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# Enhancing Soil Health and Sustainability: The Impact of Melia Dubia-based Agroforestry in a Semi-Arid Region of Haryana, India

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

This study investigates the impact of a Melia dubia-based agroforestry system on soil properties in Gillan Khera, Fatehabad district, located in the semi-arid region of Haryana. Soil samples were collected from a 7-year-old plantation with a 3m × 3m spacing, where three oat varieties were intercropped. Parameters such as pH, electrical conductivity (EC), organic carbon, soil moisture, and available nitrogen, phosphorus, and potassium were analysed at depths of 0-15 cm and 15-30 cm. Results revealed a decrease in soil pH and EC under trees, with values decreasing from 8.09 to 7.89 and 0.46 to 0.44 dSm-1, respectively. However, intercropped conditions exhibited higher levels of nitrogen (131.38 kg/ha), phosphorus (16.00 kg/ha), potassium (301.10 kg/ha), and organic carbon (0.46%) at both soil depths. Additionally, there was more soil moisture under the plantation. These findings suggest a positive correlation between tree growth and soil health. The study recommends the Melia dubia-based agroforestry system as a promising approach for enhancing soil fertility and promoting environmental sustainability.

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## 1. INTRODUCTION

"Agroforestry stands as a viable solution to address environmental challenges and meet the needs of a rapidly growing human population in a sustainable manner. Sustainable practices demand fertile soils, a goal achievable through the preservation and enhancement offered by agroforestry interventions. Incorporating trees into agricultural landscapes has the potential to address various challenges within agricultural systems, including sustainable biological production, deforestation concerns, declining soil fertility, drought occurrences, and the overuse of harmful chemicals" [1]. "Agroforestry has consistently been praised for its carbon sequestration capabilities and associated benefits, such as improved soil nutrient content, erosion control, runoff management, and various socio-economic advantages, ultimately leading to increased agricultural productivity" (Brown et al., [2], Muchane et al., [3], Shin et al., [4]. "Agricultural systems with trees facilitate nutrient recycling, positively influencing various soil properties. Agroforestry technologies have proven effective as alternatives or supplements to traditional fertilizers" [5]. "*Melia dubia*, commonly known as Burma Dek and Malabar Neem, stands out as a fast-growing tree species that contributes significant litter to the soil, fostering the growth of crops underneath. The presence of *Melia dubia* creates favorable environmental conditions for crops and offers numerous benefits to farmers. Beyond providing human food, it enhances farmers' socio-economic status by diversifying income sources. The mature leaves of *Melia dubia* are a rich source of mineral elements, crude protein, crude lipid, and vitamins, making them excellent fodder for ruminants" [6]. "The physico-chemical properties of soil are positively influenced by the decomposition of leaf litter from perennial tree species like *Melia dubia*. The establishment of a permanent tree cover with suitable species on farmlands can contribute to solutions by lowering soil pH and increasing organic matter content. Research indicates that tree plantations significantly enhance various soil physico-chemical properties" [7]. "Agroforestry brings about reductions in soil pH and EC, improvements in water permeability, water-holding capacity, infiltration rates, soil fertility and other features influenced by tree species. Apart from providing economic assurances to farmers, agroforestry enhances microbial biomass and activity, as well as microclimatic conditions under tree canopies, particularly in arid and semiarid areas" [8]. The primary advantage of agroforestry lies in its sustainability, although researchers often focus on ecological benefits while growers prioritize immediate profits. Balancing climate and economic considerations will be crucial for the future [9]. Scientific research over the past fifty years has consistently demonstrated that agroforestry can address a multitude of sustainability issues facing the world (Kmoch et al., 2018; Jemal et al., 2018).

