature, which increases the concentrations of dissolved oxygen (Hussein and Fahad 2008). In the summer season, nitrate concentrations decreased most of the study stations. It may be caused by an increase in temperature and decrease in dissolved oxygen concentrations, which leads to the reduction of nitrates to nitrites (Al-Emara et al 2001). This study is in agreement with previous studies on the marshes in southern Iraq in terms of high active nitrate concentrations in winter and spring seasons and low in summer and autumn seasons (Al-Saboonchi et al 2011, Douabul et al 2013, Al-Thahaibawi et al 2014, Al-Rikabi and Al-Kubaisi 2014). The results of the active nitrate concentrations in the current study did not exceed the World Health Organization, which is 50 mg l^{-1} (Fig. 12 a-d).

Active Phosphate (PO_4^{3-}): Phosphorus is essential for different living organisms, and its increase also leads to an overgrowth of microorganisms in large quantities, which affects other aquatic organisms (Al-Emara et al 2001, Bakan et al 2010). The current study results showed that the highest reactive phosphate concentration was at station No.9 in the spring season (0.133 µg L^{-1}). The lowest was at station No. 6 in the winter season was (0.005 µg l^{-1}). The study stations' show that the highest value of the reactive phosphate concentration was in the summer and spring seasons during seasons. The lowest concentrations were in the winter and autumn seasons (Fig.13). The statistical analysis showed a significant difference between the seasons as well as the presence of significant differences between the stations at the probability level. There is a significant negative correlation at the between the active phosphate concentrations and water temperatures (Fig. 14 a-d).

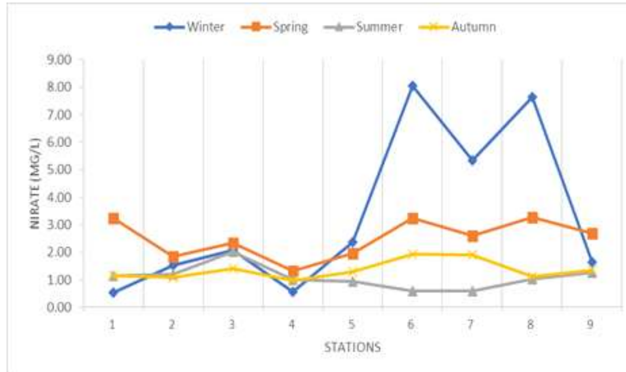

Fig. 11. Nitrate concentration (NO_3^-) mg L^{-1} in SNR

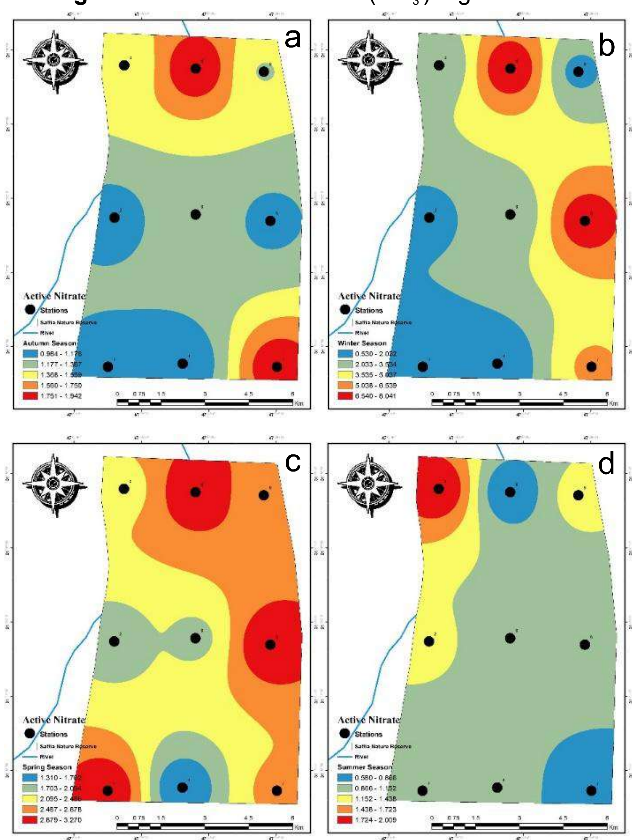

Fig. 12. Spatial distributions of NO_3^- mg L^{-1} concentrations using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

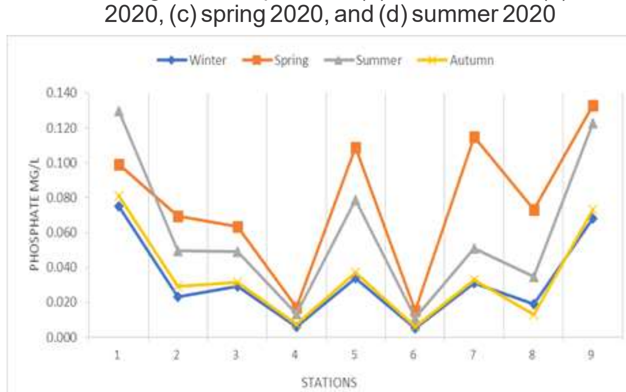

Fig. 13. Phosphate concentration (PO_4^{3-}) µg l^{-1} in SNR

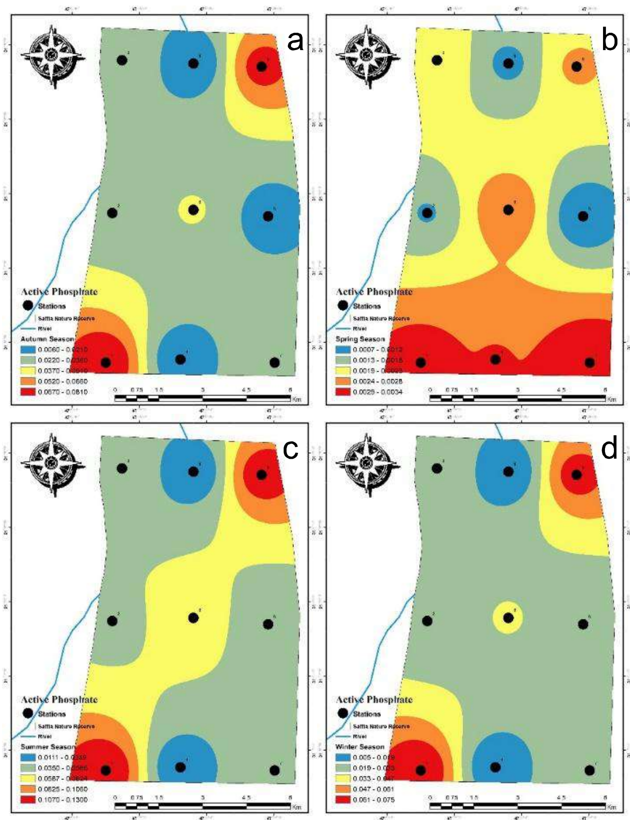

Fig. 14. Spatial distributions of PO_4^{3-} concentrations using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

CONCLUSIONS

The results of the study showed deterioration in water quality due to the high electrical conductivity during the study period and best properties were in the summer. There is a negative exponential relationship between water temperatures and pH and dissolved oxygen, and a positive relationship between water temperature and electrical conductivity.

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Parametric Optimization of Solar Powered Remote-Controlled Sprayer using RSM and TAGUCHI Method

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Abstract: Green energy-based appliances, gadgets and machines are taking over conventional counterparts in many of the sectors and agriculture is no different. Lighter farm operations such as spraying, weeding and fertilizer broadcasting can be carried out using agricultural machines powered by solar PV system. In this context, a solar powered remote-controlled sprayer was developed and was evaluated for its performance under laboratory conditions. The laboratory evaluation of SPRC sprayer was carried out according to BIS code IS: 11429 -1985. Chilli plants were raised in pots and all six nozzles were used for spraying the liquid so as to determine the droplet size and droplet density. Spray droplets were collected on glossy photographic papers fixed over the plant leaves. Deposit Scan software was used to measure droplet size and droplet density of spray. Height of spray was adjusted using adjustable stands while operating pressure was varied using pressure control valve. Three types of nozzles namely hollow cone, solid cone and flat fan nozzle were selected for evaluation. Influence of selected independent variables *viz*., height of spray, operating pressure and type of nozzle on performance parameters such as droplet size and droplet density were studied using optimal design in RSM. The droplet size varied between 165.80 and 236.40 µm whereas droplet density varied from 28.40 to 93.30 No's cm^{-2} for different combinations of selected influencing variables. Taguchi method was used to optimize the operating parameters and the optimum combination of variables was found to be 40 cm height of spray, 5 kg cm^{-2} operating pressure with hollow cone nozzle performing the best.

Keywords: Droplet size, Droplet density, Remote Controlled solar sprayer, RSM, Taguchi method

The next generation agriculture is unfolding across the globe. Today, agricultural activities are focused more on scientific and technological approaches so as to intensify the crop production. Reduction in cropping area and non-availability of timely labour has given impetus to introduction of highly sophisticated and efficient farm machines. Diminishing fossil fuels and increase in climate change conditions has compelled mankind to switch over to the cleaner and non-conventional energy sources such as solar, wind and biomass (Md. Rahman et al 2022). Solar energy is the most prominent source of renewable energy, its abundance over and across most parts of the earth makes it a potential resource besides being eco-friendly. There have been numerous applications of solar energy such as fireless cooking, space heating, water heating and steam generation using heat energy of solar radiation (Hussain and Lee 2015). Solar photovoltaic technology is probably the revolutionary development which is used for generation of electricity for various applications starting from domestic lighting to running large industry machineries.

