**Soil Organic Carbon Stock in Various Block Plantation Systems: A Case Study from Navsari, South Gujarat, India**

**ABSTRACT:** The study was carried out to assessment the concentration and stock of soil organic carbon (SOC) across nine different types of block plantation systems with randomized block design in three replication in South Gujarat, India. Soil samples at different depths (0–10, 10–20 and 20–30 cm) were collected from each of the block plantation under study to estimate SOC content in the laboratory. Thus, bulk density of soil ranged was from 1.28 to 1.42 Mg/m3 in different depth of soil under block plantation land use systems. Perusal of the plantation of trees data indicate that the available soil organic carbon was found highest (AP; 0.88%) in *A. procera*, which was at par with tree plantation of *T. grandis* (TG; 0.86%), *T. arjuna* (TA; 0.82%), *D. latifolia* (DL; 0.82%) and *M. indica* (MI; 0.81%), *M. achras* (MA; 0.80%). While it was lowest in Eucalyptus clones (EC; 0.77%) respectively. In addition,find out the depth of soil increased the bulk density. From the investigation of this research paper we concluded the top soil surface layer (0-10 cm) showed maximum soil organic carbon concentration.

***Keywords*:** Block plantation, soil organic carbon, bulk density, depth of soil, tree spacing.

**1. INTRODUCTION:** Soil plays a crucial role in the global carbon cycle due to its active carbon pool (Prentice, *et. al.* 2001). In plantation ecosystems, soil is the largest carbon sink, storing over three times the carbon present in the atmosphere and 3.8 times more than the biotic pool (Zomer, *et al.* 2003). As a result, significant carbon sequestration in soils offers a promising opportunity to mitigate global warming (Singh, *et al.* 2011). Improving the capture and storage of atmospheric CO2 across different land use systems can effectively reduce its concentration while enhancing soil quality (Babalola *et al.* 2024). Taking into account the C present in the top three-meter soil, C stored in soil is second to the amount of C present in the ocean (38400 ± 2.3 Pg), and about 1500 Pg SOC is stored in the top 1-meter soil, out of which 41% (615 Pg) SOC is trapped in the top 20 cm and ~70% (1050 Pg) SOC in the top 40 cm and it is about 1.3 times higher than that present in the atmosphere (800 Pg) (Babu *et al.,* 2020). Thus, terrestrial carbon present in the top 40 cm soil has great significance in the global C cycle, given that a minor change in SOC has a significant impact on the atmospheric CO2. The amount of SOC can increase or decrease based on various factors such as soil type, climate, topography, and land management practices. However, vegetation has a significant impact on SOC through organic matter input, making land use change a key factor in influencing SOC storage.In natural ecosystems like forests and agroforestry, soils experience minimal disturbance due to fewer cultivation practices, resulting in higher nutrient content and a diverse microbial community compared to agricultural lands. A study from Northeast India found that dense forests had the highest soil organic carbon (SOC) stock at 140.4 Tg, while shifting cultivation had the lowest at 10.7 Tg. The total SOC stock across an area of 10.10 million hectares was 339.82 Tg, with forest soils contributing more than 50%, highlighting the potential for SOC sequestration in the region (Choudhury, *et al.* 2013). Soil carbon sequestration plays a crucial role in maintaining soil health and crop productivity, aiding in climate change mitigation, and enhancing soil physical properties by improving moisture and nutrient retention. However, deforestation and land use changes that remove biomass can accelerate soil erosion, leading to substantial SOC loss from surface soils. Estimating SOC stock across different block plantation land use systems is vital for developing sustainable land management strategies and preventing SOC depletion. Therefore, this study was conducted to estimate SOC stock in various land uses and assess the relationship between SOC and land use systems in South Gujarat condition.

**2. MATERIALS AND METHODS:**

**2.1 Study site:** Geographically, Navsari is situated at 20.95o North latitude, 75.90o East longitude and at an altitude of 12.0 meters above mean sea level (MSL) (Fig.1). According to agro-climatic condition, Navsari is placed in South Gujarat heavy rainfall zone-I (Agro-ecological situation-III). The College instructional farm is located 12 km away in the east from the Arabian Seashore, Dandi. This region belongs to tropical climate characterized by fairly hot summer, moderately cold winter and more humid and warm monsoon with heavy rain. The average annual precipitation is 1355 mm. The soil of the experimental site is dark grayish brown type with flat topography. The soil is characterized by medium to poor drainage and good water holding capacity. The predominant clay mineral is montmorillonite. The present investigation was carried out in Navsari district of Gujarat by choosing Nine tree plantation Sapota-*Manilkaraachras* L. (MA), Mango- *Mangifera indica* L. (MI), Teak-*Tectonagrandis*L.f. (TG), Killai- *Albizzia procera* (Roxb.)Benth. (AP), Eucalyptus- *Eucalyptus clones* (EC), Casuarina- *Casuarina equisetifolia*L.ex J.R.&C.Fraser (CE), Shisham- *Dalbergialatifolia*Roxb. (DL), Jatropha- *Jatropha curcas*L.,(JC) and Arjun- *Terminalia arjuna* (Roxb.ex DC.) Wight & Arn. were selected for comparison their soil organic carbon potential.Table 1;showed the detail of block plantation with 3 replication, number of tree/hectare, were taken for observations.

