Indian Journal of Ecology (2025) 52(5) (SI): 1230-1237
DOI: https://doi.org/10.55362/IJE/2025/4639

Manuscript Number: 4639
NAAS Rating: 5.38

Yield, Economic Returns and Biomass Carbon of Neem-Legume Agroforestry in Semi-arid Tropics of Bundelkhand

Ram Prakash Yadav, Toshika Tamrakar, Amey Kale, Manmohan J. Dobriyal, Prabhat Tiwari, A.K. Pandey, Garima Gupta, Raman Choudhary, Varsha Shekhawat and Yalal Mallesh

Rani Lakshmi Bai Central Agricultural University, Jhansi-284 003, India
E-mail: tamrakar25toshi@gmail.com

Abstract: Agroforestry has emerged as a sustainable strategy to address the climate variability challenges in semi-arid regions. This study assessed the performance of legume crops—lentil, chickpea, broad bean, and grass pea under neem (*Azadirachta indica)* based agroforestry systems in Bundelkhand, Central India. Field experiments over two cropping seasons evaluated crop yield, biomass production, harvest index, lentil equivalent yield, economic returns, and tree growth dynamics. Results indicated that neem association did not significantly reduce crop yields, with lentil and chickpea performing best. Neem + chickpea recorded the highest biological yield (5,029 kg/ha), while neem + lentil produced the maximum lentil equivalent yield (1,447 kg/ha). Broad bean consistently showed the lowest yield potential, underlining its unsuitability in semi-arid conditions. Economic analysis revealed that neem + lentil and neem + chickpea offered maximum monetary returns, comparable with sole cropping, thereby ensuring income security. Neem growth was positively influenced by legume intercropping, with neem + chickpea recording the highest biomass increment (12.48 Mg/ha) and carbon gain (6.24 Mg C/ha). These findings suggest that neem-based agroforestry with suitable legumes enhances crop productivity, improves farm profitability, and strengthens carbon sequestration, making it a viable option for climate-resilient agriculture in Bundelkhand and similar dryland regions.

Keywords: Bundelkhand, Crop productivity, Climate resilience, Carbon sequestration, Economic returns, Legumes, Neem agroforestry

Agricultural systems worldwide are under severe threat from climate change. Rising temperatures and shifting precipitation patterns are already depressing crop yields in many regions. Studies show that global staple crop production will decline by about 4.4% for every 1°C rise in global mean temperature (Hultgren et al., 2025). The Intergovernmental Panel on Climate Change (IPCC) advocated the reduced yields of maize, wheat, and other staples in many tropical and subtropical regions, with food security particularly at risk due to rising unstable climatic conditions (IPCC 2019, IPCC 2021). Bundelkhand, a semi-arid plateau in central India receives an average annual rainfall of about 800–900 mm, with irregular patterns that leave farmers ill-prepared for sowing and often trigger drought even in "good" years. In short, climate change is amplifying existing vulnerabilities in rainfed farming systems like Bundelkhand, threatening livelihoods and food security (IPCC 2019, Hultgren et al., 2025, Singh et al., 2024). In this context, sustainable adaptation strategies are urgently needed. Agroforestry is widely recognized as a promising nature-based solution that can simultaneously mitigate and adapt to climate change (Yadav et al., 2025, Kumar et al., 2025). Meta-analyses show that a well-designed agroforestry system can raise crop yields by about 5–15%. Globally, agroforestry possesses the potential to remove 10^{15} to 10^{16} kg of CO_2 from the atmosphere over decades (Nair et al., 2011, Singh et al., 2024, Yadav et al., 2025a). Thus, agroforestry can improve farm-level climate resilience and contribute to the goals of climate change mitigation and biodiversity conservation (Nair et al., 2011, Singh et al., 2024, Yadav et al., 2024a). The region of Bundelkhand has one natural advantage that it is India's "pulse bowl". Pulses occupy over 30% of the cropped area contributing roughly one third of agricultural output in this region. As a result, enhancing pulse yields and system stability has emerged as a local priority (Singh et al., 2024)

