

# Scope of horticultural land-use system in enhancing carbon sequestration in ferruginous soils of the semi-arid tropics

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**Soil exhaustion is a major concern particularly in ferruginous soils of the tropics and restoration of soil quality through management of soil organic carbon (SOC) is one of the options to combat the situation. To understand the scope of different systems to sequester organic carbon in ferruginous soils (Typic Rhodustalfs), three representative systems, viz. agriculture (40 years), horticulture (20 years) and forestry (several centuries) were selected in a contiguous area under semi-arid tropical climate. The study indicated that the quasi-equilibrium value (QEV) of SOC decreased from 1.78 to 0.68% in the first 30 cm, when the soils are used for agriculture instead of retaining them as forest. A shift from agricultural to horticultural system over 20 years increased the QEV to 0.81% indicating accumulation of SOC. The highest threshold value of SOC is observed in forest system, followed by horticultural and the lowest in agricultural system. The present study indicates that horticultural system is a better option to enhance the SOC if forestry is not feasible in these ferruginous soils.**

**Keywords:** Carbon sequestration, ferruginous soils, land-use systems, semi-arid tropics.

SOIL exhaustion is a major concern, particularly in ferruginous soils of the tropics because of their inherent low fertility and intensive use for crop production. Apart from importance in crop production, the accelerated decomposition of soil organic carbon (SOC) due to agriculture resulting in the loss of carbon to the atmosphere and its contribution to the greenhouse effects is a serious global problem. The contribution of SOC to physical, chemical and biological properties of soils in sustaining their productivity has been appreciated since the dawn of civilization. Restoration of soil quality through management of SOC is one of the options to enhance soil quality. Knowledge about the variation in SOC due to changes in land use is required to restore soil quality and sustain productivity.

Several investigators have studied the effect of forest clearing and cultivation on soil properties. The amount of

SOC declines when agricultural lands are used more intensively to augment agricultural production<sup>1</sup>. Decomposition further decreases the SOC content with increased exposure of bare soil<sup>2</sup>. Thus, SOC decline is rapid within 5–25 years of forest clearing, with losses ranging from 25% to 75% in the surface soil horizons<sup>2</sup>.

The soil systems attain a quasi-equilibrium stage after accumulation of organic matter in soil and its loss over a period of time and it depends upon the prevailing land use system. After each change in land-use system, the soil system acquires a new quasi-equilibrium level of SOC over a period of time depending on the vegetation cover and management practice. Thus, SOC levels show tooth like cycles of accumulation and loss<sup>3</sup>. A period of constant land-use management is required to reach a new quasi-equilibrium value (QEV) which is a characteristic representative of the new land use, vegetation cover, management practice, climate and soil. Under natural vegetation, SOC values tend to attain QEV in 500–1000 years in a forest system of the tropics<sup>4,5</sup> and 30–50 years in agricultural systems after forest clearing<sup>6,7</sup>. In ferruginous soils of Orissa (eastern India) under sub-humid condition<sup>8</sup>, a new QEV is reached in 5–15 years in an agricultural system after deforestation. Naitam and Bhattacharyya<sup>9</sup> reported that quasi-equilibrium values of 0.7% and 0.8% SOC were attained in cracking clay soils under horticulture and forest system respectively over a period of 30 years and several centuries. In agricultural system, a QEV of 0.6% SOC is attained in 25 years<sup>10</sup>. It appears that under semi-arid tropical (SAT) conditions with an enrichment of 2 : 1 expanding lattice clay minerals, the horticultural land-use system can help in sequestering higher amounts of SOC. We, therefore, investigated this point for ferruginous soils under SAT-India with mixed mineralogy class (containing considerable amount of 2 : 1 expanding and non-expanding minerals along with some amount of 1 : 1 lattice minerals) in a contiguous area in the semi-arid tropical part of India where different land-use systems have been established in similar soil types and climatic conditions over a considerable period of time. This information may help land managers to adopt land-use options that sequester more SOC in similar soil

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and climatic conditions not only in India but also elsewhere.

