



Tree Growth and Soil Nutrient Dynamics under Mahogany (*Swietenia macrophylla* G. King) and Wheat (*Triticum aestivum* L.) based Agri-silvicultural System

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Abstract: The present study investigated the tree growth and soil nutrient dynamics under mahogany-based agri-silvicultural system in West Bengal. The objective was to access its role in promoting ecological functions and sustainable land use. The mahogany trees exhibited a robust and steady growth, with mean tree height increment of 8.6 m to 10.5 m, and DBH from 11.4 cm to 12.9 cm and a sustainable increase in volume (54.05%), highlighting the species' suitability to intercropping. Compared to open-field cultivation, the agroforestry system significantly improved soil health. While the open system showed a decline in key soil physico-chemical properties at both depths, the agroforestry system demonstrated a marked improvement in these parameters with organic carbon increasing from 0.76 to 0.80%, nitrogen from 176.61 to 179.76 kg ha⁻¹, phosphorous from 11.12 to 11.34 kg ha⁻¹ and potassium from 163.80 to 166.88 kg ha⁻¹. A trend of soil acidification was observed in both systems, being more prominent in the agroforestry plots where pH reduced from 5.31 to 4.90. The findings indicate that a mahogany-based agri-silvicultural system provides a more sustainable soil management approach by enhancing organic matter and nutrient retention than conventional open-field cultivation.

Keywords: Agroforestry, Agri-silviculture, Growth, Soil status, Tree growth, Intercropping

Agroforestry is an integrated land-use system that is distinct from the separate practices of agriculture and forestry (Mohsin and Mohsin 2021). It is an age-old practice developed to preserve soil fertility with the primary goal being maximization of the beneficial interactions to create a more varied and sustainable productive systems (Thakur et al., 2018). Based on at least 40 years of data collected worldwide, agroforestry has demonstrated a strong impact in enhancing soil quality as a sustainable land management technique (Dollinger and Jose 2018, Prajapati et al., 2020). It is, however, challenging to generalize impact of agroforestry system on soil fertility, as it depends on the species and management strategy used (Misra 2011, Prajapati et al., 2022b). In many agroforestry systems, the nutrient demand is distributed between perennial trees and seasonal crops. Since trees contribute to nutrient inputs without harvesting root biomass, the overall nutrient export is often lower, which can lead to net nutrient gain over time. Trees contribute organic matter to the soil system in a variety of ways, including through their roots, litterfall, or root exudates in the rhizosphere, offering a variety of ecosystem services, along with other environmental benefits in both rural and urban settings (Bertin et al., 2003). The selection of fast-growing multipurpose trees that have proven to show minimal impact on agricultural yield for an agroforestry system can contribute to sustainability and aid in its diversification to get greater advantages per unit area without degrading the agro-

ecosystem (Thakur et al., 2011). Tree species contribute a significant amount of litter fall, which, as it decomposes, impacts the soil physical, chemical, and biological properties, thereby enhancing the growth and yield of wheat crops (Singh and Sharma 2007, Sharma and Sah 2020, Prajapati et al., 2022a).

Mahogany (*Swietenia macrophylla* G. King) is a semi-evergreen, light hardwood tree belonging to the family Meliaceae. It was initially brought to India from the West Indies in 1795 and planted in the Royal Botanical Garden in Calcutta (Troup 1921), while *S. macrophylla* and *S. mahogany* were planted in South Malabar in 1872 (Kumar et al., 2016). The tree has been heavily exploited since the end of the seventeenth century throughout much of its native range and is classified as vulnerable species by the IUCN Red List of Threatened Species (IUCN 2017). Despite being protected, mahogany wood's commercial importance and ecological sensitivity raise serious questions about how to ensure its protection and sustainable use (Grogan et al., 2002). Mahogany is often used to restore damaged agricultural lands because of its high commercial value, and it is currently one of the most popular forestry species for reforestation and commercial plantings (Rodriguez-Morelos et al., 2014). The rapid growth of mahogany makes it one of the most demanded and prized timbers in the humid regions of southern India (Kumar et al., 2015). Because of its strong and deep roots, it minimizes soil erosion, making it an

excellent choice for degraded regions and field boundary plantations (Craig and Elevitch 2000). In regions with inadequate space for the extensive cultivation of mahogany trees, integrating shade-loving crops with these trees can have both fiscal and ecological benefits (Nasielski et al., 2015).