Recent trends of technological innovations in agriculture are also focusing on using solar energy to carryout various farm operations and to develop machineries and solar motors for various agricultural applications including post harvest handling of agriculture produce (Kumar et al 2018, Gorjian et al 2021). Introduction of automation and robotics in agriculture has enormous potential to lower cost of production, reduce the drudgery involved in manual operations, to raise the quality of fresh produce and to improve the environmental conditions (Bawden et al 2017, Ghobadpour et al 2019, Oliviera et al 2021). In agriculture, spraying of pesticides is an important task to protect the crops from insect pest ensuring high yield. However, farmers are mainly using traditional/conventional techniques like hand operated and power operated sprayers for spraying pesticides (Ritiesh et al 2015). Exposures to pesticides both occupationally and environmentally cause a range of human health problems (Damalas and Koutroubas 2016). The farmers reported excessive sweating, burning/stinging/ itching of eyes, dry/sore throat and excessive salivation all more prevalent among sprayers (Chitra et al 2006).

In present context, shortage of man power for spraying is a major constraint. Escalating costs of gasoline fuels and hiring charges of heavy machineries are also major challenges faced by the farmer. The conventional method of spraying (hand operated spraying) results in excessive application of chemicals ultimately leading to environmental pollution, less uniformity rendering to more operational cost and also continuous spraying operation leads to fatigue of the operator. Thus with the application of pesticides using remote control spraying technology powered by the use of non-conventional sources of energy that is abundantly available would prove to be environmentally friendly by eliminating fuel operated engines, human interventions in the field and also by reducing health hazards. The electrical energy obtained through solar PV cells can be utilized for doing lighter field operations such as spraying, shallow depth soil working, and thinning. Off late, automated ground vehicles with spraying attachment, powered by solar energy are making their way in agricultural field. Mousazadeh et al (2010) evaluated alternative technologies for a solar assisted plug-in hybrid electric tractor and reported that life cycle cost of valve regulated lead acid (VRLA) battery was highest followed by Ni-MH, Li-ion and Ni-Cd batteries when coupled with a solar photovoltaic (PV) cells. The attempt has been made to develop a solar powered remote-controlled sprayer and optimize the operational parameters to suit varied field conditions.

MATERIAL AND METHODS

Description of the machine: The developed solar powered remote-controlled sprayer consisted of chassis, solar photovoltaic (PV) module of 220 W capacity, spray tank of 100 litre capacity, lead acid storage batteries, DC motors, pneumatic wheels, foldable spray boom with four nozzles, signal receiver, transmitter and electronic circuit board (Fig. 1). The chassis was separated into three sections namely, the base, middle and the spray boom section. In the base, two dry batteries were mounted below the tank with a wheel track and wheel base of 825 and 1020 mm respectively are connected to rear tyres through individual motors having enough capacity to carry 350 kg total weight including 100 kg fluid payload through chain and sprocket mechanism ultimately converting rotational energy into energy required to produce thrust, hence driving action taking place. On the left-hand side of the chassis, one dry battery is also connected to the servo motor whose function is to convert rotary motion into angular motion of front tires which are connected through tie rod mechanism rendering to steer simultaneously.

The middle section of chassis carries spray liquid tank, spray motor with pump, hose pipes, electronic circuit board and pressure gauge. Above all these components, the solar PV panel of 220W capacity (1580 x 810 mm) was mounted on a frame through nut and bolt system at a height of 610 mm. The outlet of the fluid tank pipe was connected to the inlet of the 12 V DC spray motor with pump which generates enough pressure to spray the liquid. The outlet pipe of the spray motor with pump was connected to spray nozzles through a pressure gauge by hose pipes. The spray boom section was mounted to the rear side of the developed prototype sprayer at a distance of 520 mm from the chassis with a provision of variable height adjustment for the spray boom. Total of three pairs of nozzles were used, each pair covering one row of the crop respectively. The spray boom was foldable at a distance of 800 mm from both the ends for easy transportation to the field (Fig. 2).

The electronic circuit board consisted of receiver board, battery charging box and controller board. The transmitter used was a wireless radio frequency device which controls the operating and spraying mechanism of the sprayer. FLYSKY transmitter and receiver is a 6-channel operation remote controlled device with a reliability of 2.4 GHz signal range which receives the signal from the transmitter and further processes the signal to micro controller unit for further action.

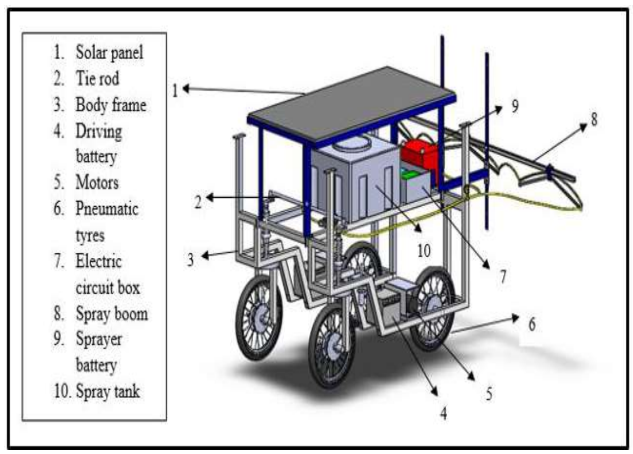

Fig. 1. Conceptual view of solar powered remote-controlled sprayer

Fig. 2. Stationary view of solar powered remote-controlled sprayer

Laboratory evaluation of SPRC sprayer: The developed solar powered remote-controlled sprayer was evaluated in laboratory conditions to study the effects of selected influencing variables *viz*., height of spray (H), operating pressure (P) and type of nozzle (N) at three levels each on performance parameters namely droplet size (D_s) and droplet density (D_d) (Table 1). Droplet size and droplet density were selected as they are the cardinal characteristics in determining the effectiveness of spray over the target crop. Height of spray was varied by varying the position of spray boom on the vertical plate made for the purpose whereas the operating pressure was varied using a pressure control valve at the spray pump. Three types of nozzles namely hollow cone, solid cone and flat fan were used for evaluation.

The laboratory evaluation of SPRC sprayer was carried out according to the procedures as mentioned in BIS code IS: 11429 -1985. Chilli plants were raised in the polyethylene bags and after certain age, the plants were placed in pots (Gholap and Mathur 2012). All the six nozzles were used for spraying the liquid and to determine the droplet size and droplet density. Height of the spray nozzle was maintained at 20, 30 and 40 cm above the plant canopy. The operating pressure was varied at 3, 4 and 5 kg cm^{-2}. The three types of nozzles used for the study were hollow cone, solid cone and flat fan nozzle (Senthilkumar and Kumar 2007).

Droplet size (D_s): Volume mean diameter (VMD) and number mean diameter (NMD) are two commonly used measures of droplet size. As the measurement of VMD and NMD is affected by the proportion of large and small droplets respectively, the ratio between these parameters indicates the ranges of sizes *i.e.* more the uniform the size of droplets are more the nearer is the ratio to unity (Matthews 1992). For evaluating VMD and NMD, glossy photographic paper of size 7.5 × 2.5 cm was selected as it has low spreading factor and was placed on upper and underside of leaves at top, middle and bottom portion of plants. They are fixed to leaves at location horizontally. Methylene blue MS dye mixed @ 5 g l^{-1} in water and photographic paper were the same as that used by Jassowal et al (2016). Deposit Scan is a portable scanning program for spray deposit quantification that can quickly evaluate spray deposit distribution on water sensitive paper or kromokote paper. Glossy papers were scanned using a PC connected high resolution scanner. In this program, the scanning resolution was chosen up to 2400 dpi or 10.58 µm per pixel length. When the Deposit Scan program is started, it opens an image-processing program, and prompts the user to scan the sample. The program then reports the individual droplet sizes, their distributions, the total number of droplets, and the percentage of area covered. The program batch file calculates $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ and displays the results from the area of the selected section, the total number of spots and the percentage area covered by the spots. $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ represent the distribution of the droplet diameters such that droplets with a diameter smaller than $DV_{0.1}$, $DV_{0.5}$, and $DV_{0.9}$ compose 10 per cent, 50 per cent and 90 per cent of the total liquid volume, respectively.

Table 1. Variables and levels selected for laboratory evaluation

Parameters	Levels		
	1	2	3
Independent parameters			
Height of spray (H), cm	20	30	40
Operating pressure (P), kg cm^{-2}	3	4	5
Type of nozzle (N)	Hollow cone (HC)	Solid cone (SC)	Flat fan (FF)
Performance parameters			
Droplet size (µm)			
Droplet density (No's cm^{-2})			

Droplet density (D_d): By using droplet analyzer, the number of droplet spots on one square centimetre (cm^2) area of water sensitive paper was obtained. The number of droplets per square centimetre area is termed as droplet density. The droplet density was also measured in Deposit Scan software.

Experimental design and statistical analysis: Response Surface Methodology (RSM) is one of the popular statistical tools used for analysis of variable data and to examine the extent of relationship between independent variables and performance parameters (Lee et al 2006). There are various designs in RSM including Central Composite Rotatable Design (CCRD), Box-Behnken Method and Optimal (Custom) Design. The variables selected for the study consist of both numerical and categorical factors. Hence, Optimal design best fits for the experimentation.

Optimal design is a recommended choice when both categorical and numeric factors, constraints, need to fit a cubic or higher order model, or trying to fit a custom model (El-Gendy et al 2016). Three levels of numerical independent variables were selected with coded values of - 1, 0 and + 1. Two nominal levels of categorical factor were chosen. The response function in optimal design is expressed in the following linear equation form and used in data analysis.

$$Y = \beta_o + \sum_{i=1}^{q} \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum_{i=1}^{q} \sum_{j=i+1}^{q} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

Where,

Y= response, β_o= intercept, β_i, β_{ii}, β_{ij} = regression coefficients, X_i, X_j= coded variables and ε = error

Design Expert (v12.0) statistical software was used for the analysis of data and interpretation of results.

Parametric optimization: Parametric optimization was carried out using Taguchi method to find out optimum combination of independent parameters that maximize the performance of the developed sprayer.

