E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(9): 277-283
Received: 17-07-2025
Accepted: 19-08-2025

Sanjay BS
M.Sc. Scholar, Department of Soil Science, College of Horticulture, Bagalkot, University of Horticultural Sciences, Bagalkot, Karnataka, India

IB Biradar
Professor and Head, Department of Natural Resource Management, College of Horticulture Bagalkot, University of Horticultural Sciences, Bagalkot, Karnataka, India

SM Prasanna
Assistant Professor and Head, Dept. of Soil Science College of Horticulture, Bidar, Karnataka, India

Sanjeevraddi G Reddi
Associate Professor (Agronomy), University of Horticultural Sciences, Bagalkot, Karnataka, India

Sayeed Almas R Mulla
Assistant Professor, Department of Soil Science, College of Horticulture, Bagalkot, University of Horticultural Sciences, Bagalkot, Karnataka, India

Corresponding Author:
Sanjay BS
M.Sc. Scholar, Department of Soil Science, College of Horticulture, Bagalkot, University of Horticultural Sciences, Bagalkot, Karnataka, India

Evaluating soil fertility and carbon sequestration potential in different land use ecosystem in northern dry zone of Karnataka

Sanjay BS, IB Biradar, SM Prasanna, Sanjeevraddi G Reddi and Sayeed Almas R Mulla

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i9d.3766

Abstract
A field experiment was conducted during 2023-24 at MHREC, UHS main campus, Bagalkot district. The study entitled "Evaluating Soil Fertility and Carbon Sequestration Potential in different land use ecosystem in Northern dry zone of Karnataka". The experiment was conducted with nine treatments and four replications using randomized complete block design. The primary objectives were to compare soil fertility status, soil carbon stocks and their relationship under different land use ecosystem. The results of soil fertility status of different land use ecosystems indicated that. The soil available nitrogen (201.01 kg/ha), potassium (352.73 kg/ha) and organic carbon (7.80 g/kg) was highest in the rhizosphere of teak ecosystem compared to other treatments. Whereas, available phosphorus was higher in the rhizosphere of guava ecosystem (66.17 kg/ha) and the exchangeable calcium [21.02 (cmol (p^+) kg^{-1})] and magnesium [5.10 (cmol (p^+) kg^{-1})] was recorded higher in the rhizosphere of mango ecosystem, while highest available sulphur (23.85 mg/kg) was noticed in the rhizosphere of teak ecosystem. Lower bulk density (1.28 Mg/m^3) were found in teak ecosystem. The highest soil organic carbon stock (1.50 t/ha), highest total carbon and total nitrogen (13.45 g/kg and 0.67 g/kg, respectively) were found in the rhizosphere of teak ecosystem compare to all other ecosystem. Based on overall assessment of results, it could be concluded that the teak ecosystem shows the best result for capturing carbon stock in soil which help in maintaining soil fertility status.

Keywords: Soil fertility, carbon, rhizosphere, grape, teak, biomass, soil organic carbon stock

Introduction
Soil carbon is essential for promoting plant health by enhancing nutrient availability, boosting the soil's ability to retain water, supporting biodiversity within the soil, and minimizing salinity levels (Scotti *et al.*, 2015) [32]. The quantity of soil carbon differs greatly based on the cropping system and land management practices. Among the various indicators used to assess soil quality, soil organic matter (SOM) is particularly significant. SOM not only underpins agricultural productivity but also contributes to environmental services such as carbon capture and air purification. It also plays a central role in maintaining biological activity within the soil ecosystem.
Carbon sequestration is the process by which atmospheric carbon dioxide (CO_2) is absorbed by plants—such as trees and crops—and stored in the form of biomass (roots, leaves, stems, branches) and soil through the mechanism of photosynthesis (EPA, 2011) [10]. Agroforestry, which blends trees with crops or pastures, provides a sustainable alternative to environmentally harmful practices like deforestation and shifting agriculture. This approach can significantly increase carbon capture, although the level of sequestration is influenced by ecological and socio-economic conditions. For example, in tropical humid areas, agroforestry systems can store more than 70 Mg/ha of carbon in the top 20 cm of soil (Mutuo, 2005) [23]. Additionally, tree roots—which contribute 20-25% of total plant biomass—decompose over time and enrich the soil with organic material, thereby boosting carbon content (Dhyani & Tripathi, 2000) [9].
Carbon credits serve as a tool in the global fight against climate change by offering financial incentives for emissions reduction. Each credit represents one ton of CO_2 (or its equivalent) that

can be emitted and is tradable on carbon markets. The credibility and effectiveness of these credits depend on stringent monitoring, reporting, and verification frameworks, as well as mechanisms to prevent problems like double-counting or awarding credits for non-genuine activities.

Horticulture systems, especially those cultivating fruit crops, contribute notably to carbon sequestration by storing CO_2 in plant structures above and below the ground, as well as in the soil. Perennial fruit trees such as mango (*Mangifera indica*), sapota (*Manilkara zapota*), guava (*Psidium guajava*), grape (*Vitis vinifera*), and pomegranate (*Punica granatum*) are effective carbon sinks due to their long life cycles. Compared to monocultures, agroforestry systems that include fruit trees typically have a higher potential for carbon storage. Practices like mulching with organic matter, reduced soil disturbance, and the use of compost can further elevate levels of soil organic carbon.

To measure these benefits, carbon stock assessments evaluate the carbon stored in above-ground plant biomass, root systems, and soil. Technologies like GIS and remote sensing are increasingly used for large-scale carbon assessments, particularly in orchard systems. When paired with carbon credit markets, sustainable fruit production can serve dual purposes: climate change mitigation and economic reward. However, heavy reliance on chemical fertilizers can undercut these benefits by degrading soil health and reducing carbon storage capacity.