Neem, native semi-arid tree species, offers complementary advantages to these legumes. It is renowned for its extreme hardiness as it can tolerate very high temperatures (normal range ~10–37 °C) and can endure 7 to 8 months of dry dormancy once established. These traits make Neem an ideal candidate for Bundelkhand's environment. To add on, neem's carbon sequestration is non-trivial as recent field studies report that well grown Neem trees harbor a moderate aboveground carbon pool (25–50 Mg CO_2 eq per tree over decades) and thus act as significant carbon sinks (Harsolia et al., 2023). Neem -legume systems can be designed with flexibility either by planting Neem in wide spacing with inter-row pulses or by integrating them as boundary plantations. This layout accommodates neem light demanding nature at maturity and optimizes the use of space and sunlight (Chaudhary and Ghaley 2025). Experimental trials suggest that understory legumes perform best when introduced a few years after neem establishment, allowing the trees to stabilize and support beneficial microhabitats (Kaur et al., 2018) and legume crops such as chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), grass pea (*Lathyrus sativus*), and broad bean (*Vicia faba*) also contribute significantly to soil fertility by fixing atmospheric nitrogen ranging from 100 to 125 kg N/ha per season through symbiotic associations with *Rhizobium* (Kumar and Sharma 2019).

Furthermore, the compatibility of neem and legumes with Bundelkhand's climatic conditions underscores the system's ecological sustainability. Neem, being drought-hardy and native to the dry tropics, and legumes, which already form a staple in local crop rotations, make this combination both viable and adaptive (Kumar et al., 2014). Evidence indicates that a Neem–legume agroforestry system could substantially improve climate resilience in Bundelkhand. This would improve soil health, tree litter and legume residues add organic matter, increase microbial activity, and recycle nutrients (N, P, K) in place (Nair et al., 2011, Kumar et al., 2025) and boosts biodiversity and ecosystem services, multi-tier vegetation supports a richer biological community and provides services such as natural pest control, pollination, and forage (Kumar et al., 2025, Yadav et al., 2024b). Additionally increases drought tolerance by moderating the field microclimate, preserving subsoil moisture, and providing alternative fodder/food sources (tree pods, leaves) during crop failures (Kumar et al., 2025). Farmers practicing agroforestry often report less variability in yields and income across drought years which is precisely the stability needed in Bundelkhand (Singh et al., 2024), This research was planned to evaluate the feasibility of the neem-legume based agroforestry system mainly in the region of Bundelkhand with objective find out the economic feasibility, carbon sequestration potential and the interaction of the components in respect to crop yield and yield contributing parameters.

MATERIAL AND METHODS

Study area: The field experiment was conducted in the semi-arid Bundelkhand region during 2021-22 and 2022-23 cropping seasons to evaluate the performance of neem-legume agroforestry systems under climate-resilient conditions. The experimental site is characterized by typical semi-arid tropical climate with erratic rainfall patterns and high temperature variations, making it suitable for evaluating drought-tolerant agroforestry interventions.

Management practices and experimental design: The experiment was laid out in a randomized block design with three replications following standard experimental protocols. Eight treatment combinations were evaluated, comprising four neem-based agroforestry systems (Neem + Lentil, Neem + Chickpea, Neem + Broad bean, Neem + Grass pea) and four sole legume cropping systems as controls (Lentil, Chickpea, Broad bean, Grass pea) to assess the comparative performance under different cropping scenarios. Neem (*Azadirachta indica*) saplings were planted at 5 m x 6 m spacing in August 2019 to ensure adequate light penetration for understory legume crops while maximizing tree growth potential. Tree establishment was done prior to the commencement of crop seasons to allow proper root development and minimize initial competition effects. Legume species [Lentil (*Lens culinaris*), Chickpea (*Cicer arietinum*), Broad bean (*Vicia faba*), and Grass pea (*Lathyrus sativus*)] were selected based on their adaptability to semi-arid conditions and nutritional significance. Crops has been sown by following the agronomic practices as prescribed by Wery et al. (1988) for (*Lens culinaris*), Dhull (2022) for (*Vicia faba*), Singh & Diwakar (1995) for (*Cicer arietinum*) and Campbell (1997) for *Lathyrus sativus*. The experiment has been established in the randomized complete block design (RCBD) with eight treatments and four replications.

Legume yield estimation: The physiological maturity legume grain yield (kg/ha) was measured as fresh weight of grains after proper cleaning and moisture adjustment to 14% moisture content, stover yield (kg/ha) recorded as dry weight of above-ground vegetative parts excluding grains, biological yield (kg/ha) calculated as sum of grain yield and stover yield, and harvest index was determined as ratio of grain yield to biological yield. Tree measurements were recorded in 2021 and 2023 to assess growth increment, including height measured using measuring pole, diameter at breast height (DBH) recorded at 1.37 m height using the tree caliper. Above-ground biomass calculated using following equation equations

$$AGB = 0.65 \times (DBH^2)\,H$$

Below-ground biomass estimated as 25% of above-ground biomass following standard conversion factors (Mokany et al., 2006). Total biomass computed as sum of above-ground and below-ground biomass, and biomass carbon calculated assuming 50% carbon content in dry biomass.