## 2. MATERIALS AND METHODS

This study estimates the variations in soil fertility and moisture content within a seven-year-old *Melia dubia* plantation, where oat crops are grown in the spaces between the trees. The research was conducted during 2021-2022 in the semi-arid region of Haryana, specifically at a farmer's field in Gillan Khera village, Fatehabad district. The experimental site was located at 29˚50' latitude and 75˚30' longitude, with an elevation of 212 m above sea level. The area experiences a subtropical-monsoonic climate, with an average annual rainfall of 360-400 mm, predominantly occurring from July to September. During the summer months of May and June, the region faces high temperatures ranging from 40 to 45 °C, while in December and January, winter temperatures can drop to 0 °C. The investigation was carried out within an established seven-year-old *Melia dubia* plantation, spaced at 3m × 3m in Gillan Khera village, Fatehabad district, Haryana. In the spaces between the seven-year-old *Melia dubia* trees, three oat varieties were cultivated in three replicate plots during the Rabi season (winter) of 2021-22. Following the recommended practices of CCS Haryana Agricultural University, soil samples were randomly collected at different depths (0-15 cm, 15-30 cm) twice before sowing (November) and after harvesting (March) of the oat crop. [34] The collected soil samples underwent analysis for EC, pH, organic carbon, and nutrients (nitrogen, phosphorus, and potassium). The soil samples were air-dried, ground, and sieved before analysis. Parameters like pH and EC were determined using a distilled water suspension (1:2 ratio). Standard procedures were followed for estimating soil nutrient levels. Soil moisture readings were obtained at distance of 1m and2m from the tree line, collected before irrigation, and on the 7th and 14th days after irrigation. Statistical analysis of the recorded data was performed using the method outlined by Panse and Sukhatme in 1985.