Among commercial plantation crops, coconut (Cocos nucifera) is of major significance in India, occupying 2.17 million hectares and yielding over 21 billion nuts annually. Key production areas include Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh (Maheswarappa *et al*., 2005) [20]. Incorporating diverse crop species within such plantations can mimic forest ecosystems, thereby enhancing carbon sequestration potential.

Biofuels, which are produced from plant material, are often considered carbon-neutral because the CO_2 they emit during combustion is nearly equal to what the plants absorb during growth. Advanced biofuels from non-edible sources (second-generation) and algae (third-generation) offer even more promise, especially since they can be cultivated on degraded or marginal lands. Coupling biofuel production with carbon capture and storage (CCS) technologies can achieve negative emissions, playing a crucial role in climate mitigation strategies (Qin *et al*., 2016) [28]. Nevertheless, their long-term viability depends on sustainable land use and avoiding direct competition with food crops.

Fast-growing tree species such as teak (*Tectona grandis*) and Melia dubia (Malabar neem) are also recognized for their strong carbon storage potential. Teak, one of the most widely planted tropical hardwood species, locks carbon in its biomass and in the long-lasting wood products made from it (Sreejesh *et al*., 2013) [34]. However, pressure to reduce rotation cycles for economic reasons can decrease its overall carbon storage. On the other hand, Melia dubia, native to India's moist deciduous forests, is increasingly popular due to its adaptability and rapid growth, making it a strong candidate for carbon stock improvement (Nair *et al*., 2005) [25].

Reducing greenhouse gas emissions is vital for addressing climate change, ensuring public health, preserving biodiversity, and supporting economic growth. Agroforestry and horticultural land-use practices are key components of climate-smart agriculture. Through their ability to absorb CO_2 and enrich soil carbon levels, these systems play a major role in carbon sequestration and are critical to achieving long-term environmental sustainability.

Objective of the Study

To quantify the carbon sequestation and to assess the soil fertility status of different land use ecosystem.

Materials and Methods

The study was conducted during 2023-2024 at the Main Horticultural Research and Extension Center (MHREC), UHS, Bagalkot, located in the Northern Dry Zone of Karnataka (Agro-climatic Zone III), at 16.10° N latitude, 75.610° E longitude, and an altitude of 563 m above mean sea level. The climate is semi-arid with an average annual rainfall of 550 mm. The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine treatments and four replications, using different perennial crop-based ecosystems. The treatments included: T1 - Mango (11 years, 560-720 kg/m³), T2 - Sapota (11 years, 800-1100 kg/m³), T3 - Guava (11 years, 750-850 kg/m³), T4 - Coconut (11 years, 600-900 kg/m³), T5 - Grape (7 years, 700-900 kg/m³), T6 - Pomegranate (7 years, 800-1000 kg/m³), T7 - Bio-fuel species (11 years, 550-750 kg/m³), T8 - Teak (11 years, 630-750 kg/m³), and T9 - Malabar Neem (11 years, 500-600 kg/m³). For each treatment, one gunta plots were randomly selected, and soil samples were collected from two depths (0-15 cm and 15-30 cm) from the rhizosphere zone during December 2023 and January 2024. Composite samples were formed from 8-10 spots per plot. After air drying, soils were ground and sieved (2 mm; 0.2 mm for carbon and CHNS analysis). Bulk density (Mg/m³) was measured using the core method, based on oven-dry weight per unit core volume. Soil organic carbon (SOC) was estimated by the Walkley and Black (1934) [39] wet oxidation method, and carbon stock (t/ha) was computed using the formula: SOC × bulk density × depth. Total carbon and nitrogen were analyzed using a CHNS analyzer (LECO). Available nitrogen was estimated using the alkaline $KMnO_4$ method (Subbaiah and Asija, 1956) [35], phosphorus via Olsen's method with colorimetric detection, and potassium by 1N ammonium acetate extraction followed by flame photometry. Exchangeable calcium and magnesium were measured by EDTA titration, available sulfur by 0.15% $CaCl_2$ extraction and turbidimetry (Hesse, 1994) [12], and micronutrients (Fe, Mn, Zn, Cu) by DTPA extraction and atomic absorption spectrophotometry (Lindsay and Norvell, 1978) [18].

Results and Discussion

Soil bulk density (Mg/m³)

The data presented in Table. 1 clearly indicate significant variation in soil bulk density across both surface and sub-surface layers among the different land use systems. At the surface layer (0-15 cm), bulk density ranged from 1.28 to 1.48 Mg/m³. The highest value (1.48 Mg/m³) was observed under the pomegranate ecosystem, which was statistically at par with the grape ecosystem (1.44 Mg/m³), followed by guava (1.41 Mg/m³), sapota (1.38 Mg/m³), coconut (1.35 Mg/m³), malabar neem (1.33 Mg/m³), mango (1.32 Mg/m³), and biofuel ecosystems (1.29 Mg/m³). The teak ecosystem recorded the lowest bulk density (1.28 Mg/m³) at the surface soil. In the sub-surface layer (15-30 cm), the highest bulk density (1.47 Mg/m³) was again found in the pomegranate ecosystem, closely followed by grape (1.45 Mg/m³) and sapota (1.44 Mg/m³), with guava (1.43 Mg/m³), mango (1.39 Mg/m³), coconut (1.38 Mg/m³), malabar neem (1.35 Mg/m³), and biofuel (1.32 Mg/m³) ecosystems trailing behind. Teak once again recorded the lowest value (1.31 Mg/m³). Overall, bulk density increased with soil depth, which is likely due to greater compaction in sub-surface layers resulting from the weight of overlying soil, as noted by Patil and Jagadish (2004) [27]. This trend is consistent with the findings of Dhole (2017) [8], who attributed increased bulk density at greater depths to soil compaction and variations in cropping systems. Additionally, limited incorporation of organic matter into deeper soil layers, compared to surface layers where organic inputs are concentrated, may contribute to this pattern, as supported by the findings of Tejada *et al*. (2008) [37] and Rudrappa *et al*. (2005) [30].