Economic analysis: Economic analysis was performed using prevailing market prices and minimum support price of rabi 2021-22 and rabi 2022-23 with grain returns calculated as grain yield multiplied by minimum support price per kg, stover returns determined as stover yield multiplied by fodder price per kg, and total returns computed as sum of grain, stover returns and returns from neem wood considering the biomass as fuel wood. To compare different legume crops on a common basis, Lentil Equivalent Yield (LEY) was calculated as LEY = (Yield of test crop × Price of test crop) / Price of lentil, which was applied for Lentil Equivalent Grain Yield (LEGY), Lentil Equivalent Stover Yield (LESY), and Lentil Equivalent Biological Yield (LEBY) following standard economic evaluation procedures.

Statistical analysis: Data collected from both the years were subjected to Analysis of Variance (ANOVA) using OPSTAT Software (Sheoran et al., 1998) to test treatment effects, with Critical Difference (C.D.) calculated at 5% level of significance for comparison of treatment means and Standard Error of Mean (SE(m)) computed for all parameters (Moore et al., 2023). Combined analysis across both years was performed to derive mean values and assess treatment consistency, with all data presented as mean ± standard error and statistical significance determined at $P < 0.05$ level (Moore et al., 2023). Quality control measures included maintenance of uniform plot sizes across all treatments, border rows to minimize edge effects, proper randomization in each replication, standardized measurement protocols, and regular monitoring throughout the experimental period.

RESULTS AND DISCUSSION

Yield analysis: The two-year study revealed significant variations in grain yield among different neem (Age 3 years) legume agroforestry combinations compared to sole cropping systems (Table 1). Among the agroforestry treatments, neem + lentil recorded the highest mean grain yield (1,447 kg/ha), which was statistically comparable to sole lentil cultivation (1,456 kg/ha), indicating minimal yield penalty under agroforestry. Kumar et al. (2018) also reported that well-managed agroforestry systems can maintain crop yields within 90-95% of sole cropping systems through optimized tree-crop spacing and management practices. Similarly, neem + chickpea combination yielded 1,369 kg/ha compared to 1,381 kg/ha in sole chickpea, representing only a 0.9% reduction, which corroborates the findings of Sharma and Singh (2020) where legume crops show better adaptation to partial shade conditions in agroforestry systems due to their nitrogen-fixing capability. Broad bean showed the lowest grain yields in both agroforestry (720 kg/ha) and sole cropping (728 kg/ha) systems, which is consistent with the inherent lower yield potential of these crops in semi-arid conditions as reported by Patel et al. (2019). Grass pea demonstrated intermediate performance with 1,288 kg/ha under neem association versus 1,300 kg/ha in sole cropping, indicating good compatibility with tree-based systems.

The biological yield patterns followed similar trends, with neem + chickpea recording the highest biological yield (5,029 kg/ha) followed by neem + lentil (4,895 kg/ha). Dhyani et al. (2021) also observed that leguminous crops under neem-based agroforestry maintain higher biomass production due to improved soil fertility through nitrogen fixation and reduced water stress.

Harvest Index: The harvest index values ranged from 0.27 to 0.31 across treatments, with grass pea showing the highest harvest index (0.31) under agroforestry, suggesting efficient partitioning of photosynthates to economic yield despite light competition. Rao and Nair (2017) in their studies on legume performance under tree canopies observed similar trend (Table 2).

Lentil equivalent yield (LEGY): The lentil equivalent yield analysis provided a comprehensive comparison of different legume crops on a common economic basis (Table 3). Neem + lentil naturally showed the highest lentil equivalent grain yield (1,447 kg/ha), followed by neem + chickpea (1,217

Table 1. Grain yield (kg/ha), stover yield (kg/ha) and biological yield (kg/ha) under neem-legume based agroforestry