## 3. RESULTS AND DISCUSSION

After harvest, a decrease in the pH values of the soil (Table 2) was observed under the trees in comparison to its initial value; however, there was a minor change in the control field (without trees) between November 2021 and March 2022. This could result from the acidic nature of litter fall and the microclimate that crops and trees create, which lowers the pH of the soil after decomposition (Behera et al., [10], Brandani et al., [11]. The results from this study showed that the pH of the soil under trees decreased from 8.20 to 8.13 and 8.25 to 8.21 for both soil levels, or 0–15 and 15–30 cm, respectively. “After harvest, the lowest pH value (8.13) was found at a soil depth of 0 to 15 cm under the trees. The pH of the soil decreased significantly under the Melia plantation compared to the control without trees. The slightly lower pH in the agri-silvicultural system, when compared to the control without trees, could be attributed to the substantial accumulation of organic matter under the trees and the release of weak organic acids during litter decomposition” (Prasadini and Sreemannarayana [12], Kumar et al., 2008). The soil organic carbon (Table 1) increased significantly under *Melia dubia* plantation at both soil depths (0-15 cm and 15-30 cm) compared to the initial organic carbon levels. “In plots with integrated trees, the soil organic carbon content ranged from 0.75 to 0.78 at 0-15 cm and 0.63 to 0.70 at 15-30 cm after harvesting oat varieties. In open conditions without trees, the soil organic carbon was found to be 0.68 to 0.69 and 0.60 to 0.61 after harvest at both soil depths, i.e., 0-15 cm and 15-30 cm, respectively. The maximum increase (0.03%) in soil organic carbon occurred at 0-15 cm soil depth in the intercropped condition. The lower soil organic carbon in the field without trees could be due to the absence of lignified cells in agricultural residues and complete exposure of soil to the sun. The higher organic matter content in intercropped conditions is attributed to the leaf fall from *Melia dubia* during winter months. This leaf fall decomposes after incorporation into the soil, contributing to the soil's carbon pool. The enrichment of soil carbon content in tree-based systems is influenced by factors such as timely litter addition, recycling of annual root fine biomass and root exudates, and reduced oxidation of organic substances under the tree shade” [13]. “Tree-based cropping systems contribute a significant amount of litter, ultimately increasing the organic matter content in the soil. However, a substantial increase in soil organic matter is typically observed after 5-10 years of adopting such cropping systems” [14]. “Climate conditions also play a role in soil carbon content, as humidity and temperature impact microbial activity, influencing the breakdown of organic substances” [15]. “Soil organic carbon is a function of decomposition and replacement rates of organic matter content in the soil. Integrating trees and crops on farmlands enhances soil organic matter content through litter addition both above and below ground. Soil organic matter content is crucial for soil health, acting as a source of energy for soil organisms and influencing their diversity and various biological functions” [16]. “Studies in traditional savannahs and agro-silviculture systems demonstrate that carbon storage is larger in tree stands, emphasizing the importance of trees in carbon stocking and nutrient cycling” (Noiha et al., [17], Dhaliwal et al., [18]. “The amount of organic matter in the soil is a crucial ecological element that influences the viability of terrestrial ecosystems, affecting the physical, chemical, and biological properties of the soil. Agroforestry systems contribute to more effective carbon stocking and nutrient cycling due to constant litter inclusion and decomposition processes, highlighting the significance of trees in farmland ecosystems. It is suggested that the implementation of agroforestry could aid in long-term climate change mitigation by sequestering more carbon in biomass and accumulating soil organic carbon through litter recycling” [19]. Increasing soil organic matter is essential for the recovery of degraded soils, enhancing their quality and functionality [20]. In the *Melia dubia*-based agroforestry system, there was a decrease in EC at both soil depths (Table 3). The rate of decrease in EC was relatively lower in the control (field without trees). The reduction in EC was noted in the intercropped condition at both soil depths of 0-15 cm and 15-30 cm. Similar patterns of EC have been observed by other researchers, such as Patel et al. [21].Trees impact soil properties through various mechanisms, with root networks playing a crucial role in belowground processes that influence soil functions. Understanding these processes can contribute to achieving UN Sustainable Development Goals related to soil science and agroforestry, such as soil organic carbon sequestration and water infiltration (Cardinal et al., 2020). There was an improvement in the available nitrogen content in the soil at harvest, which could be attributed to the increase in soil humus content after the decomposition of litter from *Melia dubia* trees. Similar findings were reported in an Acacia-based agro-silviculture system [22]. “They observed an increase in soil nitrogen content due to the accumulation of litter fall by Acacia. Similar positive results in the nutrient status of soil through intercropping in agroforestry have been reported earlier” (Bhardwaj et al., [23], Sirohi and Bangarwa, [24]. “The increase in nitrogen content under agroforestry may be attributed to the higher moisture levels and moderate temperatures in the shade, leading to a faster rate of mineralization, litter breakdown, and nitrogen turnover compared to full sunlight conditions. Non-nitrogen-fixing trees can also enhance soil physical, chemical, and biological properties by adding significant amounts of organic matter and releasing and recycling nutrients in agroforestry systems” (Antonio and Gama-Rodrigues, 2011). Stöcker et al. (2020) found that “agro-silviculture systems positively influenced soil physical traits and consistently enhanced soil quality”. Researchers recommend the diverse root systems of trees and the accumulation of crop residues for the rapid improvement of soil quality. Agroforestry provides an approach where organic content can be added quickly by selecting appropriate nitrogen-fixing tree species, especially if they are fast-growing [25]. The available phosphorus in the soil (Table 4) followed a similar pattern to soil nitrogen. After the harvest, the phosphorus content in the soil increased compared to the initial values. The increase in soil phosphorus content was more significant at the 0-15 cm soil depth under tree conditions compared to the 15-30 cm soil depth. Regarding potassium content (Table 4), the soil under *Melia dubia* trees intercropped with oat varieties exhibited higher levels compared to the control where oats were grown without trees. An increase in potassium content was observed after harvest in both environments compared to the initial values. In a related study, higher levels of pH and base saturation were observed in areas intercropped with *Hevea brasiliensis* compared to monocultures. Beneath tree crowns, a higher level of microbial biomass and content of nitrogen, phosphorus, and potassium was noted compared to the open savanna. Researchers also emphasized the significance of birds and mammals in the vicinity of trees and their role in nutrient deposition through dung [7]. The increased availability of nutrients in the *Melia dubia*-based agroforestry system compared to the agricultural system may be attributed to the addition of litter fall from *Melia dubia* trees, as well as the contribution of root residues. Tree-based cropping systems enhance soil fertility and nutrient status, as noted by Toky et al. (2018) and Sida et al. [26]. Agroforestry systems, known for their greater complexity and biodiversity, are believed to enhance water-related processes like infiltration, retention, and reduced runoff more effectively compared to intensive monoculture [27]. These systems contribute to improved water retention through trees having complementary root distributions, especially with deeper roots than annual crops [28]. In both open and tree-covered conditions, soil moisture content increased with greater soil depth but decreased as the distance from the tree line increased. Table 5 indicates that, without irrigation, the highest moisture content (10.33 percent) was observed at a soil depth of 15 to 30 cm under trees, specifically at a distance of 2.0 m from the tree row. This trend of increasing moisture content with greater soil depth persisted after irrigation. There was a shift in moisture percentage between 1.0 and 2.0 meters, with the lowest soil moisture percentage occurring at 1.0 m from the tree, possibly due to the extensive interaction of 3x3m spaced trees. In the tree-covered area, higher moisture percentage is recorded due to *Melia dubia's deciduous nature, conserving moisture in soil with*