## Materials and methods

### General characteristics of the study area

The study area is a 80 ha research farm situated in Gunegal village, Yacharam (Mandal), Rangareddy District of Andhra Pradesh, India (17°06'03"–17°06'53"N lat. and 78°40'06"–78°40'20"E long.). This farm is managed by a Central Research Institute for Dryland Agriculture (CRIDA) under the Indian Council of Agricultural Research (ICAR), New Delhi. The geological formation of the area is dominated by granite-gneiss with sporadic exposures of granitic tors in denuded hillocks. The climate is semi-arid (dry)<sup>11</sup> with well expressed summer (March to May), rainy season (June to September) and winter (November to February). The mean annual rainfall is 764 mm of which about 85% is received during the rainy season. The general topography of the area is undulating and the fields under cultivation are bunded to protect water and soil from erosion.

### History of land use

The area was under dry deciduous forests for centuries and it was acquired by the Institute in the 1960s. During 1960, about 60% of the forest area (42 ha) was cleared for agricultural use. Locally grown crops like castor, maize and sorghum along with minor millets and pulses were cultivated in the area. During 1985, horticultural crops like guava, custard apple, citrus and mango were introduced in 11.5 ha of the previously cleared farm land. This provided an opportunity to study the soils under three adjacent land-use systems, viz. forest, general agriculture (40 years) and horticulture (20 years) for different periods. The forests lands (38 ha) are occupied by centuries-old mixed deciduous species and the area of our study was undisturbed (i.e. no agricultural or horticultural use).

The natural forest species include *Santalum album* (white sandal wood), *Abutilon indicum* (Kanghi), *Zizyphus jujuba* (ber), *Azadirachta indica* (neem), *Tectona grandis* (teak), *Ficus benghalensis* (banyan), *Ficus religiosa* (Peepal), *Cassia fistula* (Indians laburnum or amal-tas), *Cassia auriculata* (tanners) and some grass species.

The field crops are grown as rainfed kharif (monsoon crop) with 5–8 months fallow including summer. The land-use types are rainfed sorghum–castor (2-year rotation) with pearl-millets and pigeon-pea as intercrops. Topping is done in castor to extend the season and increase the total seed production. The management practice includes field bunding and ridge and furrow cultivation for soil–water conservation. Residue management includes sorghum and castor stover at 2 tonnes/ha and *Glyricidia*

lopping at 2 tonnes fresh weight/ha. Nutrient management includes application of 5 tonnes of FYM/ha followed by 20–60 kg N, 40–50 kg P<sub>2</sub>O<sub>5</sub> and 20 kg K<sub>2</sub>O/ha. N, P and K are applied as a basal dose or 2–3 equal splits at different stages of growth<sup>12,13</sup>. Management of horticultural system includes field bunds to conserve soil and water from erosion. Nutrient application includes 50 kg of FYM in each pit before planting and 300–1000 g N, 120–2000 g P<sub>2</sub>O<sub>5</sub> and 150–5000 g K<sub>2</sub>O per tree per year depending on the crop and age<sup>14</sup>.

## Methods

A detailed soil survey on 1 : 2200 scale was carried out in 2005 for the entire farm following a standard method<sup>15</sup>. Profiles were exposed and studied at frequent intervals depending upon the slope, surface erosion, surface phase and also land use. Auger bores were also studied to identify the soil boundary. A total of 40 soil profiles and 30 auger bores were studied and a detailed soil map was prepared. In total, six soil series each were identified under the agricultural and forest systems and four soil series under the horticultural system. The samples for each series were collected for laboratory characterization. The soils have been classified as Typic Rhodustalfs as per US Soil Taxonomy<sup>16</sup>.

The bulk density of the samples was determined by the field moist method using core samples (diameter 50 mm) of known volume (100 cubic cm; refs 17 and 18). Particle-size distribution was determined by the international pipette method after removal of organic matter, CaCO<sub>3</sub> and free iron oxides<sup>19</sup>. The oriented Ca- and K-saturated clays were subjected to X-ray diffraction (XRD) analysis using a Philips diffractometer with Ni-filtered Cu K $\alpha$  radiation at a scanning speed of 2°2 $\theta$ /min. Minerals were identified following the method described by Jackson<sup>19</sup> and Brown<sup>20</sup>.