Soil organic carbon (g/kg)

The statistical analysis of organic carbon content (g/kg), as presented in Table 1, revealed significant differences among the rhizospheres of various land use ecosystems at both surface (0-15 cm) and sub-surface (15-30 cm) soil depths. At the surface level, the highest organic carbon content was recorded under the teak ecosystem (7.8 g/kg), followed by biofuel (7.6 g/kg), mango (7.1 g/kg), malabar neem (6.9 g/kg), coconut (6.5 g/kg), sapota (6.1 g/kg), guava (5.9 g/kg), and grape ecosystems (5.8 g/kg). The lowest value (5.6 g/kg) was observed in the pomegranate ecosystem. In the sub-surface soil, organic carbon ranged from 4.6 to 6.8 g/kg, with the teak ecosystem again showing the highest value (6.8 g/kg), closely followed by biofuel (6.7 g/kg), malabar neem (6.4 g/kg), coconut (6.2 g/kg), and mango (6.0 g/kg). Lower values were recorded in guava (5.1 g/kg), sapota (4.9 g/kg), pomegranate (4.7 g/kg), and the lowest in grape ecosystem (4.6 g/kg). The higher organic carbon levels observed in ecosystems like teak and biofuel may be attributed to the substantial accumulation of above- and below-ground biomass, which contributes to carbon enrichment in the soil. According to Leblanc and Russo (2008) [17], continuous addition of organic residues such as grasses, weeds, and crop remains enriches the topsoil with carbon. Agroforestry systems often show elevated organic carbon due to minimal soil disturbance, as excessive tillage disrupts soil structure and depletes organic carbon (Alam *et al*., 2014) [1]. Sa and Lal (2009) [31] also emphasized that reduced tillage promotes carbon retention. Moreover, irrigated ecosystems generally support greater biomass turnover compared to rainfed systems, which can enhance soil carbon levels, as supported by Nagaraja *et al*. (2016) [24], who linked improved productivity and biomass accumulation with irrigation practices.

Soil organic carbon stock (SOC) (t/ha)

The data in Table 1. reveal significant variation in soil organic carbon (SOC) stock across different ecosystems at both surface (0-15 cm) and subsurface (15-30 cm) soil layers. At the surface, the highest SOC stock was recorded in the teak ecosystem (1.50 t/ha), followed closely by the biofuel ecosystem (1.47 t/ha), mango (1.41 t/ha), malabar neem (1.38 t/ha), coconut (1.32 t/ha), sapota (1.26 t/ha), and both guava and grape ecosystems at 1.25 t/ha each. The lowest surface SOC stock was found in the pomegranate ecosystem (1.24 t/ha). Similarly, at the subsurface layer, teak showed the highest SOC stock (1.34 t/ha), comparable to biofuel (1.33 t/ha) and malabar neem (1.30 t/ha), followed by coconut (1.28 t/ha), mango (1.25 t/ha), guava (1.09 t/ha), sapota (1.06 t/ha), pomegranate (1.04 t/ha), and grape with the lowest value (1.00 t/ha). The consistently higher SOC stocks in the teak ecosystem highlight its strong capacity for organic carbon accumulation compared to systems like pomegranate and grape. This is likely due to minimal soil disturbance and the accumulation of organic matter such as leaf litter and crop residues in surface soils, with limited vertical movement due to lack of tillage, as supported by Marriott and Michele (2006) [22]. Similar declines in SOC with depth were reported in perennial cropping systems like arecanut (Vinayak, 2022) [38]. Plantation systems maintain higher SOC stocks through continuous leaf litter decomposition (Asha, 2016) [2]. Additionally, deciduous trees contribute to faster SOC stock changes compared to evergreen and coniferous species, especially in the top 0-20 cm soil layer, due to greater annual litter production, which increases carbon input into surface soils (Liu *et al*., 2018) [19].

Table 1: Soil organic carbon and SOC stock in surface and sub-surface soil as influenced by different land use ecosystem

Treatment	Bulk density (Mg/m^3)		OC (g/kg)		SOC stock (t/ha)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1: Mango	1.32	1.39	7.10	6.00	1.41	1.25
T_2: Sapota	1.38	1.44	6.10	4.90	1.26	1.06
T_3: Guava	1.41	1.43	5.90	5.10	1.25	1.09
T_4: Coconut	1.35	1.38	6.50	6.20	1.32	1.28
T_5: Grape	1.44	1.45	5.80	4.60	1.25	1.00
T_6: Pomegranate	1.48	1.47	5.60	4.70	1.24	1.04
T_7: Biofuel	1.29	1.32	7.60	6.70	1.47	1.33
T_8: Teak	1.28	1.31	7.80	6.80	1.50	1.34
T_9: Malbar neem	1.33	1.35	6.90	6.40	1.38	1.30
S. Em.±	0.02	0.01	0.05	0.04	0.02	0.01
C.D. (P = 0.05)	0.04	0.03	0.15	0.12	0.05	0.04