Taguchi method: Taguchi method is one of the robust statistical tools in the design of experiments. It provides lesser numbers of experiments while giving more quantitative information (Kazemian et al 2021). Taguchi orthogonal array can be regarded as a general fractional factorial design process and it can analyze the experimental data based on the SN ratio (Kuo et al 2011 and Girish et al 2019). In present study, Taguchi orthogonal array of L9 configuration was constructed in Minitab 19 software considering height of spray (H), operating pressure (P) and type of nozzles (N) at three levels each (Table 2). Measured values of performance parameters *i.e.,* droplet size (D_s) and droplet density (D_d) were recorded and given as result inputs for further analysis. The goal was to optimize the combination of independent parameters which will minimize the droplet size and maximize the droplet density. Hence, the goal of "Smaller is Better" was set for droplet size and "Larger is Better" was set for droplet density in Taguchi method using following model equations.

(Smaller is better)

$$Z = -10\log\frac{\sum_{i=1}^{n} y_i^2}{n} \quad (2)$$

(Larger is better)

$$Z = -10\log\frac{\sum_{i=1}^{n}\frac{1}{y_i^2}}{n} \quad (3)$$

Where, Z = S/N ratio, y = Response factor

RESULTS AND DISCUSSION

The developed SPRC sprayer was evaluated in laboratory conditions to arrive at optimal combination of affecting parameters and take up the field evaluation under optimized conditions.

Laboratory Evaluation of Solar Powered Remote-Controlled Sprayer

Droplet size (D_s): The maximum droplet size of 236.40 µm was obtained at 30 cm height of spray, operating pressure of 3 kg cm^{-2} for solid cone nozzle. The droplet size varied from 165.80 to 236.40 µm with a mean value of 207.25 µm. The minimum value was observed at 40 cm height of spray, operating pressure of 5 kg cm^{-2} for flat fan nozzle (Table 3). The droplet size decreased with increase in operating pressure and height of spray for all three types of nozzles. This may be because of the fact that droplet size is inversely proportional to the operating pressure and as the height of spray increased, the spray droplets were subjected to more descent time before getting deposited on the target during which a part of the droplet either get evaporated or get halved by air resistance. Droplet sizes of solid cone nozzle were on higher side compared to other two types of nozzles (Fig. 4).

Droplet density (D_d): The droplet density varied between 28.40 and 93.30 No's cm^{-2} with a mean value of 51.62 No's cm^{-2}. The maximum droplet density was obtained at 20 cm height of spray, operating pressure of 5 kg cm^{-2} for flat fan nozzle. The minimum value was observed at 40 cm height of spray, operating pressure of 4 kg cm^{-2} for solid cone nozzle (Table 3). The droplet density increased with increase in operating pressure and decreased with height of spray for all three types of nozzles (Fig. 5). This may be attributed to the fact that operating the sprayer at higher pressure releases a greater number of droplets from the nozzle and hence the density also increases and as the height of spray increases, the deposition rate of droplets over the target plant decreases because of drift caused by prevailing wind. Droplet density of flat fan nozzle had highest values followed by hollow cone

Table 2. Orthogonal array in Taguchi Design

Height of spray (H), cm	Operating pressure (P), kg/cm^2	Type of nozzle (N)
20	3	HC
30	3	SC
40	3	FF
20	4	SC
30	4	FF
40	4	HC
20	5	FF
30	5	HC
40	5	SC

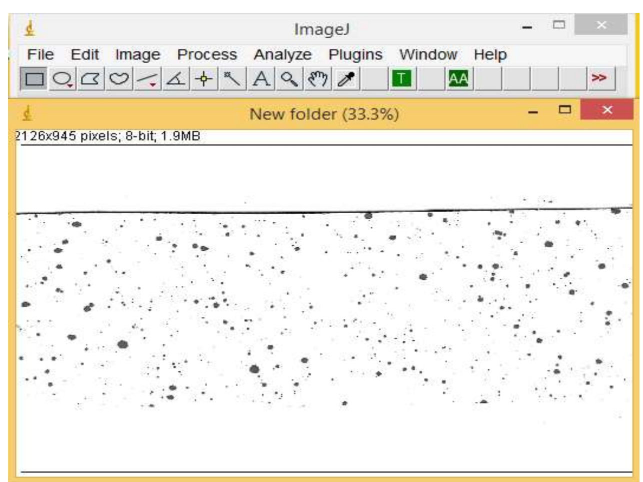

Fig. 3. User interface of image programme in deposit by scan software

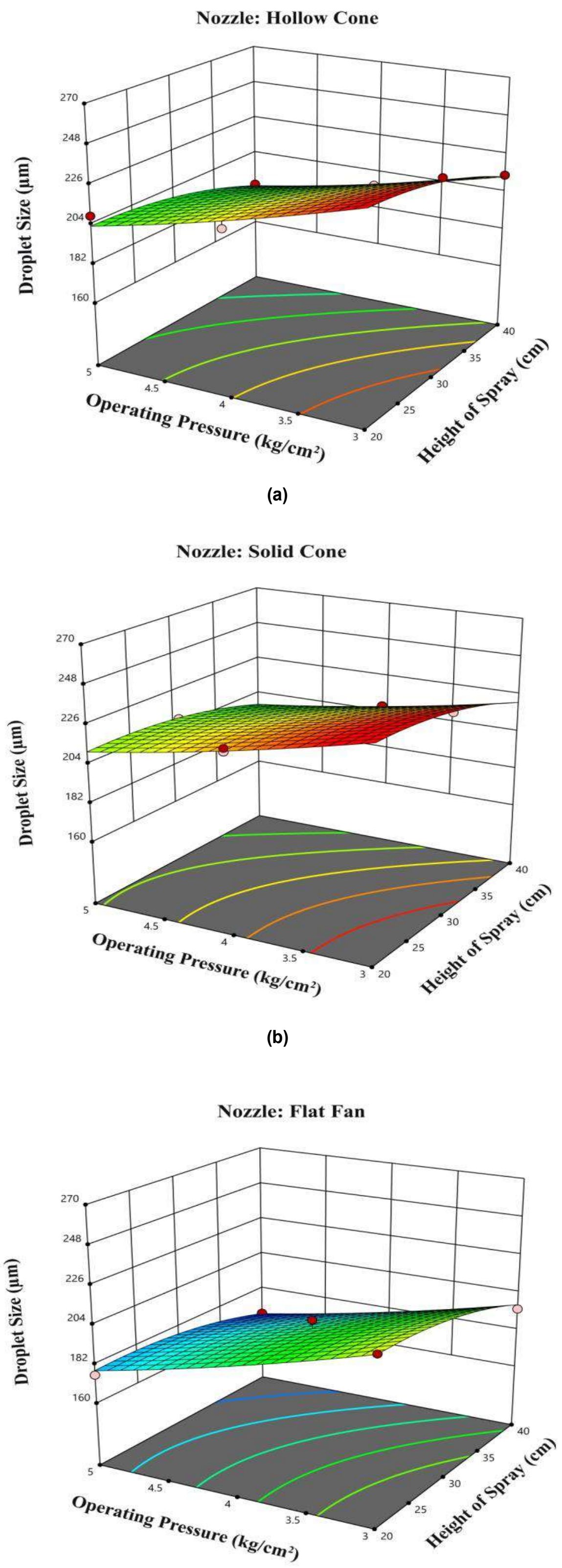

Fig. 4. Effect of height of spray (H) and operating pressure (P) on droplet size (D_s) for hollow cone (a), solid cone (b) and flat fan (c) nozzles

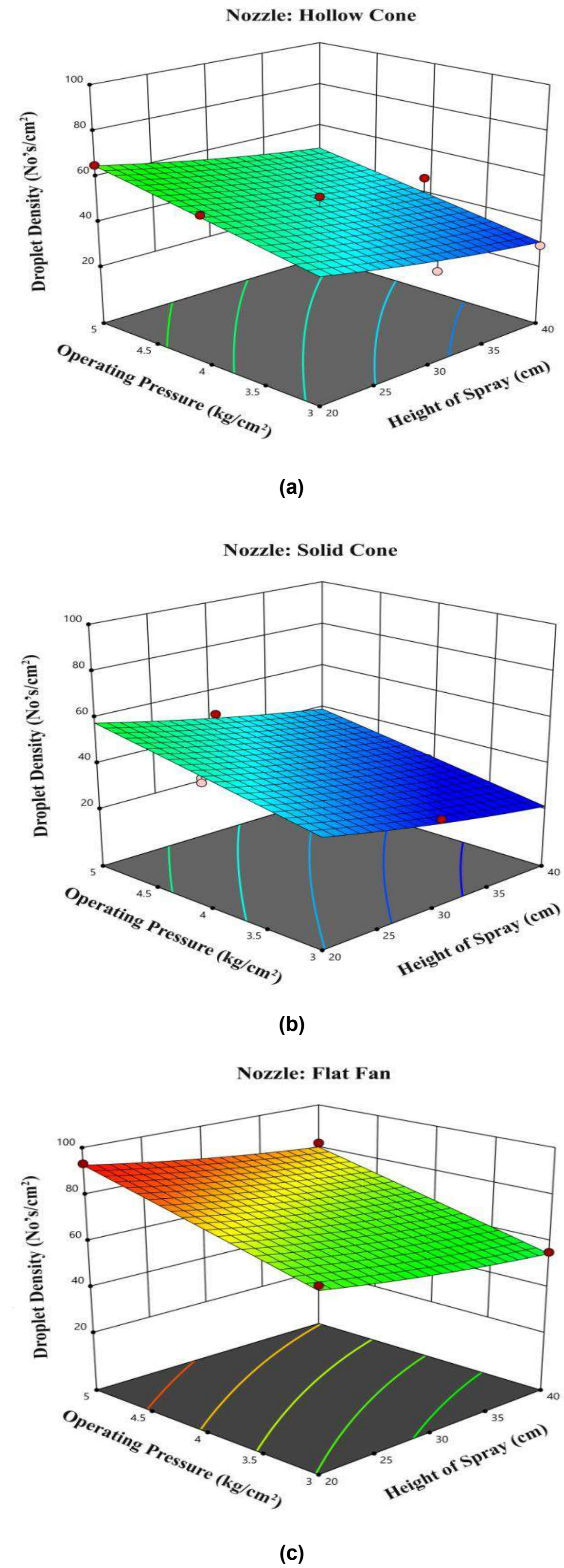

Fig. 5. Effect of height of spray (H) and operating pressure (P) on droplet size (D_s) for hollow cone (a), solid cone (b) and flat fan (c) nozzles on droplet density (D_d)