Chemical properties of soils such as pH, CEC (cation exchange capacity) and extractable cations were determined by standard methods<sup>21,22</sup>. For the determination of organic carbon, the modified Walkley and Black<sup>23</sup> rapid titration procedure was followed.

### The quasi-equilibrium values of soil organic carbon

Quasi-equilibrium value (QEV) was calculated using the SOC% of the soil over different depths (0–15, 0–30, 0–50 and 0–100 cm) for each soil series under a particular land use and averaged.

$$QEV = \sum(C \times d)/D, \quad (1)$$

where *C* values refer to the SOC% under different land-use systems, viz. 40–45 years under agricultural system<sup>6,7,10</sup>, 20–30 years under horticultural system<sup>9</sup> and cen-

turies for forest systems<sup>4,5,9</sup>,  $d$  is depth of soil horizon (cm) and  $D$  the depth increment for which this is to be calculated (i.e. 30, 50, 100 cm, etc.).

Organic carbon (OC) stocks were calculated by the methods of Batjes<sup>3</sup> and Bhattacharyya *et al.*<sup>24</sup>. The first step involves calculation of OC by multiplying OC content ( $\text{gg}^{-1}$ ) with the bulk density (BD) ( $\text{Mg m}^{-3}$ ) and thickness of each horizon ( $m$ ) for individual soil series at different depths (0–15, 0–30, 0–50 and 0–100 cm).

$$\text{Total SOC stock} = \sum(C \times \text{BD} \times d) \times a, \quad (2)$$

where  $C$  is carbon (%), BD the bulk density and  $a$  the area covered by that particular soil.

The total SOC content determined by this process was again multiplied with the areal extent of that series. The SOC content thus determined was divided by the total area of that particular land-use system to get the SOC stock per unit area.

$$\text{SOC stock/unit area} = \sum(C \times \text{BD} \times d) \times a/A,$$

where  $A$  is the total area under that land-use system, i.e. 30.5, 11.5 and 38 ha for agriculture, horticultural and forest systems respectively.

## Results and discussion

For the sake of brevity, the properties of only three soil series, one from each system are detailed here for discussion.

### Morphological properties

The soils are moderately deep to deep with depth varying from 75 to 100 cm (Table 1). The colour of the soils varies from dark reddish-brown to brown with hue 2.5 YR, value 3 and chroma 4–6. The colour of the surface soil is somewhat darker with hue 5 YR probably due to intimate mixing of highly decomposed organic matter. This was more pronounced in the surface soils in the forest. The soils are well-drained with well-developed subangular blocky structure. Thin to moderately thick clay skins in the subsurface horizons were observed in all soils. The morphometric properties of all systems are similar because of their development under a similar climate and parent material.

### Physical properties

The surface soils had low clay and high sand content in all the pedons (Table 2). In the subsurface layers, clay content increased to some extent and then decreased and this trend is common in ferruginous soils of semi-arid and subhumid tropical areas of India<sup>25–28</sup>. The dominance of

fine clay ( $\approx 75\%$ ) in the total clay fractions (Table 2) indicate that much of the clay was formed in an earlier humid climate because the present semi-arid climate is not conducive for the formation of such high amounts of clay<sup>25</sup>. The bulk density of soils varies from 1.3 to  $1.6 \text{ Mg m}^{-3}$  (Table 2).

### Chemical properties

The soils are neutral to acidic (pH 5.4–7.6) and the pH has a tendency to increase with depth except in forest soils (Table 2.) The lowest pH (5.4–6.4) was observed in soils under agriculture. The low  $\Delta\text{pH}$  indicates that the soils are not at their point of zero charge and thus contain reasonable amounts of weatherable minerals.  $\text{Ca}^{2+}$  ions dominate among the extractable bases followed by Mg and K. The base saturation of all soils is  $>55\%$  and  $>90\%$  in soils under the horticultural system. Among the land-use systems, the forest soils have the highest amount of SOC (0.23–2.2%) followed by horticulture (0.12–0.95%) and agriculture (0.26–0.85%) systems (Table 2).