Total carbon content (g/kg)

Table 2. shows that total carbon content varied significantly in both surface (0-15 cm) and subsurface (15-30 cm) soils across different ecosystems. At the surface, the highest total carbon content was observed in the teak ecosystem (13.45 g/kg), followed by biofuel (13.10 g/kg), mango (12.24 g/kg), malabar neem (11.90 g/kg), coconut (11.21 g/kg), sapota (10.52 g/kg), guava (10.17 g/kg), and grape (10.00 g/kg), while the lowest was recorded in the pomegranate ecosystem (9.65 g/kg). In the subsurface layer, total carbon ranged from 7.93 to 11.72 g/kg, with teak again showing the highest value (11.72 g/kg), statistically similar to biofuel (11.55 g/kg), followed by malabar neem (11.03 g/kg), coconut (10.69 g/kg), mango (10.34 g/kg), guava (8.79 g/kg), sapota (8.45 g/kg), pomegranate (8.10 g/kg), and the lowest in grape ecosystem (7.93 g/kg). Since the study area has low rainfall and nearly neutral soil pH, the inorganic carbon (mostly CaCO3) is minimal, indicating that the total carbon measured mainly represents organic carbon. The differences in total carbon content among ecosystems are likely due to variations in the continuous input of organic materials like grasses, weeds, cover crops, and crop residues. Previous studies have linked higher total carbon to the quantity and quality of organic residues and manure application (Yang *et al*., 2012) [41]. Total carbon content decreased with soil depth, likely due to reduced organic matter input, lower microbial activity, and less disturbance in subsurface layers, leading to slower organic matter mineralization. Similar trends were reported by Kumar *et al*. (2019) [16], who found that subsurface soils contained less total carbon than surface soils in rice-wheat cropping systems with continuous organic amendments.

Table 2: Total carbon, total nitrogen and C:N ratio in surface and sub-surface soil as influenced by different land use ecosystem

Treatment	Total carbon (g/kg)		Total nitrogen (g/kg)		C: N ratio	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1: Mango	12.24	10.34	0.61	0.52	20.07	19.89
T_2: Sapota	10.52	8.45	0.53	0.42	19.85	19.89
T_3: Guava	10.17	8.79	0.51	0.45	19.95	19.54
T_4: Coconut	11.21	10.69	0.56	0.53	20.02	20.18
T_5: Grape	10.00	7.93	0.50	0.41	20.02	19.29
T_6: Pomegranate	9.65	8.10	0.48	0.42	20.12	19.36
T_7: Biofuel	13.10	11.55	0.66	0.58	19.86	19.92
T_8: Teak	13.45	11.72	0.67	0.59	20.07	19.87
T_9: Malbar neem	11.90	11.03	0.59	0.55	20.17	20.06
S. Em.±	0.09	0.07	0.01	0.01	0.28	0.29
C.D. (P = 0.05)	0.25	0.21	0.02	0.02	NS	NS

Total nitrogen content (g/kg)

Table 2. indicates that total nitrogen content varied significantly in both surface and subsurface soils across different ecosystems. At the surface (0-15 cm), total nitrogen ranged from 0.48 to 0.67 g/kg, with the highest values recorded in the teak ecosystem (0.67 g/kg), closely followed by the biofuel ecosystem (0.66 g/kg), then mango (0.61 g/kg), malabar neem (0.59 g/kg), coconut (0.56 g/kg), sapota (0.53 g/kg), guava (0.51 g/kg), and grape (0.50 g/kg). The lowest total nitrogen was found in the pomegranate ecosystem (0.48 g/kg). In the subsurface layer (15-30 cm), teak again showed the highest total nitrogen content (0.59 g/kg), similar to biofuel (0.58 g/kg), followed by malabar neem (0.55 g/kg), coconut (0.53 g/kg), mango (0.52 g/kg), while guava, pomegranate, and sapota ecosystems recorded 0.42 g/kg each, and the lowest was observed in grape ecosystem (0.41 g/kg). The elevated nitrogen levels in teak, biofuel, and mango ecosystems are likely linked to their higher organic carbon content, which promotes greater microbial activity and faster decomposition of organic matter. Wang *et al.* (2012) [40] emphasized that total nitrogen and soil pH strongly influence soil organic carbon levels, highlighting the interrelationship between SOC and total nitrogen (Brar *et al.*, 2013) [6]. Additionally, surface soils consistently exhibited higher total nitrogen compared to subsurface layers, which aligns with findings by Bhavya *et al.* (2018) [5].

C:N ratio

The C:N ratio did not differ significantly at both surface and subsurface soils (Table 2) and the C:N ratio was recorded in the range of 19.29 - 20.18.