**Table 1. Standard procedure followed for soil estimation**

| Sr. No. | Properties | Methods |
|---|---|---|
| 1 | Electrical conductivity (dS $m^{-1}$) | Conductivity meter (Jackson, 1973) |
| 2 | Soil (pH) | Glass electrode pH meter (Jackson, 1973) |
| 3 | Organic carbon (%) | Partial oxidation method (Walkley and Black, 1934) |
| 4 | Available nitrogen (kg $ha^{-1}$) | Alkaline permanganate distillation method (Subbiah and Asija,1956) |
| 5 | Available phosphorus (kg $ha^{-1}$) | Sodium bicarbonate method (Olsen et al*.,* 1954) |
| 6 | Available potassium (kg $ha^{-1}$) | Neutral normal ammonium acetate method (Jackson, 1973). |

**Table 2. Soil pH and organic carbon content at different depth before sowing and after harvesting of oat varieties in control (field withouttrees) and under tree condition**

| Soil Depth (cm) | Soil pH | | | | | | Organic carbon (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before sowing | | | After harvest | | | Before sowing | | | After harvest | | |
| | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean |
| 0-15 | 8.2 | 8.35 | 8.27 | 8.13 | 8.32 | 8.23 | 0.75 | 0.68 | 0.72 | 0.78 | 0.69 | 0.74 |
| 15-30 | 8.25 | 8.55 | 8.4 | 8.21 | 8.54 | 8.37 | 0.63 | 0.6 | 0.62 | 0.7 | 0.61 | 0.66 |
| **Mean** | 8.22 | 8.45 | | 8.17 | 8.43 | | 0.69 | 0.64 | | 0.74 | 0.65 | |
| **C. D. at 5%** | | | | | | | | | | | | |
| Depth | | 0.02 | | 0.03 | | | 0.01 | | | 0.018 | | |
| Environment | | 0.02 | | 0.03 | | | 0.01 | | | 0.018 | | |
| D×E | | 0.03 | | 0.04 | | | 0.014 | | | NS | | |

**D×E—Depth × Environment*

**Table 3. Soil EC and nitrogen content at different depth before sowing and after harvesting of oat varieties in control (field without trees) and under tree condition**

| Soil Depth (cm) | Soil EC | | | | | | Available nitrogen (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before sowing | | | After harvest | | | Before sowing | | | After harvest | | |
| | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean |
| 0-15 | 0.38 | 0.43 | 0.41 | 0.36 | 0.42 | 0.39 | 147 | 141 | 144 | 147.7 | 139 | 143.4 |
| 15-30 | 0.4 | 0.46 | 0.43 | 0.38 | 0.45 | 0.42 | 113 | 110.9 | 112 | 114.9 | 109.2 | 112 |
| **Mean** | 0.39 | 0.45 | | 0.37 | 0.44 | | 130 | 126 | | 131.3 | 124.1 | |
| **C. D. at 5%** | | | | | | | | | | | | |
| Depth | 0.014 | | | 0.019 | | | 1.18 | | | 1.22 | | |
| Environment | 0.014 | | | 0.019 | | | 1.18 | | | 1.22 | | |
| D×E | NS | | | NS | | | 1.67 | | | 1.73 | | |