**2.2 Procedure of soil sample collection and preparation:**

From the different land use system, soil were collected from different soil depth such as-0-10 cm, 10-20 cm, 20-30 cm in triplicates. The composite soil samples for each depth were obtained by mixing three samples. For analysis of soil physio-chemical, sample were air dried in shade, ground with wooden pestle, passed through 2 mm sieve and stored in cloth bags (Walkley and Black, 1934).

**Table 1: Details of different block plantation land use systems.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no** | **Block plantation Land use systems** | **Tree spacing (m)** | **Planting Year** | **No of trees (Per hectare)** |
| 1 | Sapota- *Manilkara achras* L. (MA),  | 8 x8 | 1994 | 156 |
| 2 | Mango- *Mangifera indica* L. (MI) | 8 x8 | 1990 | 156 |
| 3 | Teak-*Tectona grandis* L.f. (TG),  | 3 x3 | 1990 | 1111 |
| 4 | Killai- *Albizzia procera* (Roxb.) Benth. (AP) | 3 x3 | 1995 | 1111 |
| 5 | Eucalyptus- *Eucalyptus clones* (EC),  | 2 x2 | 2009 | 2500 |
| 6 | Casuarina- *Casuarina equisetifolia* L. ex J.R. & C. Fraser (CE),  | 2x 2 | 2009 | 2500 |
| 7 | Shisham- *Dalbergia latifolia*Roxb. (DL),  | 3 x 3 | 1991 | 1111 |
| 8 | Jatropha- *Jatropha curcas* L.,(JC)  | 2 x 2 | 2006 | 2500 |
| 9 | Arjun- *Terminalia arjuna* (Roxb.ex DC.) Wight & Arn. (TA)  | 4 x 4 | 1990 | 400 |

The samples were air dried and usedfor determining organic carbon. Soil bulk density was measured by core method(Allen *et al*., 1974). Soil OC stock (Mg/ha) at different soil depths in different agroforestry systems werecalculated using the formula given by Nelson and Sommers (1996):

**SOC stock (Mg/ha1) = SOC (%) × bulk density (Mg/m3) ×soil depth (m) × 100**

**2.3 Data analysis:** The experimental data were subjected to the statistical analysis as per the procedure suggested by Gomez and Gomez (1984). The treatment differences were tested by ‘F’ test of significance based on null hypothesis. The appropriate standard error (S.Em.±) was calculated in each case and critical difference (C.D.) at 5 percent level of probability was worked out to compare the treatment means, where the treatment effects were significant.

**3. RESULTS AND DISCUSSION:**

**3.1 Bulk density:** The bulk density (BD) of fine soil (<2 mm) across different land use types and varying soil depths ranged from 1.28 to 1.42 Mg/m3 (Figure 2). On average, the bulk density in the 0–30 cm soil profile was lowest in *Albizzia procera* (Roxb.) Benth. (AP, 1.28 Mg/m3) block plantation and highest in *Manilkara achras* L. (MA, 1.42 Mg/m3). The relatively higher soil bulk density observed in *Terminalia arjuna* (TA) and *Jatropha curcas* L. (JC) compared to other land uses, may be attributed to cultivation practices such as tillage, which can lead to soil compaction. The significant differences across soil depth were observed with upper soil depth (0-10 cm) had lesser bulk density than lower soil depth (10-20 cm & 20-30 cm). Bulk density increased with soil depth and minimum value was observed under the *Albizzia procera* (Roxb.) Benth. (AP, 1.28 Mg/m3) block plantation land use systems. Numerous studies have suggested that as soil depth increases, the bulk density tends to rise as well. In this context, the soil bulk density across all the land use types examined was consistently found to be well below the critical threshold, indicating the absence of severe soil compaction.The bulk density increased as the depth of soil sampling increased. Plantation of trees under different land use systems directly correlated to soil bulk density level decreasing due to the more organic matter which leads to better soil structure and hence more porosity of soil. Halvorson *et al*. (2002), Baruah & Barthakur, (1997) also reported the bulk density inversely related to tillage intensity. Christine, 2006 supported the finding of tree component increased the area for tillage decreases and decrease in bulk density with increase in soil depth.