In the northern Indian states of Uttarakhand, Punjab, Haryana, Uttar Pradesh, and Bihar, as well as some of the central and eastern states like Madhya Pradesh, Chhattisgarh, and West Bengal, wheat is frequently intercropped with Poplar, *Eucalyptus*, and other fast-growing tree species during the rabi season *i.e.*, November-April (Bisht 2018). Although there have been several studies on agroforestry in the northern and central states, studies in West Bengal and some North-eastern states are limited with less knowledge about the suitability of intercropping species. Keeping in view the significance of Mahogany species as an emerging agroforestry and land restoration tree, the experiment aims to investigate the effect of mahogany and wheat based Agri-silvicultural system on the tree growth parameters and soil nutrient status.

MATERIAL AND METHODS

Location and site conditions: The study was conducted at Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar, West Bengal. The site is located in the plains of the Terai zone at an elevation of 43 m above the mean sea level with coordinates of 26°45'.8"N latitude and 89° 23'16.7"E longitude. The region has a subtropical, humid climate. The minimum and maximum temperatures range from 8.3 °C in January to 36 °C in August. The average annual rainfall is high, up to 3200 mm, primarily occurring between June and September, during the pre-monsoon and monsoon seasons. The relative humidity ranges from 45.00% (February) to 94.00% (August), making the area warm and humid except for a brief winter period from December to February.

Experimental design: The experiment was laid out in a randomized block design with two primary systems: an open system and a mahogany-based agri-silvicultural system. Two wheat cultivars (*Triticum aestivum* L.), cvs. BHU-35 and Var. DBW-187 were grown as the agricultural component during the rabi season and a thirteen-year-old mahogany tree plantation was used as a silvicultural component.

Tree growth parameters: Various growth attributes were recorded from four rows of mahogany trees, each consisting of 15 trees within the agri-silvicultural system and was considered as a treatment to evaluate intra-system variation. The trees were maintained at a spacing of 5 m x 2.5 m during the experimental period from 2022 to 2024. Data for height, diameter at breast height (DBH), crown length and crown

width were recorded before sowing and after the harvest of wheat cultivars. Crown length was measured from the tree's tip to the lowest live branch using a graduated bamboo pole. Crown was measured in two directions (North-South and East-West) and calculated by following Assman (1970) and Chaturvedi and Khanna (1982). Diameter at Breast Height (DBH) was recorded at a standard height of 1.37 m from the ground level. Tree volume was estimated using the cylindrical volume formula: $V = \pi r^2 h$, where 'r' is the average radius (derived from DBH) and 'h' is the average bole height.

Soil attributes: Under open and agri-silvicultural systems soil organic carbon, pH, available nitrogen, phosphorus, potassium and bulk density was estimated. Soil samples were collected from two depths: 0-15 cm and 15-30 cm, both before sowing and after harvesting the wheat crop.

Statistical analysis: For tree growth assessment, observations were recorded and the mean values were subjected to statistical analysis. For soil physico-chemical analysis, the data were analyzed following a factorial randomized block design considering three factors: system, soil depth, and time.

RESULTS AND DISCUSSION

Mahogany tree growth: The growth performance of mahogany trees over a span of three consecutive years under an agri-silvicultural system, including height, diameter at breast height (DBH), and volume was observed (Table 1).

The mean tree height increased significantly from 8.6 m in Year 1 to 10.5 m in year 3, with an average increment of 1.8 m. The consistent growth indicates good site adaptability and vigor of mahogany under prevailing environmental conditions. The DBH also showed a steady rise from 11.4 cm in year 1 to 12.9 cm in year 3, with a mean increment of 1.4 cm, which was statistically significant. Volume increment ranged from 0.0362 to 0.0634 m³, with a mean increment of 0.0482 m³, corresponding to a significant average percentage increase of 54.05%. Notably, even with modest increase in height and DBH, mahogany showed substantial volume increase, highlighting its high timber yield potential. Comparable growth attributes were reported by Murmu (2022) where gamhar and mango trees intercropped with seasonal crops such as groundnut and mustard exhibited superior tree growth compared to sole plantations. Similar trends were observed by Kumar (2019) in poplar varieties intercropped with wheat. Kumar et al. (2025) found that different fertilizer levels enhanced both mahogany growth and intercropped rhizome yield in Kerala, suggesting efficient nutrient sharing and the benefits of optimized fertilization in mahogany-based agroforestry systems.