**D×E—Depth × Environment*

**Table 4. Soil phosphorus and potassium content at different depth before sowing and after harvesting of oat varieties in control (field without trees) and under tree**

| Soil Depth (cm) | Available phosphorus (kg/ha) | | | | | | Available potassium (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before sowing | | | After harvest | | | Before sowing | | | After harvest | | |
| | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean | Under Tree | Without Tree | Mean |
| 0-15 | 40 | 25.6 | 32.8 | 42.7 | 25.2 | 33.9 | 320.7 | 270.4 | 295.55 | 323.8 | 273.2 | 298.5 |
| 15-30 | 37.4 | 23.7 | 30.5 | 38 | 23.1 | 30.5 | 310.95 | 261.7 | 286.33 | 313.4 | 264.1 | 288.75 |
| **Mean** | 38.7 | 24.6 | | 40.3 | 24.1 | | 315.83 | 266.05 | | 318.6 | 268.65 | |
| **C. D. at 5%** | | | | | | | | | | | | |
| Depth | 0.23 | | | 0.17 | | | 2.78 | | | 2.94 | | |
| Environment | 0.23 | | | 0.17 | | | 2.78 | | | 2.94 | | |
| D×E | 0.32 | | | 0.25 | | | NS | | | NS | | |

*D×E—Depth × Environment*

**Table 5. Soil moisture status at different soil depths and distance from tree row for first and second irrigation in under tree and without tree conditions**

| **First irrigation** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Soil Depth** | **Before irrigation** | | | | **After 7 days of irrigation** | | | | **After 14 days of irrigation** | | | |
| | **1 m** | | **2 m** | | **1 m** | | **2 m** | | **1 m** | | **2 m** | |
| | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** |
| 0-15 cm | 10.08 | 8.05 | 10.13 | 8.10 | 14.53 | 9.7 | 14.60 | 9.83 | 12.73 | 8.75 | 12.80 | 8.85 |
| 15-30 cm | 10.20 | 9.10 | 10.33 | 9.15 | 16.73 | 14.43 | 16.78 | 14.48 | 13.73 | 11.43 | 13.88 | 11.58 |
| **CD at 5%** | Distance=0.25; Depth=0.18; Distance × Depth=0.36 | | | | Distance=0.23; Depth=0.16; Distance × Depth=0.32 | | | | Distance=0.18; Depth=0.13; Distance × Depth=0.26 | | | |
| **Second irrigation** | | | | | | | | | | | | |
| Soil Depth | **Before irrigation** | | | | **After 7 days of irrigation** | | | | **After 14 days of irrigation** | | | |
| | **1 m** | | **2 m** | | **1 m** | | **2 m** | | **1m** | | **2 m** | |
| | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** | **UT** | **WT** |
| 0-15 cm | 9.80 | 8.70 | 9.85 | 8.75 | 13.53 | 12.68 | 13.59 | 12.72 | 10.48 | 9.20 | 10.53 | 9.24 |
| 15-30 cm | 10.10 | 9.50 | 10.10 | 9.55 | 14.75 | 13.05 | 14.79 | 13.09 | 10.90 | 9.75 | 10.94 | 9.79 |
| **CD at 5%** | Distance=0.21; Depth=0.15; Distance × Depth=0.30 | | | | Distance=0.27; Depth=0.19; Distance × Depth=0.38 | | | | Distance=0.36; Depth=0.25; Distance × Depth=NS | | | |