### Mineralogy of clay

The X-ray diffraction patterns of the soil clays from the three land-use systems are similar (Figure 1). This indicates that the substrate quality (mineralogy) of these soils was not affected by the changes in land use. The diffraction pattern indicates the presence of dominant peaks at 0.7, 1.0 and 1.4 nm. The disappearance of the 0.7 nm peak on K-saturation and heating at  $550^\circ\text{C}$  indicates the presence of kaolin. The broadening of the base of the 0.7 nm mineral, its tailing towards the low angle side and the decrease in its intensity on glycolation indicates that the 0.7 nm mineral is not a true kaolinite but interstratified with 2 : 1 mineral. This is common in ferruginous soils of India<sup>26–29</sup>. This was further confirmed by the increase in intensity of the 1.0 nm region on K-saturation and heating. The persistence of the 1.0 nm minerals throughout the treatment indicates the presence of mica. The 1.4 nm mineral on glycolation shifts entirely to the 1.7 nm region, indicating the presence of expanding minerals. On K treatment and subsequent heating, this peak shifts and reinforces the 1.0 nm region. This confirms that the 1.4 nm mineral is a smectite.

## Discussion

### Changes in soil properties due to changes in land use

Soils under the forest system were used as a control to evaluate the changes in soil properties due to land use and management interventions in the two managed systems.

## RESEARCH ARTICLES

**Table 1.** Morphological properties of soils under different land use system

| Horizon  | Depth (cm) | Munsell colour (moist) | Texture                      | Structure <sup>1</sup> | Reaction (in dil. HCl) | Other features (clay cutans) |
|--|------------|------------------------|------------------------------|------------------------|------------------------|------------------------------|
| Pedon 1: Agricultural system: Fine, mixed, iso-hyperthermic family of Typic Rhodustalfs  |            |                        |                              |                        |                        |                              |
| Ap   | 0–13       | 5 YR 4/4               | Loamy sand                   | f1 sbk                 | Nil                    | –                            |
| Bt1  | 13–35      | 2.5 YR 3/6             | Sandy clay                   | m2 sbk                 | Nil                    | Thin in patches              |
| Bt2  | 35–56      | 2.5 YR 3/6             | Sandy clay                   | m2 sbk                 | Nil                    | Thin in patches              |
| Bt3  | 56–77      | 2.5 YR 3/6             | Sandy clay                   | m2 sbk                 | Nil                    | Moderately thick in patches  |
| Cr   | 77–98+     |                        | Partially weathered material |                        | e1                     |                              |
| Pedon 2: Horticultural system: Fine, mixed, iso-hyperthermic family of Typic Rhodustalfs |            |                        |                              |                        |                        |                              |
| Ap   | 0–15       | 5 YR 3/4               | Sandy loam                   | m2 sbk                 | Nil                    | –                            |
| Bt1  | 15–45      | 2.5 YR 3/3             | Sandy clay loam              | m2 sbk                 | Nil                    | Thin patchy and broken       |
| Bt2  | 45–75      | 2.5 YR 3/3             | Clay                         | m3 sbk                 | Nil                    | Thin patchy and broken       |
| Bt3  | 75–102     | 2.5 YR 3/3             | Clay                         | c3 sbk                 | Nil                    | Thin patchy and broken       |
| Cr   | 102–115    | 5 YR 4/4R              | Partially weathered material |                        |                        | –                            |
| Pedon 3: Forest system: Fine, mixed, iso-hyperthermic family of Typic Rhodustalfs        |            |                        |                              |                        |                        |                              |
| Ap   | 0–10       | 5 YR 3/3               | Sandy loam                   | m2 sbk                 | Nil                    | –                            |
| Bt1  | 10–30      | 2.5 YR 3/4             | Sandy clay loam              | m2 sbk                 | Nil                    | Thin in patches              |
| Bt2  | 30–55      | 2.5 YR 3/4             | Clay                         | m3 sbk                 | Nil                    | Thin patchy and broken       |
| Bt3  | 55–92      | 2.5 YR 3/4             | Sandy clay loam              | c3 sbk                 | Nil                    | Thin patchy and broken       |
| Cr   | 92+        |                        | Partially weathered material |                        |                        |                              |

<sup>1</sup>f, fine; m, medium, c, coarse; 1, weak; 2, moderate; 3, strong; sbk, sub-angular blocky.