Table 3. Variables with coded values and of laboratory evaluation using optimal design in RSM

Height of spray (H), cm	Operating pressure (P), kg cm^{-2}	Type of nozzle (N)	Droplet size (D_s), μm	Droplet density (D_d), No's cm^{-2}
40 (+1)	3 (-1)	HC	214.10	29.50
30 (0)	4 (0)	HC	211.30	51.60
30 (0)	4 (0)	FF	192.4	70.30
20 (-1)	5 (+1)	FF	176.10	93.30
20 (-1)	4 (0)	HC	215.80	57.20
20 (-1)	4 (0)	SC	224.40	46.30
20(-1)	4 (0)	SC	226.30	48.20
40 (+1)	4 (0)	SC	207.90	28.40
30 (0)	3 (-1)	SC	236.40	30.90
30 (0)	5 (+1)	SC	208.80	49.20
30 (0)	3 (-1)	HC	233.60	33.40
20 (-1)	3 (-1)	FF	216.80	69.20
30 (0)	5 (+1)	HC	195.20	53.80
30 (0)	5(+1)	SC	208.80	49.20
30 (0)	3 (-1)	SC	236.40	30.90
40 (+1)	5 (+1)	FF	165.80	82.30
40 (+1)	3 (-1)	FF	194.50	55.60
20 (-1)	5 (+1)	HC	209.20	65.40
40 (+1)	4 (0)	HC	195.90	47.00
40 (+1)	4 (0)	SC	207.90	28.40
30 (0)	4 (0)	FF	197.50	70.30
40 (+1)	5 (+1)	HC	184.30	45.20

Table 4. Mean droplet size and SN ratios for droplet size and droplet density

Means droplet size (D_s)					
Level	1	2	3	Delta	Rank
Height	229.4	224.1	211.8	17.6	1
Pressure	228.3	222	215.1	13.3	2
Nozzle	217.9	221.3	226.2	8.3	3
SN Ratios (Smaller is better)					
Level	1	2	3	Delta	Rank
Height	-47.21	-47	-46.52	0.7	1
Pressure	-47.17	-46.92	-46.64	0.53	2
Nozzle	-46.75	-46.89	-47.09	0.33	3
Droplet Density (D_d)					
Level	1	2	3	Delta	Rank
Height	48.5	58.07	64.13	15.63	2
Pressure	44.3	59.7	66.7	22.4	1
Nozzle	60.7	52.67	57.33	8.03	3
SN Ratios (Larger is better)					
Level	1	2	3	Delta	Rank
Height	33.59	35.08	36.05	2.46	2
Pressure	32.87	35.38	36.46	3.58	1
Nozzle	35.36	34.22	35.14	1.14	3

and solid cone nozzles, respectively.

Optimization of operational parameters using Taguchi method: The results obtained by experiments were fitted into L9 array given by Taguchi design and analysis was carried out for both droplet size (D_s) and droplet density (D_d). Responses for SN ratio and means of droplet size with a goal of "smaller is better" were obtained. The height of spray (H) had highest effect on droplet size with a rank of 1 followed by operating pressure (P) and type of nozzle (N). Similarly response table for SN ratio and response for means of droplet density with a goal of "larger is better" were also obtained. The operating pressure (P) had highest influence on droplet density followed by height of spray (H) and type of nozzle (N) (Table 4).

The optimum parametric combination was H3P3N1 which corresponds to 40 cm height of spray (H), 5 kg cm^{-2} operating pressure (P) and hollow cone nozzle (N) (Fig. 6, 7). The main effect plot for means and main effect plot for SN ratio of droplet density (D_d) indicate that parametric combination of H3P3N1 gave the optimum combination with "larger is better" goal (Fig. 8, 9).

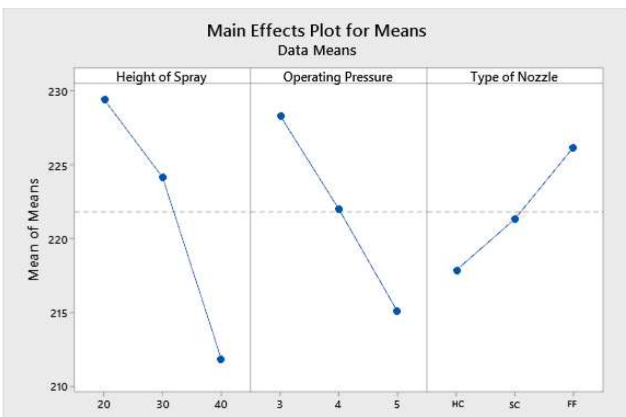

Fig. 6. Main effect for mean (smaller is better) for droplet size (D_s)

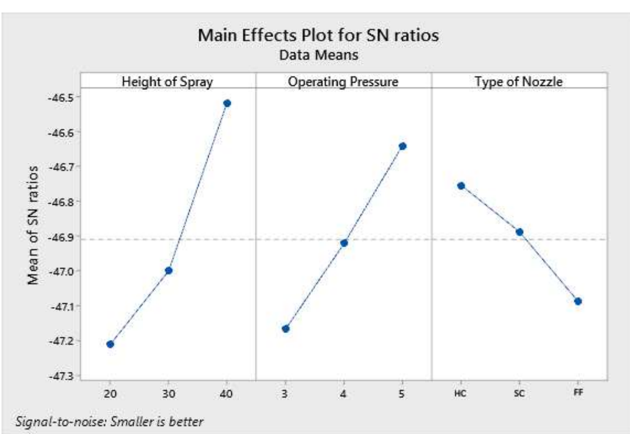

Fig. 7. Main effect on SN ratios (smaller is better) for droplet size (D_s)

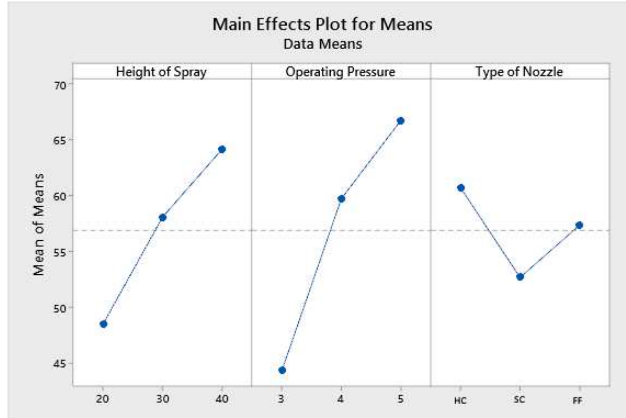

Fig. 8. Main effect for means (larger is better) for droplet density (D_d)

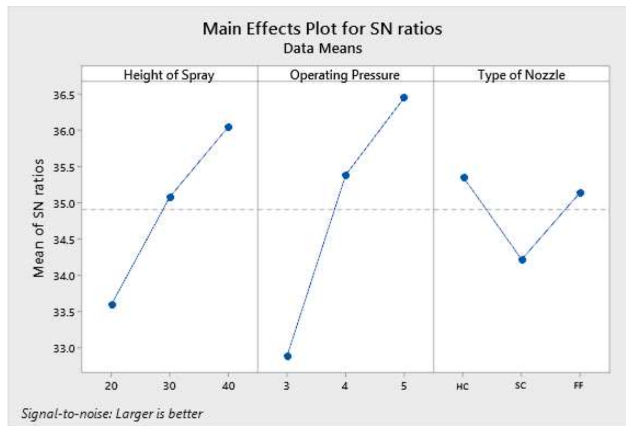

Fig. 9. Main effect plot for SN ratios (Larger is better) for Droplet Density (D_d)

CONCLUSIONS

Droplet size (D_s) was significantly affected by selected independent variables and decrease with increase in height of spray and operating pressure. The hollow cone nozzle produced the smallest value of droplet size. All the selected independent parameters significantly affected the droplet density (D_d). The droplet density decreased with increase in height of spray and increased with increase in operating pressure. Taguchi analysis of parameters revealed that the optimum height of spray was 40 cm, operating pressure was 5 kg cm^{-2} and hollow cone type nozzle was the best among selected parameters to operate the developed SPRC sprayer.

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Micro-level Impact Assessment of Mobile Based Specific Agromet Advisory for Farmers in Karnal , Haryana, India

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Abstract: The weather forecast and advisories have been helping the farming community to take advantage of prognosticated weather conditions and form the response strategy. Introduction of District Agro Met Units (DAMU) service by India Meteorological Department (IMD), helped farmers over different regions to minimize crop losses as a result of extreme weather conditions and helps to overcome negative impacts of changing climatic conditions on crop productivity. The study was conducted to analyze feedback received from farmers from three consecutive years 2020 to 2022 and revealed that numbers of farmers using AAB are significantly increased from 2020 to 2022. Crop situations of these farmers were compared with nearby fields having the same crop where forecast is not adopted by the farmers. Further net benefits obtained by the farmers were incurred from land preparation till the harvesting stage in rice and wheat crop. The net income of AAB followed farmers in rice and wheat crop were ₹ 4672 and ₹ 5992/ ha over Non AAS (Non agro-met advisory services) farmers. The farmers who have adopted the AAB in their day-to-day operations have realized additional benefit, the application of AAB based on current and forecast weather is a useful tool for enhancing the production and income at farm level.