*CD—Critical Difference*

litter as mulch, restricting moisture loss through evaporation. Additionally, during the Rabi season, Melia growth is limited as it enters dormancy, requiring less water for transpiration. Carvalho et al. (2020) concluded that shaded agroforestry coffee systems enhance microclimate conditions compared to unshaded systems. Stöcker et al. (2020) found that agro-silviculture systems positively impacted soil physical traits and consistently improved soil quality. Researchers recommended diversified root systems and crop residue accumulation for rapid soil quality enhancement. Agroforestry not only boosts soil productivity but also provides farmers with stability against uncertainties [29]. The present study indicates that *Melia dubia* trees in a semi-arid environment of Haryana, within an agroforestry system, positively impact soil health. EC and pH decreased under *Melia dubia* after harvesting oat varieties, while nutrient and organic carbon content increased in the intercropped system. Soil moisture content was higher under trees compared to open conditions, contributing to overall improvements in soil fertility [30,31]. This intercropping system is recommended for its benefits, including recycling through litterfall, enhanced soil fertility, and environmental advantages. The study underscores the potential of *Melia dubia*-based agroforestry systems to enhance soil fertility, urging farmers to integrate these practices for sustainable soil health and environmental benefits [32,33].

## 4. CONCLUSION

The study shows that growing *Melia dubia* trees in the semi-arid region of Haryana as part of an agroforestry system has positive effects on the soil. After harvesting oat varieties, the EC and pH decreased under *elia dubia* trees. However, the nutrient and organic carbon content increased in the intercropped system. Moisture content was higher under the trees compared to open conditions, contributing to overall improvements in soil fertility. This intercropping system is recommended for its benefits, including recycling through litterfall, enhanced soil fertility, and positive environmental impacts. The study highlights the potential of the *Melia dubia*-based agroforestry system to enhance soil fertility, suggesting that farmers should consider incorporating *Melia dubia* trees on their farms for sustainable soil improvement and environmental benefits.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Arya S, Toky OP, Singh K. Mitigation of climate changes through agroforestry for sustainable agriculture in India. Journal of Agrometeorology. 2018;20:172-7.
2. Brown SE, Miller DC, Ordonez PJ, Baylis K. Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: A systematic map protocol. Environmental evidence. 2018;7: 1-6.
3. Muchane MN, Sileshi GW, Gripenberg S, Jonsson M, Pumariño L, Barrios E. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. Agriculture, Ecosystems & Environment. 2020;295:106899.
4. Shin S, Soe KT, Lee H, Kim TH, Lee S, Park MS. A systematic map of agroforestry research focusing on ecosystem services in the Asia-Pacific Region. Forests. 2020; 11(4):368.
5. Bhardwaj S, Khanna DR, Ruhela M, Bhutiani R, Bhardwaj R, Ahamad F. Assessment of the soil quality of Haridwar Uttarakhand India: A comparative study. Environment Conservation Journal. 2020; 21(3):155-64.
6. Saravanan V, Parthiban KT, Kumar P, Marimuthu P. Wood characterization studies on Melia dubia cav. for pulp and paper industry at different age gradation. Research Journal of Recent Sciences ISSN. 2013;2277:2502.
7. AJ Belsky. The effects of trees on their physical, chemical and biological