Primary nutrients

Available nitrogen (kg/ha)

Table 3 presents data on available nitrogen in the rhizosphere soil across different treatments and soil depths, showing significant variation. At the surface layer (0-15 cm), the highest available nitrogen was recorded in the teak ecosystem (201.01 kg/ha), closely followed by the biofuel ecosystem (200.15 kg/ha), then mango (192.64 kg/ha), malabar neem (189.56 kg/ha), and coconut and sapota ecosystems with about 188.68 kg/ha each. Lower available nitrogen was observed in guava (173.49 kg/ha), grape (166.32 kg/ha), and pomegranate ecosystems (165.03 kg/ha). In the subsurface layer (15-30 cm), teak again had the highest available nitrogen (152.68 kg/ha), comparable to biofuel (149.96 kg/ha), followed by malabar neem (144.47 kg/ha), coconut (144.43 kg/ha), and mango (144.38 kg/ha). The lowest values were noted in guava (139.43 kg/ha), sapota (130.61 kg/ha), pomegranate (121.84 kg/ha), and grape ecosystems (121.06 kg/ha). Available nitrogen content ranged from 165.03 to 201.01 kg/ha at the surface and 121.06 to 152.68 kg/ha at the subsurface, showing a clear decline with soil depth, consistent with Hartemink (2006) [11]. The higher nitrogen levels in soils under deciduous tree plantations, such as teak, are likely due to leaf fall during winter, which enriches soil nitrogen. Parthiban and Rai (1994) [26] also reported that among seven tree species studied, teak had the highest available nitrogen at 0-15 cm depth, while pomegranate recorded the lowest, possibly due to differences in soil organic carbon content and ongoing mineralization in surface soils.

Available phosphorus (kg/ha)

Table 3 presents data on soil available phosphorus across different treatments, showing significant variation at both surface (0-15 cm) and subsurface (15-30 cm) soil depths. At the surface level, the highest available phosphorus was recorded in the guava ecosystem (66.17 kg/ha), followed by pomegranate (62.47 kg/ha), mango (59.70 kg/ha), biofuel (57.96 kg/ha), teak (54.33 kg/ha), sapota (53.05 kg/ha), coconut (51.28 kg/ha), and malabar neem (47.25 kg/ha) ecosystems. The lowest phosphorus content was found in the grape ecosystem (44.24 kg/ha). Similarly, in the subsurface soil, guava again showed the highest phosphorus level (57.89 kg/ha), followed by biofuel (54.04 kg/ha), pomegranate (52.81 kg/ha), mango (50.73 kg/ha), teak (46.63 kg/ha), coconut (45.22 kg/ha), sapota (43.79 kg/ha), and malabar neem (43.69 kg/ha), while the grape ecosystem had the lowest (40.71 kg/ha). The available phosphorus content across these ecosystems ranged from medium to moderately high levels (40.71-66.17 kg/ha), with higher concentrations consistently found in surface soils, likely due to greater organic carbon content. These findings align with Gardini *et al.* (2015). The elevated phosphorus levels in the pomegranate ecosystem may be attributed to the continuous application of both organic and inorganic phosphatic fertilizers, as supported by the studies of Dhaliwal *et al.* (2008) [7] and partially by Kumar *et al.* (2006) [15].

Table 3: Available nitrogen, phosphorous and potassium in surface and sub-surface soil as influenced by different land use ecosystem

Treatment	Available N (kg/ha)		Available P_2O_5 (kg/ha)		Available K_2O (kg/ha)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1: Mango	192.64	144.38	59.70	50.73	314.64	323.05
T_2: Sapota	188.69	130.61	53.05	43.79	310.13	318.00
T_3: Guava	173.49	139.43	66.17	57.89	306.93	315.86
T_4: Coconut	188.69	144.43	51.28	45.22	308.82	317.01
T_5: Grape	166.32	121.06	44.24	40.71	305.32	312.07
T_6: Pomegranate	165.03	121.84	62.47	52.81	304.31	308.58
T_7: Biofuel	200.15	149.96	57.96	54.04	316.85	329.90
T_8: Teak	201.01	152.68	54.33	46.63	326.09	352.73
T_9: Malbar neem	189.56	144.47	47.25	43.69	310.16	319.17
S.Em.±	2.09	2.06	0.57	0.49	3.33	3.17
C.D. (P = 0.05)	6.10	6.01	1.66	1.42	9.71	9.26

Available potassium (kg/ha)

Table 3 shows that available potassium varied significantly across different ecosystems in both surface (0-15 cm) and subsurface (15-30 cm) soils. At the surface level, the highest potassium content was found in the teak ecosystem (326.09 kg/ha), closely followed by the biofuel ecosystem (316.85 kg/ha), mango (314.64 kg/ha), malabar neem (310.16 kg/ha), sapota (310.13 kg/ha), coconut (308.82 kg/ha), guava (306.93 kg/ha), and grape ecosystems (305.32 kg/ha), with the lowest available potassium recorded in the pomegranate ecosystem (304.31 kg/ha). In the subsurface soil, teak again exhibited the highest potassium level (352.73 kg/ha), followed by biofuel (329.90 kg/ha), mango (323.05 kg/ha), malabar neem (319.17 kg/ha), sapota (318.00 kg/ha), coconut (317.01 kg/ha), guava (315.86 kg/ha), and grape (312.07 kg/ha), while the pomegranate ecosystem showed the lowest value (308.58 kg/ha). The higher potassium concentration in the subsurface layer is likely due to greater kaolinite clay content at deeper soil depths, consistent with findings by Ram *et al*. (2015) [29]. The forest ecosystems, particularly teak, showed significantly greater available potassium, which may be attributed to the abundant organic matter supplied through leaf litter decomposition. This is supported by Ashoka (1998) [3], who reported higher nutrient availability, including potassium, in both surface and subsurface soils under forest tree species. Similar observations were made by Kenjale *et al*. (1994) [14] in the Konkan region of Maharashtra, where nutrient recycling by forest species resulted in notably higher potassium levels compared to barren soils.