Keywords: Agromet advisories services, Feedback analysis, Impact assessment

Agriculture is essential for livelihood and also plays a significant role in driving the economy. Farming operations were being highly associated with the weather variations lead to significant losses in produce. Weather-induced damages and losses to agriculture were reported to be 25% in developing countries during 2003-13 (FAO 2016). Droughts, floods, heat waves and hail are becoming more common as a result of climate change and threaten agricultural productivity (Bal and Minhas 2017, Chandran et al 2017). Farmers with access to real-time weather data and accurate weather forecasts can reduce weather-related losses and increase agricultural productivity (Weiher et al 2007). Weather forecasts in all temporal ranges are effective for planning activities in agriculture and help farmers make crucial farm management operations (Godgil et al 2002, Maini and Rathore 2011). As relevance of information depends on the information format and how well it is integrated into the micro-level decision-making process (Daron et al 2015, Hansen 2002) providing timely and accurate weather forecasts embedded with advisories on weather forecast-based field operations to be carried out by farmers assumes great importance (Chattopadhyay et al 2007). According to Maini and Rathore (2011), psychological well-being is important for overall health and can be improved through various interventions. Weather predictions and advisories are important for farmers because they help ensure that their activities are carried out in a timely and accurate manner. Weather scenarios for each block are now accessible for integration with micro-level agromet advisory services, as well as the availability of high-resolution numerical weather prediction models should be appreciated (Rathore and Maini 2008). The role of AAS in reducing weather-related dangers to agriculture in India was recently assessed by Chandran et al (2017). Now with the advancement in this system, weather scenarios of each block have to be developed separately for past and future weather and then match the scenarios with Agro-DSS Portal. With availability of high-resolution NWP Models, weather scenarios of each block are now available for integration with MAAS after introduction of District Agromet Field Units (DAMUs). This system of AAS has helped farmers over different regions to minimize crop losses due to extreme and adverse weather conditions (Rathore and Maini, 2008 NCAER report, 2010, 2015 and 2020).

The National Council of Applied Economic Research (NCAER 2010) conducted a national impact assessment study and found that 24% of farmers had access to weather and climate services. The potential economic impact of AAS services for four major crops was projected to be Rs. 4,20,000 million in a 2015 report (NCAER 2015). The most recent report (NCAER 2020) estimated an annual income boost of Rs 12,500 per farming household in rainfed areas for those living in poverty. Manjusha et al (2019) conducted a regional level study in the National Capital Region (NCR) and reported that farmers might save 9.6 % and 3% on input costs in rice and carrot, respectively. The major lacuna regarding forecasting we don't have sufficient data set of meteorological variable on special factors which affecting agriculture production on a local meso-scale level. To cope with Agro-meteorological risks and uncertainties we have to enhance improved use of climate knowledge and its essential is much needed, like we prepared planning, early warning and accurate strategies are the major steps for mitigating losses. In view of the importance of continuous assessment of different aspects of the service, a survey was conducted deploying Google Form and also through personal contact to the farmers by DAMUs. Therefore, the study was undertaken on use of AAS and to assess economic impact assessment of AAS for major crops during Rabi and Kharif season 2019-2020 in NW India, for, for assessing and quantifying the impacts of AAS and Non-AAS farmer using timely and need-based crop management practices as per the forecast and AAB. Theses AAB helps in increasing the economic benefit to the farmers by suggesting them suitable management practices according to the prevailing weather conditions. Understanding the potential and obligation of any service requires regular monitoring, feedback collection and economic impact assessment.

MATERIAL AND METHODS

The current study was conducted in the state of Haryana, which is situated in the north-western Trans-Gangetic plain region of India. The present investigation was conducted at District Agromet Units (DAMU), Krishi Vigyan Kendra, ICAR-National Diary Research Institutes, Karnal in Longitude - 29'04 N, Latitude - 77'02 E and 250 meters.

Impact analysis assessment framework: A constructed questionnaire was developed for primary, secondary and tertiary data sets collection from heterogeneous group of farmers (550 farmers in 80 villages). The data were collected with a structured questionnaire schedule pre tested earlier. In this questionnaire, the main emphasis was on collecting information on the adoption of advisories by the farmers for farm operations (planting dates, harvesting, spraying, irrigation and tillage operation); and on benefits or losses incurred by those following or not following the advisories related to such crucial operations. The major crops chosen for the study were food grain crops (wheat and rice). During three years of study, Karnal district eight blocks were chosen for this study. The feedback was collected in 2020-2022 from the farmers of all the eight blocks of Karnal namely Assandh, Gharaunda, Indri, Karnal, Kunjpura, Munak, Nilokheri and Nissing. A feedback questionnaire was also sent to the farmers through whatsapp groups created for the dissemination of advisories. The data were collected by personal interview/ Google forms during Pandemic period (2020) and after that farmer-to-farmer contact and telephonic interviews were used for the collection of farmer's feedbacks (2021, 2022). The beneficiaries of the advisories viz., farmers participated in this analysis by answering the questions provided in the questionnaire. After this an excel sheet was created using the information provided by the farmers. Using random sampling technique, the tool for data collection was a detailed and structured questionnaire which was tested in the field before actual collection of data. Because of the nature of the data to be collected, frequent interaction with the farmers was required and conducting face-to face interview was not economically feasible for the study. Therefore, after the initial face-to-face contact with the farmers, data was collected

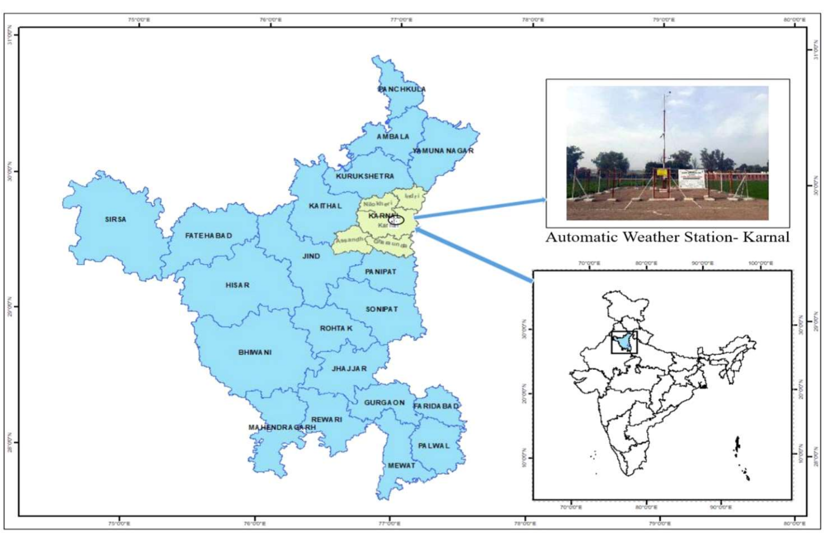

Fig. 1. Study area

through telephonic interviews (Mainly in pandemic period) where each farmer was contacted for a minimum of four to five times during entire wheat and rice crop season. Each telephonic interview lasted for an average of 20-25 min. wherein each farmer was asked about the time of scheduling and cost of relevant agricultural operations such as land preparation, sowing, irrigation, fertilizer application and so on at the time of calling.

RESULTS AND DISCUSSION

As per the response received, the total number of farmers participated was maximum in 2022 (550) with overall increment of 64.85% from 2020 to 2022. During the feedback collection process, 80 villages were covered in 2022 resulting in 80% overall increment in all the three respective years. In the year 2020, out of the total number of farmers involved in assessment process 82.5 percent observed AAB beneficial whereas in the year 2021 this percentage increased up to 90% further increasing up to 97.5% in the year 2022. Similarly, percentage of farmers those who were benefitted with the livestock advisories increased up to 83.5% with an overall increment of 7.8%. As per assessment in the year 2020 only 52.5 percent of farmers were getting special advisories on extreme events like Hailstorm, cyclone whereas in the year 2021 and this percentage increased up to 64.3 and the percentage went up to 71.5% in 2022 with an overall increment of 16.79%.

Block wise scenarios of use of Agromet Advisories Bulletin (AAB) in subsequent year: The percentage of farmers using Meghdoot app is maximum in Karnal block whereas the least are from Munak and Gharaunda. The 80 percent of farmers from Karnal block use Crop related advisories which is highest of all of the blocks whereas in Assandh block the percentage is only 50 (Table 2). Most of the farmers from Kunjpura approximately 76 percent are using livestock and fisheries related advisories whereas only 56 percent from Nissing. Maximum reach of aberrant weather alerts are in Karnal block whereas in Kunjpura and Munak was minimum.

Use of social media to get agromet advisories bulletin (AAB): the most suitable mode of dissemination of AAB was through Whatsapp followed by newspaper (Fig. 3). The 14% of the farmers responded that phone calls were suitable mode for knowing the exact situations and necessary actions for the different farming practices at different stages of crops.

Farmers are using advisories given for different farming practices like sowing, irrigation, fertilizer application, insecticides application, harvesting and post harvesting management; maximum use of advisories was during the sowing period. The crop management done by the farmers such as timely land preparation and sowing, adoption of recommended seed rate and suitable varieties, timely weeding, harvesting and irrigation and pesticide applications leads to profit. The profit was maximum recorded at the time of sowing. In sowing stage maximum farmers followed AAB whereas percentage of farmers using AAB found out to be least at harvesting period. In terms of economic benefit, AAB found out to be most beneficial at sowing stage followed by irrigation whereas least beneficial at the time of fertilizer applications (Table 3) (Kumar et al 2022).