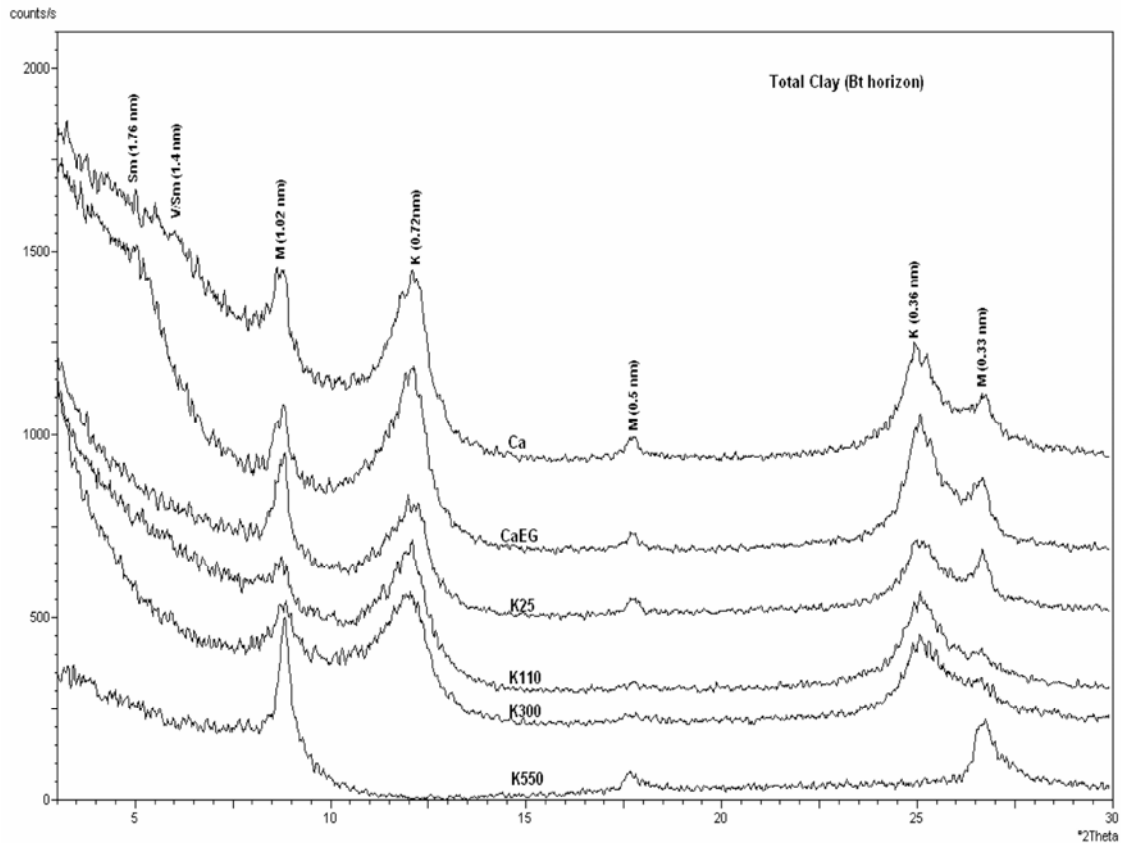
**Table 2.** Selected physical and chemical properties of the soils