**3.2 Soil organic carbon:** The mean data regarding variation in soil organic carbon under different block Plantation land use systems are presented in Fig.3. Soil organic carbon content of different soil samples (depth) collected from different block plantation land use system was compared in the study for the soil organic carbon was found amongst the systems, the top 0-10 cm soil depth in to be highest in *A. procera* (AP; 0.88%), which was at par with tree plantation of *T. grandis* (TG; 0.86%), *T. arjuna* (TA; 0.82%), *D. latifolia* (DL; 0.82%) and *M. indica* (MI; 0.81%), *M. achras* (MA; 0.80%). While it was lowest in Eucalyptus clones (EC; 0.77%) respectively. In the second sub surface depth (10-20 cm & 20-30 cm), the results showed similar trends as observed in upper surface layer (0-10 cm). It was also observed that upper layer of soil (0-10 cm) exhibited significantly higher soil organic carbon percentage compare to the lower depth in all land use systems. The variation in soil organic carbon might be due to variations in tree species composition (Singh, *et al.* 2018). This may happen because of enhanced stock of leaf litter in the tree based land use systems. The abundant leaf litter or pruned biomass returns to soil, combined with decay of roots contribute to the improvement of organic matter under complex land use systems (Kumar *et al*. 2001 and Bhalawe *et. al.* 2013).

**Fig 2:** Soil Bulk density (%) under block plantation systems in South Gujarat condition.

**Fig. 3:** Soil organic carbon properties under different block plantation land use systems in South Gujarat condition

Our findings are also supported by Tandel (2003). From the agroforestry land use system combined crops and trees practices shows that maximum ( 0.76%) available soil organic carbon in (RTG) *O.sativa* grown with *T.grandis,* which was at par with *M.paradisiaca* grown with *T.grandis* (BTG;0.70%) and *S.officinarum* grown with *C.equisetifolia* (SCE;0.69%), respectively (Bhalawe *et al.* 2024). This may be due to abundant tree leaf litter biomass returns to soil, combined with decay of roots contribute to the improvement of organic matter. Similar observations were recorded by Pandey *et al.* (2000) in *Acacia nilotica* based agroforestry systems and opined that tree canopy contribute toward nutrient conservation, soil amelioration and nutrient availability.

**Table 2: Different block plantation land use systems and soil depth on soil organic carbon stock (t/ha).**

|  |  |  |  |
| --- | --- | --- | --- |
| S.no. | **Land use systems** | **Soil depth (cm)** | **Average** |
| **( 0-10)** | **( 10-20)** | **( 20-30)** |
| a | Sapota-*Manilkaraachras* L. (MA),  | 14.10 | 11.95 | 9.80 | 11.95 |
| b | Mango- *Mangifera indica* L. (MI) | 14.88 | 12.64 | 10.20 | 12.57 |
| c | Teak-*Tectonagrandis*L.f. (TG),  | 17.42 | 14.50 | 12.80 | 14.91 |
| d | Killai- *Albizzia procera* (Roxb.)Benth. (AP) | 18.5 | 17.20 | 16.35 | 17.35 |
| e | Eucalyptus- *Eucalyptus clones* (EC),  | 11.50 | 10.45 | 9.20 | 10.38 |
| f | Casuarina- *Casuarina equisetifolia*L.ex J.R.&C.Fraser (CE),  | 12.98 | 11.10 | 9.50 | 11.19 |
| g | Shisham- *Dalbergialatifolia*Roxb. (DL),  | 15.95 | 13.60 | 11.20 | 13.58 |
| h | Jatropha- *Jatropha curcas* L.,(JC)  | 13.50 | 11.40 | 10.10 | 11.67 |
| i | Arjun- *Terminalia arjuna* (Roxb.ex DC.) Wight & Arn. (TA)  | 16.10 | 13.64 | 12.10 | 13.95 |

Note: CD (p=0.05), land use-1.62, soil depth-0.65, interactions: land use x soil depth 1---n  -1.84, soil depth x land use 1---n  -2.24