There is an increase in the number of farmers following AAB in 2022 when compared with 2020. use of AAB is increasing among the farmers. More numbers of farmers are being benefited by AAB in the 2022 as compared to 2020. Application of AAB, based on current and forecasted weather is a useful tool for reducing cost of cultivation and enhancing

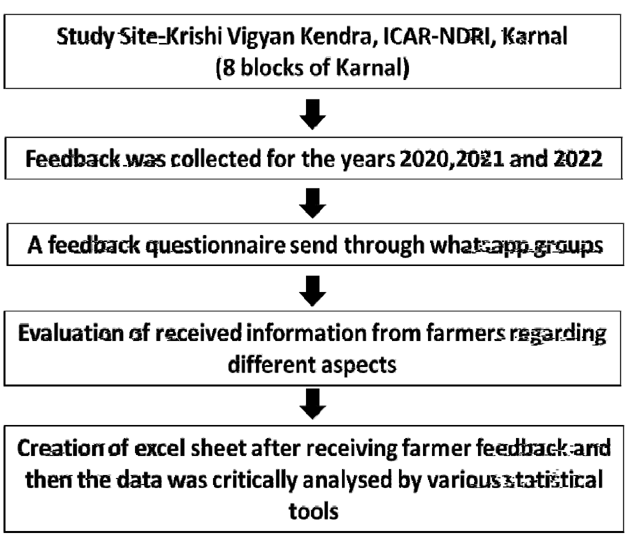

Fig. 2. Flow diagram showing steps involved in AAB feedback collection

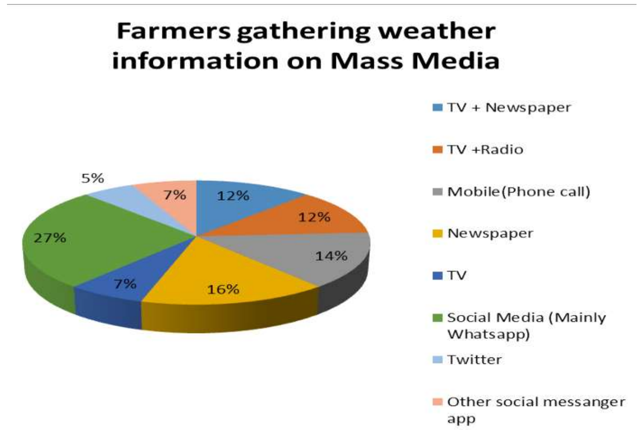

Fig. 3. Percentage of farmers gathering weather information on mass media in Karnal

the production and income. These results are supported by earlier researchers (Gadgil et al 2002, Weiher et al 2007, Vashisth et al 2013, Ray et al 2017, Manjusha et al 2019).

Comparison of AAS and Non-AAS farmers in rice and wheat crop: The cost of cultivation of rice and wheat crop in case of AAS Farmers was more as compared to Non AAS Farmers, but the farmers were getting higher grain yield) as compared to Non AAS farmers. The total cost of cultivation although was slightly greater in AAS farmers who have effectively adopted the agro-advisory compared to non AAS farmers net returns were greater than the non AAS farmers. The net return/ ha was Rs .22949, Rs. 66331, respectively in AAS farmers and Rs. 22949, Rs. 66331 in case of non-AAS farmers for rice and wheat crop. The average B:C ratio in wheat and rice crop was between 0.35 and 0.07. Kumar et al (2022). Also observed AAS farmers were benefitted more than the non-AAS farmers. Chaudhari et al (2010) reported that the percent increase in yield due to adoption of agro advisory bulletins prepared based on medium range weather forecast by NCMRWF was higher in rice, mango and cashewnut in high rainfall zone of Konkan in Maharashtra. Kushwaha et al (2010) reported that in Tarai and Babar agro climatic zone of Uttarakhand, the AAS farmers have harvested more yield of wheat and rice than non AAS farmers during four *Rabi* seasons of 2004-08.

In the framework of the adoption of AAS and its applicability in the farming community, the net benefits of using AAB in Rice and Wheat crop as compared to non-AAB farmers/ha were Rs.4672 and Rs.5992. The results concluded that application of AAS bulletin, based on current and forecasted weather, confined as a useful component in reducing input farming costs with returns enhancement and elevating production of crops. AAS farmers received weather forecast based agro-advisories; including optimum use of inputs for different farm operations has made able the AAS farmers for judicious and timely utilization of inputs in agricultural activities. Thus, despite of positive effect of AAS

Table 3. Use of AAB in context of farming operations (Pooled over three consecutive years)

Farming operations/ Economic benefits	Percentage use of AAB in farming operations	Percentage use of AAB in economic benefit
Sowing	35.7	24.4
Irrigation	23.8	22
Fertilizer application	11.9	7.3
Insecticide application	9.5	9.8
Harvesting operation	2.4	14.6
Post-harvest management	16.7	17.1

Table 1. Use of AAB in subsequent year 2020, 2021 and 2022

Treatment	2020	2021	2022	Percent increment of using of AAB in 2021 as compared to 2020	Percent Increment of using of AAB in 2022 as compared to 2021	Overall increment (%)
Total no. of farmers participated	148	262	550	77.03	52.67	64.85
No. of villages covered	27	45	80	66.67	93.33	80
Farmers using AAB (%)	72.5	91.2	97	25.79	6.35	16.07
Whether advisory beneficial or not beneficial (%)	82.5	90	97.6	9.09	8.4	8.75
Whether advisories related to livestock and fisheries are beneficial (%)	71.8	78.8	83.5	9.7	5.9	7.8
Whether farmers are benefitted for special advisories on extreme events like Hailstorm, cyclone (%)	52.5	64.3	71.5	22.48	11.1	16.79

Table 2. Block wise scenario of percentage of weather based agro- advisories by the farmers (Pooled over three consecutive years)

Block	Assandh	Gharaunda	Indri	Karnal	Kunjpura	Munak	Nilokheri	Nissing
Numbers of farmers using Meghdoot App (%)	40	26	30	46	20	26	30	40
Farmers using crop related Advisories (%)	50	60	74	80	60	70	74	60
Farmers using livestock and fisheries related advisories (%)	70	76	68	72	76	70	60	56
Farmers getting alerts regarding aberrant weather (%)	60	60	68	80	48	48	52	52

Table 4. Use and feedback of AAB in context of farming operations in subsequent year (Pooled over three consecutive years)

Feedback	Yes	No	Percentage increase over 3 years
Do you get weather information timely regarding extreme events (%)	58.4	41.6	22.48
Do you follow the weather advisories in the form of AAB (%)	81.8	18.2	25.79
Do you get weather-based livestock advisories and have you followed AAB accordingly (%)	75.3	24.7	9.7
These advisories are beneficial to increase overall production of crops (%)	93.8	6.2	8.4

Table 5. Economic assessment of wheat and rice crops influenced by AAS and Non-AAS during subsequent year (Pooled over three consecutive years (Rs/ha)

Type	Wheat				Rice			
	AAS	Non AAS	Benefits	B:C Ratio	AAS	Non AAS	Benefits	B:C Ratio
Land preparation/ Sowing/Nursery raising (Rs)	5500	7000	1500	0.21	6800	7200	400	0.05
Seed, fertilizers & manure (Rs)	4640	6056	1416	0.23	1650	2480	830	0.33
Pesticides/Insecticide/Herbicide (Rs)	1890	2430	540	0.22	2850	3760	910	0.24
Irrigation (Rs)	2500	3380	880	0.26	750	1420	670	0.47
Harvesting /Threshing (Rs)	1280	1360	80	0.05	1200	1500	300	0.20
Grain yield (q/acre)	26.9	25.8	1.1	0.04	35.3	34.1	1.20	0.96
Straw yield (q/acre)	24.3	22.5	1.82	0.08	-	-	-	-
Net benefit/acre (Rs)	22949	16956.3	5992.7	0.35	66331	61659	4672	0.07

*Where MSP of Wheat was ₹1925 (2020), ₹1975 (2021) and ₹2015 (2022)
*Where MSP of Rice was ₹1815 (2020), ₹1868 (2021) and ₹1940 (2022)

on adoption of improved production technology and practices, marginal differences were found in the yield obtained by AAS and Non-AAS farmers for some crops. Hence, providing the Agromet Advisory Services in a sustainable manner, in convergence with such recommendations, has ultimately proven efficient in helping rural people/farmers of the country for upliftment of their livelihood in a rapid way and the continued assessment of the service through critical feedback from the farmers is also considered as an important parameter for its further improvements.

CONCLUSION

The overall increment of 64.75% in the number of farmers using Agro-meteorological Advisory Bulletins from 2020 to 2022. Using AAS bulletins based on current and forecast weather has proven effective in maximizing farm input utilization and maximizing overall yields. The yields of beneficiaries and non-beneficiaries were the same but profitability and yields of beneficiaries were higher. In order to improve yield levels for beneficiary farmers, a package of recommended practices for different crops should be added with weather-related information to make information delivery more comprehensive and effective. In order to take corrective action and there is need to collect feedback from farmers on a regular basis through an online form.

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Effect of Different Packaging Materials on Storage Quality of Grain Amaranth Based Pasta

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***Abstract*:** The purpose of this study was to observe the effect of packing material and storage duration affected the qualitative features of pasta prepared from grain amaranth flour and amaranth leaf powder by extrusion. The developed extrudates were packed in 50 μm metalized polyester covers and kept at room temperature for three months to study storage induced changes in quality attributes such as moisture content, colour, sensory, texture, and microbial properties, with all quality parameters analyzed every 15 days. The moisture content and L* value dropped with time. The a* and b* values, on the other hand, were raised during storage. The hardness value of the pasta grew considerably with time when compared to the cohesiveness, springiness, gumminess, and chewiness. TPC of the pasta was enhanced with time in which yeast, mould, and E-coli development was not observed until 45 days of incubation. As the storage period progressed, there was a consistent and noticeable increase in deteriorative quality parameters. This indicates that the extrudates underwent a gradual decline in their overall quality over time. Despite these changes, the pasta remained within an acceptable range for consumption for duration of up to 45 days of storage.