| Horizon                       | Depth (cm) | Particle size (%) |               |                      |                    | Bulk density (Mg m <sup>-3</sup> ) | pH               |     |      | OC (%) |
|-------------------------------|------------|-------------------|---------------|----------------------|--------------------|------------------------------------|------------------|-----|------|--------|
|                               |            | Sand (50–2000 µ)  | Silt (50–2 µ) | Total clay (2–0.2 µ) | Fine clay (<0.2 µ) |                                    | H <sub>2</sub> O | KCl | Δ pH |        |
| Pedon 1: Agricultural system  |            |                   |               |                      |                    |                                    |                  |     |      |        |
| Ap                            | 0–13       | 80.8              | 10.5          | 8.7                  | 7.5                | 1.6                                | 5.4              | 4.4 | –1.0 | 0.51   |
| Bt1                           | 13–35      | 51.7              | 8.9           | 39.4                 | 32.7               | 1.4                                | 5.6              | 4.2 | –1.4 | 0.58   |
| Bt2                           | 35–56      | 51.6              | 11.7          | 36.7                 | 28.9               | 1.4                                | 5.9              | 4.5 | –1.4 | 0.65   |
| Bt3                           | 56–77      | 49.3              | 14.5          | 36.2                 | 29.7               | 1.4                                | 6.4              | 5.0 | –1.4 | 0.26   |
| Cr                            | 77–98+     | 64.5              | 13.9          | 21.6                 | 15.7               | 1.5                                | 8.1              | 7.0 | –1.0 | 0.23   |
| Pedon 2: Horticultural system |            |                   |               |                      |                    |                                    |                  |     |      |        |
| Ap                            | 0–15       | 65.2              | 15.9          | 18.9                 | 16.9               | 1.7                                | 7.0              | 5.9 | –1.1 | 0.95   |
| Bt1                           | 15–45      | 55.6              | 10.5          | 33.9                 | 32.0               | 1.5                                | 7.2              | 5.7 | –1.5 | 0.61   |
| Bt2                           | 45–75      | 41.0              | 13.0          | 46.0                 | 37.9               | 1.4                                | 7.6              | 5.8 | –1.8 | 0.12   |
| Bt3                           | 75–102     | 46.6              | 11.7          | 41.7                 | 34.9               | 1.3                                | 7.5              | 5.4 | –2.1 | 0.41   |
| Cr                            | 102–119    | 47.7              | 13.6          | 38.7                 | 26.4               | 1.5                                | nd               | nd  | nd   | nd     |
| Pedon 3: Forest system        |            |                   |               |                      |                    |                                    |                  |     |      |        |
| Ap                            | 0–10       | 76.8              | 10.7          | 12.5                 | 9.3                | 1.6                                | 6.5              | 5.7 | –0.8 | 2.20   |
| Bt1                           | 10–30      | 62.0              | 9.4           | 28.6                 | 21.4               | 1.6                                | 6.0              | 4.6 | –1.4 | 1.33   |
| Bt2                           | 30–55      | 43.0              | 11.5          | 45.5                 | 35.7               | 1.5                                | 5.8              | 4.2 | –1.6 | 1.22   |
| Bt3                           | 55–92      | 64.5              | 11.1          | 24.4                 | 18.6               | 1.4                                | 6.4              | 4.4 | –2.0 | 0.23   |
| Cr                            | 92+        | 63.4              | 11.0          | 25.6                 | 19.1               | 1.4                                | 6.6              | 4.5 | –2.1 | 0.40   |

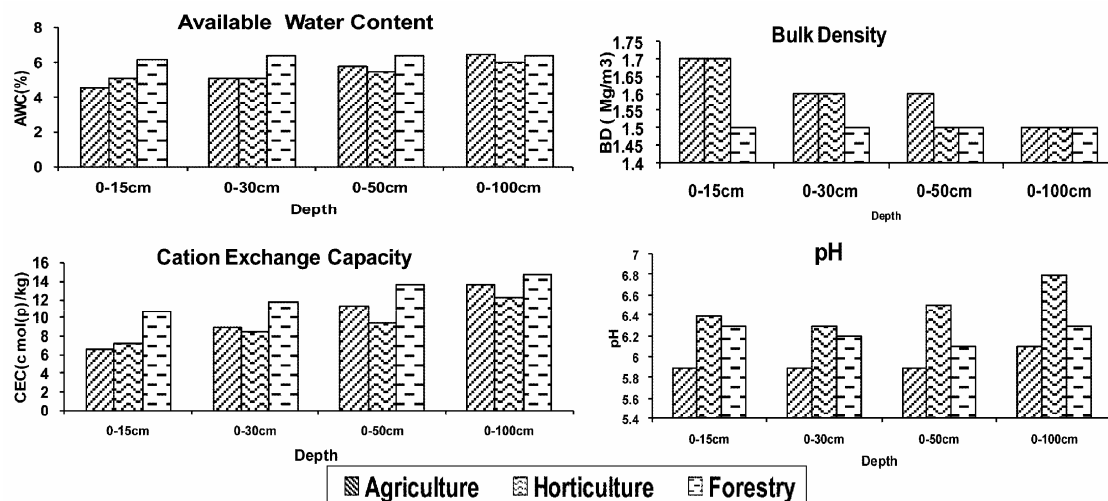
nd, not determined.