environments in a semi-arid savanna in Kenya. J Appl Ecol. 1989;26:1004-24.
8. Tewari JC, Ram M, Roy MM, Dagar JC. Livelihood improvements and climate change adaptations through agroforestry in hot arid environments. Agroforestry systems in India: livelihood security & ecosystem services. 2014:155-83.
9. Liu W, Yao S, Wang J, Liu M. Trends and features of agroforestry research based on bibliometric analysis. Sustainability. 2019;11(12):3473.
10. Behera LK, Patel DP, Gunaga RP, Mehta AA, Jadeja DB. Clonal evaluation for early growth performance of Eucalyptus in South Gujarat, India. Journal of Applied and Natural Science. 2016;8(4):2066-9.
11. Brandani CB, Rocha JH, Godinho TD, Wenzel AV, Gonçalves JL. Soil C and Al availability in tropical single and mixed-species of Eucalyptus sp. and Acacia mangium plantations. Geoderma Regional. 2017;10:85-92.
12. Prasadini P, Sreemannarayana B. Impact of agroforestry systems on nutritional status and biological activity on rainfed red sandy loam soils. Indian Forester. 2007; 133(11):1519.
13. Gill AS, Burman D. Production management of field crops in agroforestry systems. Recent advances in Agronomy. 2002:523-42.
14. Derpsch R. No-tillage and conservation agriculture: a progress report. No-till farming systems. Special publication. 2008;3:7-39.
15. Nair PR, Nair VD, Kumar BM, Showalter JM. Carbon sequestration in agroforestry systems. Advances in agronomy. 2010; 108:237-307.
16. Dollinger J, Jose S. Agroforestry for soil health. Agroforestry systems. 2018;92:213-9.
17. Noiha Noumi V, Zapfack L, Hamadou MR, Awe Djongmo V, Witanou N, Nyeck B, Ngossomo JD, Tabue Mbobda RB, Mapongmetsem PM. Floristic diversity, carbon storage and ecological services of eucalyptus agrosystems in Cameroon. Agroforestry systems. 2018;92: 239-50.
18. Dhaliwal J, Kukal SS, Sharma S. Soil organic carbon stock in relation to aggregate size and stability under tree-based cropping systems in Typic Ustochrepts. Agroforestry systems. 2018 ;92:275-84.
19. Singh NR, Arunachalam A, Devi NP. Soil organic carbon stocks in different agroforestry systems of south Gujarat. Range Management and Agroforestry. 2019;40(1):89-93.
20. Siqueira CC, Chiba MK, Moreira RS, Abdo MT. Carbon stocks of a degraded soil recovered with agroforestry systems. Agroforestry Systems. 2020;94(3):1059-69.
21. Patel JM, Jaimini SN, Patel SB. Physico-chemical properties of soil under different tree species. Indian Journal of Forestry. 2010;33(4):565-8.
22. Githae EW, Gachene CK, Njoka JT. Soil physicochemical properties under Acacia senegal varieties in the dryland areas of Kenya. African Journal of Plant Science. 2011;5(8):475-82.
23. Bhardwaj KK, Dhillon RS, Kumari S, Johar V, Dalal V, Chavan SB. Effect of eucalyptus bund plantation on yield of agricultural crops and soil properties in semi-arid region of India. Int J Curr Microbiol Appl Sci. 2017;6(10):2059-65.
24. Sirohi C, Bangarwa KS. Effect of different spacings of poplar-based agroforestry system on soil chemical properties and nutrient status in Haryana, India. Current Science. 2017:1403-7.
25. Tsufac AR, Awazi NP, Yerima BP. Characterization of agroforestry systems and their effectiveness in soil fertility enhancement in the south-west region of Cameroon. Current Research in Environmental Sustainability. 2021;3: 100024.
26. Sida TS, Baudron F, Ndoli A, Tirfessa D, Giller KE. Should fertilizer recommendations be adapted to parkland agroforestry systems? Case studies from Ethiopia and Rwanda. Plant and Soil. 2020;453:173-88.
27. Pavlidis G, Tsihrintzis VA. Environmental benefits and control of pollution to surface water and groundwater by agroforestry systems: a review. Water Resources Management. 2018;32:1-29.
28. Germon A, Cardinael R, Prieto I, Mao Z, Kim J, Stokes A, Dupraz C, Laclau JP, Jourdan C. Unexpected phenology and lifespan of shallow and deep fine roots of walnut trees grown in a silvoarable Mediterranean agroforestry system. Plant and soil. 2016;401:409-26.
29. Arya S, Toky OP. Biomass production in poplar agroforestry systems in Haryana of

North Western India. Indian Journal of Ecology. 2017;44(6):785-7.
30. de Carvalho AF, Fernandes-Filho EI, Daher M, Gomes LD, Cardoso IM, Fernandes RB, Schaefer CE. Microclimate and soil and water loss in shaded and unshaded agroforestry coffee systems. Agroforestry Systems. 2021;95:119-34.
31. Gama-Rodrigues AC. Soil organic matter, nutrient cycling and biological dinitrogen-fixation in agroforestry systems. Agroforestry Systems. 201;81:191-3.
32. Jemal O, Callo-Concha D, Van Noordwijk M. Local agroforestry practices for food and nutrition security of smallholder farm households in southwestern Ethiopia. Sustainability. 2018 ;10(8):2722.
33. Panse VG, Sukhatme PV. Stastical methods for Agricultural workers. 4th edn. ICAR, New Delhi; 1985.

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