Secondary nutrients

Exchangeable calcium and magnesium [c mol (p^+) kg^{-1}]

Table 4 presents the statistical analysis of exchangeable calcium and magnesium across different ecosystems, showing significant variation at both surface and sub-surface soil depths. At the surface layer (0-15 cm), the highest exchangeable calcium was recorded in the mango ecosystem (21.02 c mol (p+) kg^{-1}), followed by guava (18.10), sapota (16.96), teak (15.91), malabar neem (14.76), pomegranate (14.52), and grape (14.33) ecosystems. The lowest values were observed in the coconut (10.97) and biofuel (12.69) ecosystems. In the sub-surface soil (15-30 cm), exchangeable calcium ranged from 8.69 to 16.78 c mol (p+) kg^{-1}, with mango again showing the highest concentration (16.78), followed by sapota (14.91), guava (14.68), teak (14.13), pomegranate (13.88), grape (13.69), and biofuel (11.79) ecosystems, while the coconut ecosystem had the lowest value (8.69). Similarly, exchangeable magnesium showed significant differences among treatments. At the surface, mango had the highest exchangeable magnesium (5.10 c mol (p+) kg^{-1}), followed by sapota (4.98), teak (4.29), pomegranate (4.26), guava (4.19), malabar neem (3.85), grape (3.13), and biofuel (2.21), with coconut recording the lowest (2.00). In subsurface soil, mango (4.08) and teak (4.05) exhibited the highest magnesium levels, followed by pomegranate (3.77), guava (3.75), sapota (3.36), malabar neem (2.53), grape (2.24), coconut (1.71), and biofuel (1.61). The greater concentrations of exchangeable calcium and magnesium in the mango ecosystem can be attributed to the tree's deep-rooted nature, which enables access to these nutrients from deeper soil layers. This nutrient uptake and cycling to surface soils enhance their availability, a process akin to the "alkali pump" mechanism, where deep roots not only increase nutrient levels but also help regulate soil alkalinity, resulting in higher concentrations of these cations in mango ecosystems compared to others (Supriya *et al*., 2019) [36].

Table 4: Exchangeable calcium and magnesium and available sulphur in surface and sub-surface soil as influenced by different land use ecosystem

Treatment	Exchangeable Ca (cmol (p^+) kg^{-1})		Exchangeable Mg (cmol (p^+) kg^{-1})		Available S (mg/kg)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1: Mango	21.02	16.78	5.10	4.08	19.36	17.83
T_2: Sapota	16.96	14.91	4.98	3.36	13.40	9.20
T_3: Guava	18.10	14.68	4.19	3.75	12.06	8.95
T_4: Coconut	10.97	8.69	2.00	1.71	14.20	10.30
T_5: Grape	14.33	13.69	3.13	2.24	6.82	5.94
T_6: Pomegranate	14.52	13.88	4.26	3.77	8.99	6.99
T_7: Biofuel	12.69	11.79	2.21	1.61	21.69	20.26
T_8: Teak	15.91	14.13	4.29	4.05	23.85	21.42
T_9: Malbar neem	14.76	13.84	3.85	2.53	16.49	14.45
S. Em.±	0.32	0.31	0.10	0.06	0.46	0.86
C.D. (P = 0.05)	0.93	0.90	0.28	0.16	1.33	2.52

Available sulphur (mg/kg)

Table 4 shows that available sulphur content varied significantly between different ecosystems at both surface and sub-surface soil layers. At the surface (0-15 cm), available sulphur ranged from 6.82 to 23.85 mg/kg, with the highest level recorded in the teak ecosystem (23.85 mg/kg), followed by biofuel (21.69 mg/kg), mango (19.36 mg/kg), malabar neem (16.49 mg/kg), coconut (14.20 mg/kg), sapota (13.40 mg/kg), guava (12.06 mg/kg), and pomegranate (8.99 mg/kg) ecosystems, while the lowest was found in the grape ecosystem (6.82 mg/kg). In the sub-surface soil (15-30 cm), available sulphur ranged from 5.94 to 21.42 mg/kg, with teak again showing the highest concentration (21.42 mg/kg), similar to biofuel (20.26 mg/kg), followed by mango (17.83 mg/kg), malabar neem (14.45 mg/kg), coconut (10.30 mg/kg), sapota (9.20 mg/kg), guava (8.95 mg/kg), and pomegranate (6.99 mg/kg), with the lowest in grape ecosystem (5.94 mg/kg). Overall, available sulphur decreased with increasing soil depth, likely due to higher plant and microbial activity, organic matter mineralization, and fertilizer application concentrated near the surface. The greater sulphur content in surface soils is attributed to higher organic matter accumulation and surface fertilizer application, consistent with findings by Supriya *et al.* (2019) [36].

DTPA extractable micronutrients (Fe, Mn, Zn & Cu) status in soil

The data on DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu) in the soil under different ecosystems are summarized in Tables 5, showing significant variations at both surface (0-15 cm) and subsurface (15-30 cm) soil depths. At the surface level, the highest DTPA-extractable iron (Fe) was recorded in the teak ecosystem (4.56 ppm), closely followed by biofuel (4.23 ppm) and malabar neem (4.20 ppm), while the lowest was in the grape ecosystem (1.95 ppm). A similar trend was observed in subsurface soils, where Fe concentrations ranged from 1.32 to 3.93 ppm, with teak again showing the highest levels. For manganese (Mn), the teak ecosystem also showed significantly higher values (15.14 ppm surface, 13.59 ppm subsurface), whereas the lowest Mn levels were found in grape and sapota ecosystems, respectively. Zinc (Zn) content was highest in the grape ecosystem (1.50 ppm surface, 1.30 ppm subsurface) and lowest in the mango ecosystem (0.04 ppm surface, 0.03 ppm subsurface). Copper (Cu) concentrations were greatest in the grape ecosystem at the surface (5.51 ppm) and pomegranate ecosystem in subsurface soil (4.28 ppm), with the lowest levels recorded in guava (surface) and coconut (subsurface) ecosystems.