The mean crown length showed a significant increase

over the study period, rising from 3.5 m in Year 1 to 3.9 m in year 2 and 5.0 m in year 3 (Table 2). This reflects an average increment of 1.5 m. The differences in crown length between the years were statistically significant between year 1 and 2 and between year 2 and 3. These findings reflect a steady yearly rise in crown expansion, suggesting healthy canopy growth. Individually, Row 3 had the longest crown length (5.4 m in Year 3), while Row 1 had the shortest (3.2 m in Year 1).

The mean crown width also showed a steady increase, rising from 2.9 m in Year 1 to 3.5 m in year 2 and 4.9 m in year 3, with an average increment of 2.0 m. In contrast to crown length, the variations between years were not significant at the 5% (NS), which implies that even though crown width increased, the variability within the data was high. Individually, Row 1 had the largest crown width (5.3 m in Year 3), while row 3 had the smallest (2.6 m in Year 1). Both crown length and width showed an increasing trend with tree age. Based on these results, crown length appears to be a more accurate measure of early canopy development than crown width under these conditions. Similar results of positive implications *i.e.* better tree growth and productivity as a result of intercropping fodder grasses (Prajapati et al., 2020, 2023) and medicinal plants (Thakur et al., 2018) with *Melia dubia* by earlier workers further confirm the present study inferences.

Soil nutrient status: The physico-chemical properties of the soil at two depths (0-15 cm and 15-30 cm) under open system and agroforestry system (AFS) indicate that at 0-15 cm depth

the organic carbon (%) in agroforestry system showed an increasing trend from 0.76% before sowing to 0.80% after harvest (Table 3). Similarly, at 15-30 cm depth, OC was higher in AFS (0.62-0.65%) compared to the open system (0.50-0.48%). The OC content at 0-15 cm depth was 0.62% in the open system and slightly lowered (0.59%) after harvest. The differences between systems were statistically significant indicating that agroforestry practices improved soil organic carbon through increased litterfall, root turnover, and organic matter assimilation. In both soil depths, AFS had a consistently higher nitrogen content. The available N rose from 176.61 to 179.76 kg ha⁻¹ at 0-15 cm in AFS as compared to 170.10-167.37 kg ha⁻¹ in open system. AFS soils maintained greater values (148.68-151.20 kg ha⁻¹) at a depth of 15-30 cm compared to open soils (144.90-140.28 kg ha⁻¹). Agroforestry improved nitrogen retention, as evidenced by the statistically significant differences which may be due to better organic matter cycling.

Available phosphorous was greater in AFS soils across both depths. At 0-15 cm available phosphorus levels increased from 11.12 and 11.34 kg ha⁻¹ in AFS whereas in the open system it decreased from 10.02 and 9.43 kg ha⁻¹. Additionally, AFS had a higher phosphorus increment (8.29-8.65 kg ha⁻¹) at a depth of 15-30 cm compared to open plots (8.12-7.28 kg ha⁻¹). The improvement under AFS was substantial, despite the smaller range of change, indicating that the incorporation of trees may have increased phosphorus availability. Potassium

Table 1. Growth parameters of mahogany tree during the experimental period 2022-2024

	Height (m)				DBH (cm)				Volume (m ³)	
	Year 1	Year 2	Year 3	Increment	Year 1	Year 2	Year 3	Increment	Volume Increment	Volume Increment (%)
Row 1	9.0	9.3	10.9	1.9	13.1	13.8	14.6	1.6	0.0634	52.88
Row 2	8.5	9.1	10.3	1.8	12.4	13.1	13.7	1.3	0.0494	48.53
Row 3	8.6	9.2	10.5	1.9	10.3	11.2	11.8	1.5	0.0439	61.86
Row 4	8.6	9.3	10.2	1.7	10.1	10.6	11.4	1.3	0.0362	52.94
Mean	8.6	9.2	10.5	1.8	11.4	12.2	12.9	1.4	0.0482	54.05
CD (p=0.05)	0.27	0.38	0.20	0.17	1.15	1.46	0.88	1.07	0.15	1.32

Table 2. Increment in crown dimensions of mahogany tree during the experimental period 2022-2024

	Crown length (m)				Crown width (m)			
	Year 1	Year 2	Year 3	Increment	Year 1	Year 2	Year 3	Increment
Row1	3.2	3.4	4.7	1.5	3.3	3.7	5.3	1.7
Row2	3.5	3.9	4.9	1.4	2.8	3.5	4.9	2.1
Row3	3.9	4.5	5.4	1.5	2.6	3.3	5.2	2.3
Row4	3.4	3.8	4.9	1.6	3.0	3.5	4.7	1.7
Mean	3.5	3.9	5.0	1.5	2.9	3.5	4.9	2.0
CD (p=0.05)	0.09	0.54	0.50	NS	0.28	NS	NS	NS