The soils of horticultural systems had the highest pH (6.4) and the agricultural soils had the lowest pH (5.9), indicating that agricultural management interventions increased the acidity of these soils. The pH of the soils tended to increase with depth in all three systems (Figure 2). The average bulk density of the surface soils in the forest system (1.5 Mg m<sup>-3</sup>) is low due to high SOC when compared to the other two systems. Deforestation and

subsequent cultivation result in an increase in soil bulk density<sup>30</sup>. Bhattacharyya *et al.*<sup>31</sup> observed a negative correlation between bulk density and organic carbon in soils of different bioclimatic zones of India. The bulk density in the agriculture and horticulture systems decreased with depth. This was probably due to the decrease in organic matter, increase in clay and also traffic compaction during tillage in the two systems (Figure 2).



**Figure 1.** Representative X-ray diffractograms of total clay Ca = Ca saturated; Ca-EG = calcium saturated and ethylene glycol solvated; K25, K110, K300, K550 = K-saturated and heated to 25°, 110°, 300° and 550°C respectively. Sm = smectite, Vm = vermiculite; M = mica; K = kaolin.



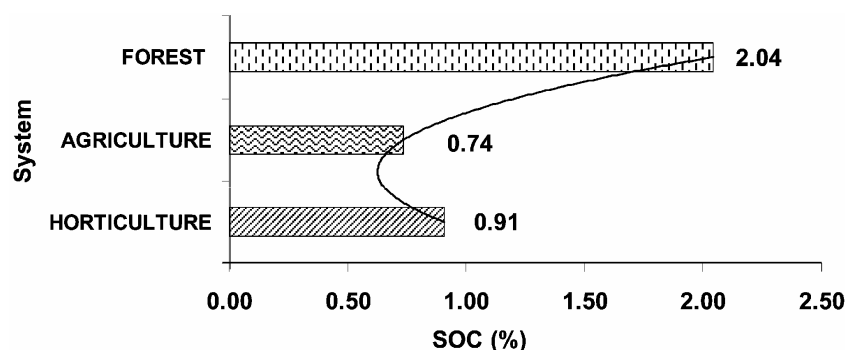
**Figure 2.** Changes in soil properties at different depths under different land use systems.

CEC of the soils also shows variations due to changes in vegetative cover. The average CEC of soils in the agricultural systems is  $6.5 \text{ cmol (p}^+) \text{ kg}^{-1}$  in the surface but is  $10.6 \text{ cmol (p}^+) \text{ kg}^{-1}$  in the forest system (Figure 2). Organic carbon and clay play a major role in controlling the CEC. Organic carbon content decreased with depth in all soils

but CEC increased. This indicates that the mineralogy of the soils probably had a larger role in regulating CEC in these soils than organic matter. Saikh *et al.*<sup>32</sup> observed a poor correlation between CEC and organic carbon in ferruginous soils under deciduous forests and attributed this change in CEC to mineralogy. The depth distributions of

**Table 3.** Quasi-equilibrium of soil organic carbon (SOC) and carbon stock in different land-use system

| Depth (cm)      | QEV of SOC (%) |      |       | Soil organic carbon stock (Mg/ha) |      |       |       |
|-----------------|----------------|------|-------|-----------------------------------|------|-------|-------|
|                 | 0–30           | 0–50 | 0–100 | 0–15                              | 0–30 | 0–50  | 0–100 |
| Land-use system |                |      |       |                                   |      |       |       |
| Agriculture     | 0.68           | 0.61 | 0.52  | 18.8                              | 33.1 | 48.5  | 63.1  |
| Horticulture    | 0.81           | 0.71 | 0.52  | 22.2                              | 37.5 | 53    | 73.1  |
| Forest          | 1.78           | 1.55 | 1.10  | 44.5                              | 79.6 | 116.3 | 169.8 |

Mg = 10<sup>6</sup> g.**Figure 3.** Quasi-equilibrium of organic carbon (0–15 cm) in different systems.

available water content (AWC) of soils in the three systems are similar to that of CEC due to their relation with clay and organic matter (Table 2).