***Keywords*:** Pasta, Storage quality, Packaging material, Amaranth

Recently, pasta has emerged among the trending foods in India with the consumption rate growing at a rapid pace. There are more than 30 pasta brands available in the country (Anonymous 2016), and most of them are made of durum wheat (*Triticum durum*) semolina, which contains gluten protein. The disorders related to gluten namely, celiac disease, wheat allergy, and non-celiac gluten sensitivity are becoming an epidemiological phenomenon with a global prevalence of about 5 per cent (Elli et al 2015) deficiencies of essential micronutrient ions or excesses of toxic ions are of concern in wheat (Abecassis et al 2000). Hence, research efforts are continuing on replacing wheat either fully or partially in pasta and similar products. Many studies targeted the improvement of pasta quality by mainly focusing on replacing the gluten network in pasta by additives and texturizing ingredients and components that enhance the nutritional value or exert a beneficial effect on health. Several authors have attempted fortification of pasta by partially or completely substituting durum wheat with diverse sources such as legume flours, dietary fibres and protein isolate with the purpose of improving the nutritional content of pasta. Pasta made with these flours could be a good diet option for persons on a low-calorie diet. The present study was aimed to evaluate the qualitative changes in grain amaranth based pasta at ambient condition. Various deterioration indicators of food products as moisture content, colour values, microbial load, textural properties and sensory quality were determined as a function of storage period.

MATERIAL AND METHODS

Raw material: The main raw materials used for the development of extruded product were grain amaranth flour and amaranth leaf powder (ALP). Amaranth flour was prepared by using domestic grain pulverizer. Amaranth leaf powder was prepared by drying clean and blanched leaves (70-100°C, <5 min) in a dehydrator unit at 45°C for 6-8 hours and fine powder of dried leaves were made using kitchen grinder.

Pasta product manufacture: The amaranth based pasta products were manufactured by following the systematic procedure (Nagi et al 2012). The sieved (BS 44 mesh size) amaranth flour and amaranth leaf powder were first blended in the extruder for 5 min and then kneaded for about 45 min after adding required quantity of water. When the dough characteristics was optimum, it was extruded using appropriate 'dies' (in all the available shapes i.e., macaroni, ribbed tube, twisted ribbons). The cutter speed was set to optimum level and then dried in a tray drier at 50℃ for about 3 hours. The dried pasta was then packed in metalized polyester bags (50μ), heat sealed and stored at ambient conditions. The complete flow chart for the production of Amaranth based cold extruded ready-to-cook pasta (Fig. 1).

Storage stability of pasta: Storage analysis of pasta sample was carried out by packaging in metalized polyester (50 µm) packaging material and stored at ambient conditions (temperature: 24±3°C; relative humidity: 65.2±12%). Analyses of moisture content, colour, sensory evaluation, textural properties and microbial analysis were conducted for every 15 days' interval during the three-month storage period.

Moisture content (%): Five grams of samples in triplicates were dried in a clean, dry and pre-weighed moisture dish at 105± 2°C for 24 hours were dried to constant weight in an oven, cooled in the desiccators and weighed (Hall 1957). The moisture loss was calculated and expressed in percentage.

$$\text{Moisture content (\% wb)} = \frac{w_1 - w_2}{w_1} \times 100$$

Where, W_1 and W_2 = Initial & Final weight of the sample, g

Instrumental color analysis: Tri-stimulus colour measurements of the samples was made using a Spectrophotometer (Make: Konica Minolta Instrument, Osaka, Japan; Model-CM5). The colour of the sample was measured in *L* a* b** coordinate system where *L** indicated lightness of the sample; *a** value indicated greenness (-) or redness (+) of the sample; and *b** value indicated blueness (-) or yellowness (+) of the sample.

Textural properties: Textural properties of cooked pasta were measured using the Texture Analyzer (Make: Stable Microsystems Ltd, UK; Model –HD$_i$)) equipped with a metal blade probe (25 mm). Texture analyzer settings used were: Mode: return to start; pre-test speed: 1.0 mm/s; test speed: 1.0 mm/s; post-test speed: 10.0 mm/s; distance: 12 mm; data acquisition rate: 200 pps. From the TPA curve, hardness (maximum peak force during the first compression).

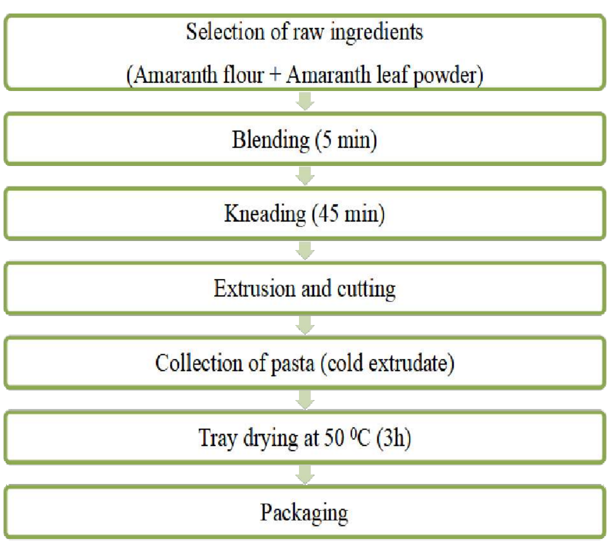

Fig. 1. Process flow chart for production of pasta products

Sensory evaluation: Sensory evaluation of the pasta product was carried out by a panel of ten members. The products was evaluated for individual characters as colour, texture, taste, flavor and overall acceptability using a 9-point hedonic scale, where 9=Like extremely, 8=Like very much, 7=Like moderately, 6=Like slightly, 5=Neither like nor dislike, 4=Dislike slightly, 3=Dislike moderately, 2=Dislike very much, 1=Dislike extremely (Ranganna 1986, Rathi et al 2004).

Microbial analysis: Prepared pasta samples were subjected to microbial analysis in terms of total plate counts (TPC) and yeast and mold count (YMC) and *E. coli*. For determination of total plate count, nutrient agar media was used. YEPD agar media was used for yeast, Potato dextrose agar media was used for mold count and EMB agar media was used for coli forms. The microbial study was conducted under a sterile environment using laminar airflow. The microbial load of the pasta samples was determined initially and after every 15 days of storage interval up to three months. The microbial growth was shown as CFU/g of the sample weight.

Pour plate technique was used to determine the microbial load of samples. One gram of sample was added to 9 ml sterile distilled water and mixed thoroughly for the first dilution i.e., 1/10thconcentration of origin sample. Subsequent dilution was obtained by transferring 1ml of previous dilution to 9 ml of sterile distilled water solution in cotton plugged test tubes. The samples were serially diluted up to 10^{-1}-$10^{-2}$for yeast and mold, 10^{-3}-$10^{-4}$for TPC and 10^{0}-10^{-1} for *E. Coli*. 1 ml of appropriate dilution was inoculated into sterile petri-dishes and molten agar media was added and left to solidify. The petri-plates with samples were allowed to cool and then, placed in an incubation period of 27±2 hr at 37℃ for TPC, 48 hr at 37 ℃ for coli forms, 70-90 hr at 30°C for yeast and mold growth. After incubation period, counts of visible colonies were recorded.

Statistical analysis: Statistical analysis of experimental data was done using OPSTAT software.

RESULTS AND DISCUSSION

Moisture content of extrudates: As per the Indian standard [BIS: 1485-(2010)], the moisture content of pasta should not be more than 12 per cent. During the storage period, a consistent increase in moisture content of pasta was recorded, but was limited within 12 per cent. Initially, the moisture content was about 6.73 per cent (w.b) (Table 1). During the storage period, a steady increase in moisture content of pasta sample was recorded. It increased from 6.73 to 9.73 per cent at the end of three months of storage period. The storage period and packaging material had significant effect on the moisture content of pasta.

This rise in moisture content was due to hygroscopic nature of the extruded product which resulted in the increase in moisture content of the product during storage period (Kocherla et al 2012). This rise in moisture content is attributed to the migration of water vapors inside the packaging material from the storage atmosphere (temperature and relative humidity changes) (Nagi et al 2012). Butt et al (2004) observed increase in moisture content of breakfast cereals during a storage period of 6 months and in barnyard millet cookies (Surekha et al 2013). Gull et al (2017) observed that for millet fortified pasta samples stored in LDPE and BOPP pouches at accelerated temperature, significant increase in moisture content was observed during the 6-months storage study. Jalgaonkar et al (2017) have reported an increase in the moisture (8.87 -11.90 %) content of pasta samples after six months of accelerated storage (32.95 ± 8.75°C and 79 ± 19 % RH) in BOPP pouches.

Tri-stimulus color value of extrudate: According to International Commission on Illumination (CIE), *L**, *a**, *b** are the three color coordinates, in which "*L**" represents the lightness (*L** = 0, absolute black/no lightness, *L** = 100 diffuse white), "*a**," varied between negative green to positive red/magenta, and "*b**," corresponds to blueness when negative and yellow when positive score. These color parameters correspond to complete color space or describe all the colors visible to the human eye; therefore, they were designed to use in the form of an independent device model as a reference (Swer et al 2019). The changes in color characteristics of pasta samples were expressed as *L**, *a**, *b** values. It was observed that lightness value (*L**) of pasta samples decreased continuously from 62.77 to 54.63 (Table 1). Both *a** and the *b** value of pasta product increased with storage period indicating that there was a greater change in color of the product with increased storage days the extrudate were significantly affected by both packaging material and storage time individually and their interaction.