**3.3 Soil organic carbon stock:** Soil organic carbon stock decreased with increase in soil depth, signifying the importance of upper layer in storing soil organic carbon Table 2. Similarly the highest average soil carbon stock was 17.35 t/ha in block plantation land use systems of *Albizzia procera* (AP), which was followed by block plantation land use systems  *Tectona grandis* (TG), *Terminalia arjuna* (TA), *Dalbergia latifolia* (DL) and least in *Eucalyptus clones* (EC;10.38 t/ha) due to the increased dead matter accumulation, longer rooting residency, belong to leguminous family nature and a significant amount of undisturbed biomass. Similar supportive result given by Odebiri *et al.* 2020 & Keenan *et al.* 2015). The upper soil layer (0-10cm) of *Albizzia procera* stored (AP; 18.50 t/ha) maximum soil organic carbon stock, which was at par with *Tectona grandis* (TG; 17.42 t/ha),*Terminalia arjuna* (TA; 16.10 t/ha), *Dalbergia latifolia* (DL; 15.95 t/ha)and least in *Eucalyptus clones* (EC;11.50 t/ha). In the sub-layer of soil profile (depth) found similar trend with top layer (0-10 cm). It was observed that the top soil layer (0-10 cm) depth showed significantly highest soil organic carbon stock compared to lower layer of soil depth (10-20 cm & 20-30 cm). Higher the soil organic carbon in tree plantation land use systems is due to the return of more organic matter to the soil in the form of leaves, bark, fruits and flowers. The study of different land use systems are conformity with the results obtained by Ladegaard *et al.* 2005, Singh *et al.* 2018 and Jha *et al.* 2003 reported the soil organic carbon stocks differed significantly among tree species.

**Fig 4:** Relation between bulk density (BD) and soil organic carbon (SOC%) under different block plantation land use systems

**Correlation regression between soil organic carbon and bulk density:** Soil organic carbon (SOC) and soil bulk density (BD) are two important soil properties that are closely related. Soil organic carbon and bulk density are typically negatively correlated, meaning that BD increase, SOC tends to decrease due to the greater soil compaction which can lead to reduced soil aeration and water infiltration, making it less favorable for organic matter accumulation and limit root growth and microbial activity (Fig 4). Similar result reported by Raju singh *et al.* (2019), Baishyand Sharma (2017), Kalita *et al.* (2016) and Das (2014).

**4. CONCLUSION:** In conclusion, the study on soil organic carbon stock in different block plantation land use systems under South Gujarat conditions provides valuable insights into the impact of plantation practices on soil health. Among the studied block plantation systems, those dominated by native species such as *Albizzia procera* (AP), *Tectonagrandis* (TG) *and Terminalia arjuna* (TA) tended to accumulate more SOC than those with exotic species *Eucalyptus clone* (EC) as well as old block plantation and those with minimal disturbance (e.g. reduced tillage, no fertilizers) generally showed higher SOC stocks than younger plantation or those with more intensive management. Soil organic carbons were negatively correlated with soil bulk density.Additionally the study areas subtropical climate with distinct wet and dry seasons, likely influenced SOC dynamics.

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**REFERENCES:**

Prentice, I.C., Farquhar, G.D., & Fasham, M.J.R. (2001) The carbon cycle and atmospheric carbon dioxide. In: Houghton JT, Ding Y, Griggs DJ, *et al.* (eds) Climate Change 2001: The scientific basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, 183–237.

Zomer, R., Ustin, S., & Ives, J. (2003) Using satellite remote sensing for DEM extraction in complex mountainous terrain: Landscape analysis of the Makalu Barun National Park of eastern Nepal*.* Int J Remote Sens, 23, 125–143.

Singh, S.K., Pandey, C.V., & Sidhu, G.S. (2011) Concentration and stock of carbon in the soils affected by land uses, soil types and climates in the western Himalaya, India. Catena, 87, 78–89.

Babalola, T.S., Omoju, O.J., Fasina, A.S., & Ajayi, S.O. (2024) Soil carbon sequestration in different land use types. Int.J.Plant Soil Sci*.,* 36(12), 16-25.

Babu, S., Singh, R., Awasthe, R.K., Yadav, G.S., Mohapatra, K.P., Selvan, T., Das, A., Singh, V.K., Valente, D., & Petrosillo, I. (2020). Soil carbon dynamics in India Himalayan intensified organic rice-based cropping sequences. Ecological Indicators, 114, 106292.

Choudhury, B.U., Mohapatra, K.P., & Das, A. (2013) Spatial variability in distribution of organic carbon stocks in the soils of North East India. Curr Sci, 104, 604–614.

Walkley, A., & Black, I. A.(1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci., 63, 251-263.