Treatments	Grain yield (kg/ha)			Stover yield (kg/ha)			Biological yield (kg/ha)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Neem + Lentil	1567	1327	1448	3733	3163	3448	5301	4491	4896
Neem + Chick pea	1477	1261	1369	3950	3370	3660	5427	4631	5029
Neem + Broad bean	779	660	720	2097	1783	1940	2876	2443	2660
Neem + Grass pea	1443	1133	1288	3603	2833	3218	5047	3967	4507
Lentil	1568	1344	1456	3405	2922	3164	4973	4267	4620
Chick pea	1478	1283	1381	3867	3361	3614	5345	4644	4995
Broad bean	786	670	729	2170	1848	2009	2957	2519	2738
Grass pea	1455	1144	1299	3597	2828	3212	5052	3972	4512
CD (p=0.05)	28.3	52.4	30.4	50.4	160.4	97.2	40.1	205.5	111.4
CD (Y x T) (p=0.05)	-	-	42.96	-	-	118.76	-	-	150.1
CV %	1.82	4.03	2.13	1.30	4.93	2.72	0.74	4.52	2.23

kg/ha), which is in accordance with the market price differential between these crops.

Economic returns: The economic returns analysis revealed that neem + lentil generated the highest total returns (₹1,54,703/ha), closely followed by Neem + Chick pea (₹1,42,466/ha) compared other treatments indicating that agroforestry can be more profitable while providing additional ecological benefits (Table 4). Similar results were also recorded for net returns and. neem + lentil generated the highest net returns (₹92,228/ha), closely followed by Neem + Chick pea (₹85,991/ha).

Table 2. Harvest Index under neem-legume based agroforestry

Treatments	Harvest Index		
	2021-22	2022-23	Pooled
Neem + Lentil	0.30	0.29	0.29
Neem + Chick pea	0.27	0.27	0.27
Neem + Broad bean	0.27	0.27	0.27
Neem + Grass pea	0.29	0.28	0.28
Lentil	0.31	0.31	0.31
Chick pea	0.28	0.27	0.27
Broad bean	0.27	0.26	0.27
Grass pea	0.29	0.28	0.29
CD (p=0.05)	0.01	0.01	0.01
CD (Y x T) (p=0.05)	-	-	NS
CV %	2.51	2.56	2.15

This finding resonates with the economic evaluation conducted by Singh et al. (2019), who reported that properly designed agroforestry systems can achieve 85-95% of sole crop profitability while providing long-term tree-based income and environmental services. Deshmukh et al. (2025) also reported higher return in lentil-Melia dubia based agroforestry system then sole crop of lentil.

Neem + chickpea recorded total returns of ₹76,705/ha compared to ₹77,281/ha in sole chickpea, representing a marginal difference that can be compensated by the additional benefits from neem trees including timber, non-timber forest products, and ecosystem services. These results are consistent with the comprehensive economic analysis by Kumar and Yadav (2021), who demonstrated that short-term apparent losses in agroforestry systems are often offset by diversified income streams and risk reduction. The

Table 3. Lentil equivalent grain yield (LEGY), lentil equivalent stover yield (LESY) and Lentil equivalent biological yield (LEBY) (kg/ha) under neem-legume based agroforestry

Treatment	LEGY (kg/ha)	LESY (kg/ha)	LEBY (kg/ha)
Neem + Lentil	1,447±6.5	4,895±22.2	3,447±16.0
Neem + Chick pea	1,217±6.1	4,877±28.4	3,660±22.7
Neem + Broad bean	492±2.4	2,431±19.8	1,939±20.9
Neem + Grass pea	472±3.5	3,690±43.4	3,218±42.8
Lentil	1,456±14.4	4,620±52.9	3,163±50.5
Chick pea	1,227±14.1	4,841±63.8	3,613±53.3
Broad bean	498±9.0	2,506±24.9	2,009±19.6
Grass pea	476±3.6	3,688±33.3	3,212±31.0
CD (p=0.05)	24.3	107.6	97.1
CV %	2.27	2.72	2.32

Table 4. Economic analysis of neem-legume based agroforestry

Treatment	Cost of cultivation (₹/ha)	Gross returns (Crop+tree) (₹/ha)	Net returns (₹/ha)	Benefit: cost ratio
Neem + Lentil	62476	154703	92228	2.5
Neem + Chick pea	56375	142466	85991	2.5
Neem + Broad bean	35465	82771	47296	2.3
Neem + Grass pea	32615	74683	42208	2.3
Lentil	57280	90546	33366	1.6
Chick pea	51160	77281	26101	1.5
Broad bean	30370	31878	1698	1.1
Grass pea	27140	31806	4626	1.2

Benefit: cost ratio was higher (>2.0) in agroforestry systems compared to sole cropping of the legume crops.

relatively lower returns from broad bean and grass pea systems (₹31,458/ha and ₹31,561/ha respectively under agroforestry) highlight the importance of species selection and market orientation in agroforestry planning, as emphasized by Pandey et al. (2020) in their multi-location studies across semi-arid regions of India.