#### Quasi-equilibrium value of SOC

The QEV of SOC under the different systems shows that the agricultural system at 30 cm depth had the lowest value of 0.68% after 40 years of agricultural use (Table 3). As expected, forest system had the highest QEV (1.78%) ranging between 1.59% and 1.97%. This was considered as a control. The maximum threshold limit of 2.04% SOC at 30 cm depth was reported for ferruginous soils in forest ecosystem in a subhumid climate under luxuriant vegetation and a minimum threshold of 0.63% was reported for shrink-swell soils under agricultural use<sup>33</sup>. QEV of SOC in the horticultural system of the present study was 0.81%, and this was attained within 20 years. This indicates that the horticultural system with more canopy cover, leaf litter and favourable micro-environment enhanced the SOC content. Earlier, Naitam and Bhattacharyya<sup>9</sup> also reported a SOC of 0.70% for QEV to upper 50 cm depth in shrink-swell soils under horticultural use. The total SOC at 0–50 cm depth was also higher in forest and horticultural systems than in the agricultural system, but at 0–100 cm depth both agricultural and horticultural systems had the same carbon level (Table 3).

When we consider the surface soil (0–15 cm) as the new zone for carbon accumulation and sequestration in

any system, then forest soil has sequestered 2.04% organic carbon (Figure 3). At this depth, the carbon decreased to 0.74% after 40 years of agricultural practice, indicating a decrease of 64%. Judging by the time required to reach the quasi-equilibrium stages of SOC for different ecosystems<sup>7–9,34</sup>, it is presumed that the soils under study have reached a QE state. However, the introduction of horticultural system for 20 years has increased the carbon status (0.91% vs 0.74%) which is about 23% higher than the agricultural system (or a decrease of 55% from the forest system). This indicates that the horticultural system has better potential to sequester carbon than the agricultural system. A recent study on the potential of land-use systems for carbon sequestration in biomass indicates that agri-horticultural system is better than other systems<sup>35</sup>. Velayutham *et al.*<sup>36</sup> proposed 1% organic carbon as the threshold for sufficiency levels in the soils of tropical India and accordingly, the soils under horticultural systems are close to this sufficiency level. Earlier, Saikh *et al.*<sup>32</sup> from their studies on the ferruginous soils of the sub-humid region (in eastern India) under forest systems reported a similar range (1–2%) of organic carbon as an equilibrium value of SOC.

Our results indicate that under semi-arid conditions, the ferruginous soils of tropical India under forestry has the capacity to store >2% organic carbon at the surface. However, in agricultural soils due to high rate of mineralization, the decomposed organic carbon is stored in the form of humic acid with inorganic clay through polyvalent cations as bridge-linked compounds<sup>37,38</sup>. Thus, car-

bon storage depends primarily on the quality and quantity of inorganic colloids and their reactive surfaces<sup>39,40</sup>.

### Organic carbon stock

SOC stock estimate for different land-use systems depends on aerial extent besides other factors such as carbon content, bulk density and depth of soil<sup>24</sup>. The carbon stock changes expressed per unit area<sup>34</sup> (Table 3) indicate that the forest system may have twice the amount of SOC at all depths than the horticultural system. The agricultural system had the lowest SOC stock (Table 3). These results suggest that the ferruginous soils of SAT enriched with 2:1 clay minerals can sequester considerable amounts of organic carbon under forest and horticultural land uses, a fact true in swell-shrink soils<sup>9</sup> as well.

### Conclusion

The ferruginous soils of SAT, India under horticultural and forest systems have attained a threshold of 0.81% and 1.78% of SOC over a period of 20 and 100 years respectively in the upper 30 cm of soil. Agriculture for 40 years has drastically reduced the QEV to 0.62%. Since all the soils under study are in a contiguous area with similar climate and substrate quality, we conclude that the variation in the QEV of these soils is primarily controlled by land-use systems. Accordingly, horticultural land-use appears to be a preferred option for maintaining soil health and for achieving economic sustainability to the stakeholders of the SAT.

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