Allen, S. E., Grimshaw, H.M., Parkinson, J. A., & Quarnby, C. (1974). Chemical Analysis of Ecological Materials. Blackwell Scientific, Oxford. pp. 1- 565.

Nelson, D. W., & Sommers. L. E. (1996). Total carbon,organic carbon, and organic matter. In: D.L Sparks(eds). Methods of Soil Analysis. Part 3. ChemicalMethods. SSSA Book Series No. 5, SSSA and ASA,Madison, WI. pp. 961-1010.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedure for agriculture Research (2nd ed.), Johan Willey and Sons, Inc. New York. 680 p.

Halvorson, Ardell D., Brian, J., & Wienhold, Black A.L.(2002).Tillage, Nitrogen, and Cropping System Effects on Soil Carbon Sequestration. Soil Science Society of America Journal*,* 66, 906-912.

Baruah, T.C., & Barthakur, H.P. (1997). A text Book Of Soil Analysis, Vikas Publishing house PVT LTD, New Delhi.

Christine, J. (2006). YLAD Living Soils Seminars: Eu-rongilly - 14 February, Young - 15 February.

Singh, M., Gupta, B., & Das, S.K. (2018) Soil organic carbon density under different agroforestry systems along as elevation gradient in north-western Himalaya. Range Management and Agroforestry, 39, 8-13.

Kumar, B. M., George, S. J., & Suresh, T. K.(2001) Fodder grass productivity and soil fertility changes under four grass + tree associations in Kerala, India. AgroforestrySystems, 52, 91-106.

Bhalawe, S., Nayak, D., Kukadia, M.U., & Gayakvad, P.(2013) Leaf litter decomposition pattern of trees. The Bioscan*,* 8(4), 1135-140.

Tandel, M. B. (2003). Influence of tree cover and litter fall on physic-chemical properties of soil and availability of nutrients. M.Sc. Thesis, Navsari Agricultural University, Navsari, Gujarat.

Bhalawe, S., Nayak, D., Lodhi, A.S., Thakur, R.K., Rai, S.K., & Shrivastava, A. (2024) Soil dynamics for carbon buildup in different land use systems in the south region of Gujarat, India. J. Experimental Agriculture International*,* 4(1), 77-86.

Pandey, A., Soccol, C. R., Nigam, P., Soccol, V. T., Vandenberghe, L. P. S., & Mohan, R. (2000). Biotechnological potential of agro-industrial residues. II: cassava bagasse. Bioresource Technol, 74 (1), 81-87.

Odebiri, O., Mutanga, O., Odindi, J., Peerbhhay, K., & Dovey, S. (2020) Predicting soil organic carbon stocks under commercial forest plantations in KwaZulu-Natal province, South Africa using remotely sensed data. GIScience & Remote sensing, 57 (4), 450-463.

Keenan, R.J., Reams, G.A., Achard, F., Joberto, V.D.F., Grainger, A., & Erik, L. (2015) Dynamics of Global Forest Area: Results from the FAO Global Forest Resources Assessment 2015.Forest Ecology and Management, 352, 9–20.

Ladegaard, P.P., Elberling, B., & Vesterdal, L. (2005). Soil car-bon stocks, mineralization rates, and CO2 effluxes under 10 tree species on contrasting soil types. Canadian Journal of Forest Research, 35(6), 1277-1284.

Singh, M., Gupta, B., & Das, S. K. (2018). Soil organic carbon density under different agroforestry systems along an elevation gradient in north-western Himalaya. Range Management and Agroforestry, 39, 8-13.

Jha, M.N., Gupta, M.K., Saxena, A., & Kumar, R. (2003). Soilorganic carbon store in different forests of India. Indian Forester, 129(6), 714-724.

Raju, S.N., Arunachalam, A., & Peetambari, D.N. (2019) Soil organic carbon stocks in different agroforestry systems of south Gujarat. Range Mgmt. &Aroforestry, 40(1), 89-93.

Baishya, J., & Sharma, S. (2017) Analysis of Physico-Chemical Properties of Soil under Different Land Use System with Special Reference to Agro Ecosystem in Dimoria Development Block of Assam, India. Int J Sci Res Educ, 5, 6526–6532.

Kalita, R. M., Das, A. K., & Nath, A. J. (2016). Assessmentof soil organic carbon stock under tea agroforestrysystem in Barak valley, north-eastIndia. International Journal of Ecology and Environmental Sciences, 42, 175-182.

Das, B., & Bindi (2014) Physical and chemical analysis of soil collected from Jaismand. UniversJ Environ Res Technol, 4, 260–164.