Overall, micronutrient concentrations followed the order Mn > Fe > Cu > Zn across most ecosystems, except in grape and pomegranate where Mn > Cu > Fe > Zn. Levels were generally lower in subsurface soils due to greater reactivity with soil organic matter. The sufficient copper and zinc levels in pomegranate and grape ecosystems are likely linked to practices such as Bordeaux mixture spraying, fertilizer and manure applications, and pesticide use, as also reported by Bhat *et al*. (2017) [4]. The availability of iron is attributed to chelation by organic compounds from decomposing organic matter, consistent with findings from Sharan *et al*. (2020) [33]. Higher iron concentrations in surface soils are explained by elevated organic carbon levels (Jagdish Prasad and Gajbhiye, 1999) [13]. Manganese content exceeded critical limits in all ecosystems and decreased with soil depth, likely due to higher organic matter in surface layers and the nature of the parent material, as noted by Mandavgade *et al*. (2015) [21].

Table 5: DTPA extractable micronutrients (Fe, Mn, Zn & Cu) in surface and sub-surface soil as influenced by different land use ecosystem

Treatment	Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1: Mango	3.22	2.54	9.80	8.59	0.04	0.03	1.85	1.15
T_2: Sapota	2.14	1.39	6.37	4.58	0.12	0.04	2.11	1.31
T_3: Guava	3.22	2.32	6.95	6.87	0.20	0.15	1.22	0.92
T_4: Coconut	3.00	2.07	6.86	6.75	0.14	0.09	1.42	0.88
T_5: Grape	1.95	1.32	6.07	5.59	1.50	1.30	5.51	4.14
T_6: Pomegranate	2.27	1.45	6.80	4.60	1.10	1.04	4.59	4.28
T_7: Biofuel	4.23	3.30	13.36	12.69	0.07	0.04	1.86	1.84
T_8: Teak	4.56	3.93	15.14	13.59	0.08	0.07	2.04	1.42
T_9: Malbar neem	4.20	2.70	11.16	9.79	0.13	0.12	1.49	1.34
S. Em.±	0.20	0.30	0.41	0.47	0.02	0.02	0.05	0.04
C.D. (P = 0.05)	0.59	0.88	1.20	1.38	0.04	0.05	0.16	0.11

Conclusion

In Northern Dry zone of Karnataka condition, coconut land use systems give higher carbon sequestration potential and total benefits than agroforestry land use systems hence need to be promoted. Whereas, in case of soil organic carbon stock, teak ecosystem has significantly higher value as compared to other ecosystems as this ecosystem has lower bulk density due less tillage less soil disturbance which accumulated the more organic carbon content in soil and hence also realized available primary, secondary and micronutrients in maximum scale. Hence to achieving (sustainable agriculture) adopting agroforestry and horticulture cropping is beneficial.

References

1. Alam MK, Islam M, Salahin N, Hasanuzzaman M. Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. Sci World J. 2014;2014(1):437283.
2. Asha SS. Impact of land use systems on nutrient and carbon distribution in soils of Thirthahalli taluk, Shivamogga district. Univ. Agril. Horti. Sci.; 2016.
3. Ashoka K. Studies on the properties of an alfisol under selected forest plantations. Uni. Agril. Sci.; 1998.
4. Bhat ZA, Akhtar FA, Padder SA, Ganale AQ, Rehman HU, Dar NA, *et al*. Nutrient status of grape orchard soils of Jammu and Kashmir, India. Moj Ecol Environ Sci. 2017;2(5):12-9.
5. Bhavya VP, Anil Kumar S, Alur A, Shivanna M, Shivakumar KM. Changes in soil physical properties as a result of different land use systems with depth. Int J Curr Microbial Appl Sci. 2018;7(1):323-7.
6. Brar B, Singh K, Dheri G. Carbon sequestration and soil carbon pools in a rice-wheat cropping system: effect of long-term use of inorganic fertilizers and organic manure. Soil Tillage Res. 2013;128:30-6.
7. Dhaliwal SS, Sharma BD, Singh B, Khera KL. Profile distribution of chemical, physical and microbial characteristics in four land use systems of Sadh Di Khad watershed in submontaneous tract of Punjab. An Asian J Soil Sci. 2008;3(2):316-22.
8. Dhole NA. Characterization, classification and evaluation of physiography of soils of Zari NAAM River watershed (Part-2) of Parbhani district by using GIS, GPS and remote sensing. Vasantrao Naik Marathwada Krishi Vidyapeeth; 2017.
9. Dhyani SK, Tripathi RS. Biomass and production of fine and coarse roots of trees under agri-silvi cultural practices in North-East India. Agrofor Syst. 2000;50(2):107-21.
10. EPA. U. S Environmental Protection Agency (EPA) Decontamination Research and Development Conference. U. S. Environmental Protection Agency; 2011.
11. Hartemink AE. Nutrient stocks, nutrient stocks, nutrient cycling, and soil changes in Cocoa ecosystems: A Review. J Plantation Crops. 2006;45(3):383-9.
12. Hesse PR. A text book of soil chemical analysis. CBS Publishing House; 1994.
13. Jagdish Prasad, Gajbhiye KS. Vertical distribution of micronutrients cations in some vertisole profiles occurring in different ecoregions. Soil Sci Soc Am J. 1999;47:153-5.
14. Kenjale RY, Chavan KN, Chavan AS. Recycling of nutrient elements by some forest tree species of Konkan in Maharashtra. Van Vigyan. 1994;32(1-2):7-14.
15. Kumar P, Verman TS, Sharma PK. Effect of land uses on relationship between organic carbon and available nutrients in dry temperate zone of Himachal Pradesh. J Indian Soc Soil Sci. 2006;54(4):485-8.
16. Kumar S, Ghosh S, Paul J, Sahoo SK. Effect of inorganic and integrated nutrient management on soil carbon and nutrient status in Mollisols. J Pharmac Phytochem. 2019;8(5):1998-2003.
17. Leblanc HA, Russo RO. Carbon sequestration in an oil palm crop system (*Elaeis guineensis*) in the Caribbean lowlands of Costa Rica. Proc Fla State Hort Soc. 2008;121(5):52-4.
18. Lindsay WL, Norwell WA. Development of a DTPA soil test for Zn, Fe, Mn and Cu. Soil Sci Soc Amer J. 1978;42:421-8.
19. Liu X, Yang T, Wang Q, Huang F, Li L. Dynamics of soil carbon and nitrogen stocks after afforestation in arid and semi-arid regions: A meta-analysis. Sci Total Environ. 2018;618:1658-64.