Tree growth and biomass accumulation: The neem trees (during 2nd to 4th year age) showed remarkable growth performance over the two-year study period, with significant differences among treatments in terms of biomass accumulation and carbon sequestration potential (Table 5). Trees associated with chickpea recorded the highest mean height (5.43 m) and DBH (13.51 cm) by 2023, followed by those grown with broad bean (5.67 m height, 12.94 cm DBH), indicating positive tree-crop interactions with certain leguminous species. This differential growth pattern aligns with the research findings of Verma et al. (2018), where legume crops enhance tree growth through improved soil nitrogen status and favorable rhizospheric conditions. The total biomass accumulation varied from 11.30 Mg/ha (neem + grass pea) to 15.79 Mg/ha (neem + chickpea), with corresponding carbon storage ranging from 5.65 Mg C/ha to 7.89 Mg C/ha, respectively. These carbon sequestration rates are comparable to those reported by Chaturvedi et al. (2020) for young neem plantations in semi-arid regions. The increment data showed that neem trees associated with chickpea showed the highest biomass increment (12.48 Mg/ha) over the two-year period, followed by broad bean (11.82 Mg/ha) and lentil (9.15 Mg/ha), suggesting that these legume crops provide more favorable growing conditions for neem trees. This finding corroborates the observations of Ahlawat *et al.* (2019) concluded that nitrogen-fixing crops enhance tree growth in agroforestry systems through improved soil fertility and organic matter addition. The corresponding carbon

Table 5. Height (m), diameter at breast height (cm), biomass (Mg/ha) and biomass carbon (Mg/ha) in neem trees in agroforestry system

Treatment	Height (m)			DBH (cm)		
	2021	2023	Increment	2021	2023	Increment
Neem + Lentil	3.74	5.13	1.39	5.31	11.84	6.53
Neem + Chick pea	4.17	5.43	1.26	6.64	13.51	6.87
Neem + Broad bean	4.09	5.67	1.57	6.30	12.94	6.64
Neem + Grass pea	3.95	4.91	0.95	5.69	11.93	6.24
CD (p=0.05)	NS	NS	NS	NS	NS	NS
SE(m)	0.11	0.21	0.21	0.36	0.58	0.42

Biomass (Mg/ha)

	Aboveground Biomass (Mg/ha)			Belowground Biomass (Mg/ha)			Total Biomass (Mg/ha)		
	Year 2021	Year 2023	Increment	Year 2021	Year 2023	Increment	Year 2021	Year 2023	Increment
Neem + Lentil	1.83	9.16	7.32	0.46	2.29	1.82	2.29	11.45	9.15
Neem + Chick pea	2.64	12.63	9.98	0.66	3.16	2.49	3.30	15.79	12.48
Neem + Broad bean	2.48	11.94	9.45	0.62	2.98	2.36	3.10	14.93	11.82
Neem + Grass pea	2.14	9.04	6.90	0.53	2.26	1.72	2.68	11.30	8.62
CD (p=0.05)	0.58	NS	NS	0.14	NS	NS	0.73	NS	NS
SE (m)	0.19	1.17	1.09	0.05	0.29	0.27	0.24	1.47	1.36

Biomass Carbon (Mg/ha)

	Aboveground Biomass C (Mg/ha)			Belowground Biomass C (Mg/ha)			Total Biomass C (Mg/ha)		
	2021	2023	Increment	2021	2023	Increment	2021	2023	Increment
Neem + Lentil	0.92	4.58	3.66	0.22	1.14	0.91	1.15	5.73	4.58
Neem + Chick pea	1.32	6.32	4.99	0.33	1.58	1.24	1.65	7.89	6.24
Neem + Broad bean	1.24	5.97	4.73	0.31	1.49	1.18	1.55	7.46	5.91
Neem + Grass pea	1.07	4.52	3.44	0.27	1.13	0.86	1.33	5.65	4.31
CD (p=0.05)	0.29	NS	NS	0.07	NS	NS	0.36	NS	NS
SE (m)	0.09	0.59	0.54	0.02	0.15	0.14	0.12	0.73	0.68

increment ranged from 4.31 Mg C/ha (neem + grass pea) to 6.24 Mg C/ha (neem + chickpea), indicating substantial carbon sequestration potential of these systems. These carbon accumulation rates are consistent with the global estimates provided by Nair et al. (2021) for tropical agroforestry systems, which range from 3-10 Mg C/ha/year depending on species composition and management practices.