The *L** value of the pasta product was decreased significantly with storage time. This decreased lightness scores of pasta products is due to Maillard browning reaction and might be lower barrier properties of packaging material. Similar observations were also reported by Kamble et al (2020) after 4 months storage of multigrain pasta by packaging in HDPE and BOPP films. Redness (*a**) of optimized pasta product increased significantly during a storage period of 3 months. This increased *a** of the products might be the result of the formation of non-enzymatic browning components at the storage time was also observed by Kumar et al (2017) in case of storage study of the cereal-based food product. The yellowness (*b**) of the pasta sample was increased significantly during storage y. This increase in *b** might have been due to the occurrence of non-enzymatic browning. Similarly, Gull et al (2017) found a similar pattern of increase in yellowness score for millet pomace based functional pasta after the storage period of 4 months at accelerated condition (40 ± 1 °C and 90 ± 1 % RH).

Sensory characteristics: The storage conditions had a significant effect on the sensory quality of the pasta by judges after 3 months of storage (Table 2). The sensory acceptability of the ready- to- cook pasta product were assessed on each withdrawal for 15-day interval. For optimized pasta sensory score for color, texture, flavor, taste and overall acceptability were rated as 7.90, 7.60, 7.80, 7.60, and 7.70, respectively, at 0 day of storage time. Decreasing trends were observed for all the sensory attributes like color, texture, flavor, taste and overall acceptability at ambient condition.

With increasing storage period, mean sensory scores for overall acceptability of the pasta product declined from 7.7 to 5.3. At the end of the storage period, the sensory scores for colour, texture, flavour, taste and overall acceptability of pasta was rated as 5.8, 4.2, 5.5, 5.8 and 5.3 respectively. The highest average overall acceptability was observed at 0, 1 and 2 months of storage indicated that pasta was acceptable up to 45 days of storage. Decreasing trends were observed for all the sensory attributes like color, taste, texture, appearance and overall acceptability of product during storage. Sensory evaluation of the pasta revealed significant effect of storage period and packaging material on the liking of pasta by the panelists in terms of color, texture, flavor, taste, and overall acceptability. The overall change in the

Table 1. Effect of storage on moisture content and colour values of pasta sample stored in Metalized Polyester (MP) film

Storage period (days)	Moisture content (%)	Mean Tri-stimulus colour value		
		L*	a*	b*
0	6.73 ±0.033	62.77	1.98	19.33
15	6.90 ± 0.058	61.72	2.80	19.57
30	7.63 ±0.033	60.19	3.32	19.98
45	8.03 ± 0.033	59.65	3.98	20.18
60	8.80 ± 0.058	57.80	4.52	20.52
75	9.16 ± 0.033	56.67	4.87	20.85
90	9.73 ± 0.033	54.63	5.33	21.07
CD (p=0.05)	-	0.333	0.084	0.137

L*: Lightness, a*: Greenness or redness, b*: Blueness or yellowness sensory acceptability of the products could be due to change in color, texture, flavor and taste that contributed more to overall acceptability of the samples. This might be due to the minor biochemical changes (moisture intake, a_w, color, FFA, peroxide and microbial growth) takes place during storage resulted in lowering of sensory scores. Puyed et al (2010) and Shoba et al (2015) also reported that overall acceptability of noodles made from composite flours affected significantly over the storage duration of 4 months, which may be the result of alternative biochemical changes like increase in moisture.

Textural properties of extrudate product: During the entire storage period of three months, hardness values of pasta stored in metalized polyester packaging film was varied from 11.83 to 10.64 N (Table 3). Textural attributes decreased with storage period. Both storage period and packaging material individually and their interaction had significant) effect on the textural qualities of pasta during storage up to 90 days. Hardness values decreased with increase in the storage days. This may be due to moisture intake of the product from the storage environment. Moisture migration and redistribution, product composition, physical changes of the main components and the interactions between them which become highly heterogeneous and exhibits significant effect on product texture Wang et al (2002). Similar results were reported by Charunuch et al (2008) in rice snacks stored for four month. Variation in the texture of the pasta products during storage may be attributed to the variation in gluten strength as it is reduced due to the substitution of different flours. Incorporation of fibre rich flours exhibit decreased textural attributes as they have high affinity for water. Similarly, Krishnan and Prabhasankar (2010) also reported the same results in pastas incorporated with sprouted finger millet and green banana flours.

Microbial load: Microbial quality of optimized pasta sample was analyzed in terms of TPC and yeast mold count during storage at ambient conditions (Table 4). The packaging material and storage environment had a significant influence on the TPC of pasta samples. During the storage period of three months, bacteria, yeast and mold were detected and *E.coli* was absent . Bacterial count were in the range of 0.3×10^4 to 4.3×10^4 CFU/g. Yeast count were increased from 60^{th} day of storage period in the range of 0.6×10^1 to 3×10^1 CFU/g and mould count were increased from 75^{th} day of storage period in the range of 1.3×10^1 to 2.6×10^1 CFU/g. bacterial count and fungal count be increased with storage days. The packaging material and storage time significantly affects the product quality. The TPC load of the pasta kept in

Table 2. Effect of storage on sensory scores of pasta sample stored in metalized polyester film

Storage period (days)	Colour and appearance	Texture/mouth feel	Flavor/aroma	Taste	Overall acceptability
0	7.9	7.6	7.8	7.6	7.7
15	7.6	7.4	7.6	7.6	7.5
30	7.4	6.7	7.2	7.1	7.1
45	7.2	6.5	7.0	7.0	7.0
60	6.4	5.1	7.0	6.5	6.3
75	6.0	4.6	6.4	6.2	5.9
90	5.8	4.2	5.5	5.8	5.3
CD (p=0.05)	0.26	0.26	0.28	0.28	0.20

Table 3. Effect of storage on textural characteristics of pasta sample stored in metalized polyester film

Storage period (Days)	Hardness (N)	Cohesiveness	Springiness (mm)	Gumminess (N)	Chewiness (N.mm)
0	11.83	0.60	1.23	6.01	6.27
15	11.65	0.61	1.21	6.11	6.15
30	11.52	0.62	1.17	6.27	6.17
45	11.46	0.63	1.19	6.40	6.45
60	10.97	0.64	1.20	6.45	6.36
75	10.85	0.60	1.17	5.95	6.27
90	10.64	0.61	1.26	5.98	6.45
CD (p=0.05)	0.01	0.02	0.02	0.02	0.02

Table 4. Effect of storage on microbial load of pasta sample stored in metalized polyester film

Storage period (days)	Total plate count (10^4 CFU/g)	Yeast (10^1 CFU/g)	Mold (10^1 CFU/g)	*E. coli* (10^0 CFU/g)
0	0.3	ND	ND	ND
15	1.3	ND	ND	ND
30	2.0	ND	ND	ND
45	2.6	ND	ND	ND
60	3.3	0.6	ND	ND
75	4.0	2.3	1.3	ND
90	4.3	3.0	2.6	ND
CD (p=0.05)	0.28	0.11	0.06	-

ND: Not detected

metalized polyester pouches at ambient storage conditions increased significantly from 0.3×10^4 to 4.3×10^4 CFU/g. This higher bacterial count could be due to the adverse conditions of storage environment (temperature and relative humidity), which facilities the rapid entry of moisture inside the pasta sample and subsequently enhance the bacterial count of product. Kamble et al (2020) in multigrain pasta products reported a significant increase in TPC that might be due to higher moisture and water activity of the products during storage. Other researchers also specified increasing trends of TPC during the storage study of food products (Yadav et al 2014, Verma et al 2015, Gull et al 2017). The fungal count of stored pasta increased more rapidly under ambient conditions (25°C – 28°C). This may be due to yeast and molds grow luxuriantly at an optimum temperature of around 25°C – 37°C. Hence, the microbial load of the packed pasta samples was satisfactory up to 2 months of storage. Yadav et al (2014) observed in pasta prepared from a blend of wheat, pearl millet with vegetable paste during 90 days storage in polyethylene bags (50 µm) at ambient condition.

CONCLUSION

The quality attributes of the extrudates were significantly influenced by both the packaging material used and the duration of storage. As the storage period progressed, there was a consistent and noticeable increase in deteriorative quality parameters. This indicates that the extrudates underwent a gradual decline in their overall quality over time. Specifically, there was an observed rise in moisture content and total plate count (TPC), which are indicative of potential spoilage and microbial growth. In contrast, the color parameter, sensory scores, and textural properties exhibited a reduction, suggesting a decline in visual appeal, taste, and overall texture. Despite these changes, the pasta remained within an acceptable range for consumption for duration of up to 45 days of storage.

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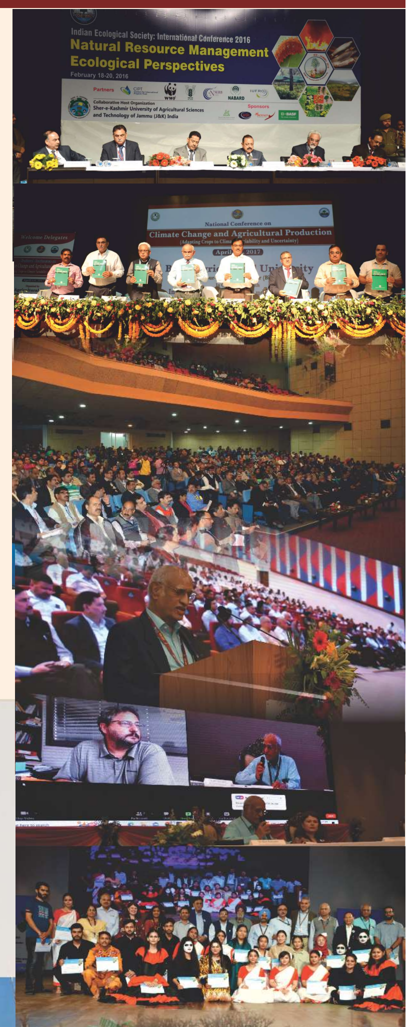

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