20. Maheswarappa HP, Kumari PA, Kamalakshiamma PG, Shanavas M. Influence of integrated nutrient management and high-density multi-species cropping system on soil properties, plant nutrition and yield in root (wilt) affected coconut palms. Cord. 2005;21(02):34-4.
21. Mandavgade RR, Waikar SL, Dhamak AL, Patil VD. Evaluation of micronutrient status of soils and their relation with some chemical properties of soils of Northern tahsils (Jintur, Selu and Pathri) of Parbhani district. J Agri Vet Sci. 2015;8(2):38-41.
22. Marriott EE, Michelle MW. Total and labile soil organic matter in organic and conventional farming systems. Soil Sci Soc Am J. 2006;70:950-9.
23. Mutuo PK, Cadisch G, Albrecht A, Palm CA, Verchot L. Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. Nutr Cycling Agroecosyst. 2005;71:43-54.
24. Nagaraja MS, Bharadwaj AK, Reddy GVP, Parama VRR, Kaphaliya B. Soil carbon stocks in natural and manmade agri-horti-silvipastural land use systems in dry zones of Southern India. J Soil Water Cons. 2016;13:258-64.
25. Nair KKN, Mohanan C, Mathew G. Plantation technology for selected indigenous trees in the Indian peninsula. Bioset Forets des Tropiques. 2005;285:17-23.
26. Parthiban KT, Rai V. Trees on farm lands-their effects on soil fertility. Van Vigyan. 1994;32:7-14.
27. Patil RB, Jagdish P. Characterization and classification of some sal (*Shorea robusta*) supporting soils in Dindori district of Madhya Pradesh. J Indian Soc Soil Sci. 2004;52(2):119-25.
28. Qin Z, Dunn JB, Kwon H, Mueller S, Wander MM. Soil carbon sequestration and land use change associated with biofuel production: empirical evidence. Gcb Bioenergy. 2016;8(1):66-80.
29. Ram SS, Dipesh R, Upendra B, Lekhendra T, Ranjan A, Suthma D, *et al*. Physico-chemical characteristics of soil along an altitudinal gradient at southern aspect of Shivapuri Nagarjun National Park, Central Nepal. Int Res J Earth Sci. 2015;3(2):1-6.
30. Rudrappa LT, Purakayastha J, Dhyan Singh S, Bhadraray. Longterm manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid sub-tropical India. Soil Tillage Res. 2005;88:180-92.
31. Sa JCM, Lal R. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. Soil Till Res. 2009;103:46-56.
32. Scotti R, Bonanomi G, Scelza R, Zoina A, Rao MA. Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. J Soil Sci Plant Nutr. 2015;15(2):333-52.
33. Sharan BR, Nagaraja MS, Mallesha BC, Kadalli GG. Enzyme activities at varied soil organic carbon gradients under different land use systems of Hassan district in Karnataka, India. Int J Curr Microbiol Appl Sci. 2020;9(3):1739-45.
34. Sreejesh KK, Thomas TP, Rugmini P, Prasanth KM, Kripa PK. Carbon sequestration potential of teak (*Tectona grandis*) plantations in Kerala. Res J Recent Sci. 2013;2:167-70.
35. Subbaiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:259-60.
36. Supriya K, Naidu MVS, Kavitha P, Reddy MS. Characterization classification and evaluation of soils in semi-arid region of Mahanandi mandal in Kurnool district of Andhra Pradesh. J Indian Soc Soil Sci. 2019;67(2):125-36.
37. Tejada M, Garcia C, Gonzalez JL, Hernadez MT. Use of organic amendments as strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. Soil Biol Biochem. 2008;38:1413-21.
38. Vinayak KK. Evalation of soil fertility status under different nutrient management practices in arecanut and blackpepper cropping system of Uttara Kannada district [M. Sc. (Horti.) Thesis]. Univ. Horti. Sci.; 2022.
39. Walkley AJ, Black CA. An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37:29-38.
40. Wang S, Liang X, Luo Q, Fan F, Chen Y, Li Z, *et al*. Fertilization increases paddy soil organic carbon density. J Zhejiang Univ Sci. 2012;13:274-82.
41. Yang X, Ren W, Sun B, Zhang S. Efects of contrasting soil management regimes on total and labile soil organic carbon fractions in a loess soil in China. Geoderma. 2012;177:49-56.