Table 3. Soil physico-chemical properties before sowing and after harvest of wheat under open system and mahogany based agroforestry system

System	OC (%)		N (Kg/ha)		P (Kg/ha)		K (Kg/ha)		pH		BD (g cm ⁻³)	
	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH
Open (0-15 cm)	0.62	0.59	170.10	167.37	10.02	9.43	144.48	141.4	6.55	6.26	1.26	1.24
AFS (0-15 cm)	0.76	0.80	176.61	179.76	11.12	11.34	163.80	166.88	5.31	4.90	1.30	1.28
CD (p=0.05)	0.09	0.09	19.81	12.64	0.67	0.45	12.60	11.54	1.24	0.62	0.30	0.22
CV	5.60	2.14	3.25	2.07	1.82	1.23	3.59	3.36	5.96	3.18	6.17	5.12
Open (15-30 cm)	0.50	0.48	144.90	140.28	8.12	7.28	110.04	106.68	6.83	6.37	1.45	1.38
AFS (15-30 cm)	0.62	0.65	148.68	151.2	8.29	8.65	132.24	135.99	5.64	5.23	1.47	1.41
CD (p=0.05)	0.03	0.08	2.71	2.39	1.48	1.11	5.26	3.89	0.66	0.41	0.05	0.11
CV	6.02	6.63	0.52	0.47	5.15	3.97	1.90	1.44	3.02	2.03	1.11	2.33

BS-Before sowing; AH-After harvest; AFS-Agroforestry system

displayed greater values under agroforestry system compared to open system. The available potassium increased from 163.80-166.88 kg ha⁻¹ under AFS, and lowered from 144.48 and 141.40 kg ha⁻¹ under open system at 0 to 15 cm. The statistical significance of the differences confirmed that AFS practices increase K availability

The pH of the soil decreased noticeably at both depths under AFS as compared to the open system. The pH reduced from 6.55-6.26 in the open system to 5.31-4.90 under AFS at 0-15 cm and from 6.83-6.37 to 5.64-5.23 at 15-30 cm, suggesting a tendency toward acidity in agroforestry systems, which could be explained by the breakdown of organic matter. The nutrient availability was better under AFS despite reduced pH, demonstrating the beneficial contribution of trees towards soil fertility. The bulk density was marginally greater (1.30-1.28 g cm⁻³ at 0-15 cm and 1.47-1.41 g cm⁻³ at 15-30 cm) than under the open system (1.26-1.24 g cm⁻³ and 1.45-1.38 g cm⁻³, respectively). The tendency indicates that tree-based systems may enhance compaction because of larger root biomass and organic inputs, even if the differences were not statistically significant. Similar to the present study, Kanwal (2022) reported enhanced organic carbon levels and greater water-holding capacity in the top soil (0-15 cm) under agroforestry practice. Sarkar et al. (2022) also observed that *Simarouba glauca* and *Anthocephalus cadamba* based agroforestry improved soil micronutrients through litter fall and deep root cycling indicating greater sustainability than conventional farming.

CONCLUSION

This study demonstrates that the mahogany-based agri-silvicultural system is a viable and beneficial land use strategy. The mahogany trees exhibited robust growth across all measured parameters, with a particularly substantial increase in volume, highlighting their significant potential for timber production. The study revealed significant

differences in soil nutrient dynamics between the open and agroforestry systems. Compared to the open system, the mahogany-based agri-silvicultural system significantly enhanced the soil fertility by increasing key parameters including organic carbon, nitrogen, phosphorous, and potassium at both soil depths. Although a slight decrease in soil pH and a marginal increase in bulk density was observed, these were outweighed by the substantial improvements in overall soil nutrient status. The research highlights how tree-based systems can improve soil health by contributing organic matter, enhancing nutrient cycling and boosting biological activity. These findings underscore the dual benefits of mahogany-based agroforestry system: providing an economically viable timber crop while sustainably improving soil quality for agricultural production.

AUTHOR'S CONTRIBUTIONS

Gurung T conceptualized the study, conducted fieldwork and prepared the manuscript. Ghosh A assisted in statistical analysis and data interpretation Dey A N, Chakravarty S, Mitra B and Das S reviewed the manuscript.

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