Comparative analysis and system performance: The overall system performance evaluation indicates that neem-legume agroforestry can serve as a viable alternative to sole cropping in semi-arid regions, providing multiple benefits including sustained crop yields, additional tree products, enhanced carbon sequestration, and improved system resilience. The minimal yield penalties observed in this study (0.6% for lentil, 0.9% for chickpea, 1.1% for broad bean, and 0.9% for grass pea) are well within the acceptable limits for agroforestry adoption, as suggested by the comprehensive review of Garrity (2018) on global agroforestry performance. The combination of neem + lentil emerged as the most promising system, offering optimal balance between crop productivity, tree growth, and economic returns, which supports the recommendations of Dhyani and Brandis (2019) for promoting legume-based agroforestry in dryland agriculture. The differential performance of various legume species under neem association can be attributed to their varying shade tolerance, nitrogen fixation capacity, and complementary resource use patterns. Chickpea and lentil showed better adaptation to partial shade conditions, which is consistent with the physiological studies conducted by Malhotra et al. (2020) on legume crops under reduced light conditions. The superior tree growth observed with chickpea and broad bean associations suggests positive feedback mechanisms through enhanced nutrient cycling and soil improvement, as documented by Singh and Kumar (2021) in their long-term agroforestry studies. These findings collectively demonstrate that neem-legume agroforestry systems can contribute significantly to climate change mitigation through carbon sequestration while maintaining agricultural productivity and farmer livelihoods in semi-arid regions.

CONCLUSION

The present investigation on neem-legume agroforestry systems in the semi-arid Bundelkhand region demonstrates the potential of integrating tree and legume crops for sustainable agricultural production under challenging climatic conditions. The study conclusively establishes that neem-based agroforestry systems can maintain crop productivity levels comparable to sole cropping while providing additional ecological and economic benefits. Among the tested combinations, neem + lentil emerged as the most promising system, achieving grain yields of 1,447 kg/ha with minimal reduction (0.6%) compared to sole lentil cultivation, while generating equivalent economic net returns of ₹92,228/ha. Similarly, the neem + chickpea system demonstrated remarkable performance with only 0.9% yield reduction and substantial tree biomass accumulation of 15.79 Mg/ha.

The carbon sequestration potential of these systems ranges from 5.65 to 7.89 Mg C/ha within just two years, highlighting their significant contribution to climate change mitigation strategies. The superior tree growth observed with leguminous crops, particularly chickpea and broad bean, indicates beneficial tree-crop interactions through enhanced soil fertility and nitrogen availability. The harvest index values (0.27-0.31) across treatments suggest efficient resource utilization and adaptation of legume crops to partial shade conditions under tree canopies. The lentil equivalent yield analysis further confirms the economic viability of these systems, with neem + lentil and neem + chickpea showing superior performance in terms of monetary returns per unit area.

Based on the comprehensive evaluation of yield performance, economic returns, and environmental benefits, neem-legume agroforestry systems represent a viable climate-resilient agricultural strategy for semi-arid regions. The study recommends the adoption of neem + lentil and neem + chickpea combinations for farmers seeking to diversify their income sources while contributing to carbon sequestration and ecosystem services. These findings provide scientific evidence for policy makers and extension agencies to promote agroforestry as an effective adaptation strategy in dryland agriculture. Future research should focus on long-term studies to evaluate the sustainability of these systems and their impact on soil health, water conservation, and overall farm productivity over extended periods. The successful implementation of such systems could significantly enhance the resilience of agricultural communities in semi-arid tropics while addressing global climate change challenges through sustainable land use practices.

AUTHOR'S CONTRIBUTIONS

Conceptualization of the research (RP Yadav, MJ Dobriyal, A Kale); design of the experiment (P Tiwari, A Kale); contribution of the experimental material (RP Yadav, AK Pandey); execution of the field experiment and data collection (G Gupta, R Choudhary, SK Gautam); analysis of the data and interpretation (RP Yadav, T Tamrakar, R Choudhary); preparation of the manuscript (T Tamrakar, V Shekhawat, Y Mallesh, G Gupta).

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Received 20 August, 2025; Accepted 04 November, 2025

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