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Soil organic carbon stock in agroforestry systems in western and southern plateau and hill regions of India

The rising level of carbon dioxide (CO_2) in the atmosphere is a major concern, as scientific evidences show that it is the primary cause of global warming. CO_2 concentration is expected to double by the middle or end of the 21st century, with a temperature rise between 1.5°C and 4.5°C (ref. 1). The importance of agroforestry as a land-use system is receiving wider recognition not only in terms of agricultural sustainability, but also in issues related to carbon sequestration or climate change[2]. Trees in association with annual crops add carbon to both above- and belowground portions, through photosynthesis, and thereby increase the organic matter content of the soil[3,4]. Although it is generally assumed that agroforestry system has the potential to increase soil organic carbon (SOC) stocks[5], and as reported by Nair[6], very few studies have focused on soil layers deep inside[7,8].

The present study was undertaken in 2015 under the National Innovations in Climate Resilient Agriculture Project to assess the SOC stock in existing agroforestry system in farmer's field from eight villages of Nashik and four villages of Thane district in Maharashtra, six villages of Chittoor district in Andhra Pradesh, and four villages each of Tumkur and Bellary districts in Karnataka, under the western and southern plateau and hill regions. From each block, two villages were randomly selected to represent the whole block. In each village, transect walk was conducted during July and October 2015, with a hand-held GPS system and preliminary information was acquired on indigenous tree species, inter-crops, climatic data and soil type (Table 1). Soil samples were collected from the existing agroforestry system and crop fields from different soil depths (0–15, 15–30, 30–60 and 60–90 cm) with three replications; a total of 5–8 sampling sites were selected from each location in a zigzag manner and were mixed to prepare a composite sample for analysis. In Tumkur, SOC varied from 0.24% to 0.60% from one location to another. Similarly, in Bellary, it varied from 0.23% to 0.54%. In Thane and Nashik, the variation was 0.38–0.98% and 0.34–1.34% respectively. In Chittoor, SOC varied from 0.17% to 0.66%. Soil bulk density measurements were made using soil core sampler.

The soil samples were analysed to estimate organic carbon using the method of Walkley and Black[9]. SOC stock was calculated using the formula

$$\text{SOC stock (t ha}^{-1}) = \text{SOC} \times \text{BD} \times \text{SD} \times 10, \quad (1)$$

where SOC is the soil organic carbon (g kg^{-1}), BD the bulk density (Mg m^{-3}), SD the soil depth (m), and 10 is a conversion factor.

There are several scientifically acceptable evidences to support the positive influence of trees in enhancing SOC[10,11]. Table 2 presents the distribution of SOC in different soil depths. SOC content in agroforestry system was 1.02% in 0–15 cm depth over 0.96% under sole crop in Thane. Similarly, for 15–30 cm depth, SOC varied from 0.89% under agroforestry over 0.70% under sole crop. There was a decrease in SOC content with increase in soil depth. This might be due to the fact that turnover rate of fine roots decreases with increase in depth, which in turn affects the organic matter input in deep soil layers[12]. In Nashik, more or less similar results were obtained with SOC content under agroforestry system varying from 0.95% in 0–15 cm to 0.67% in 15–30 cm soil depth. While in case of sole crop, it was 0.74% in 0–15 cm and 0.60% in 15–30 cm depths. In Chittoor, SOC varied from 0.46% under sole crop to 0.55% under agroforestry system, while Tumkur and Bellary showed 0.64% and 0.57% SOC in agroforestry over 0.40% and 0.51% in sole crop in 0–15 cm soil depth respectively. When soil sampling was done up to 90 cm soil

Table 1. Site characteristics, dominant trees/crops and crop productivity in the surveyed districts

Attributes	Thane	Nashik	Chittoor	Tumkur	Bellary
Location	19°12′N, 73°02′E	20°02′N, 73°50′E	13°13′N, 79°8′E	13°20′N, 77°8′E	15°16′N, 76°26′E
Rainfall (mm)	2360	1018	438	688	611
Climate	Humid	Semi-arid	Hot-arid	Hot, moist, semi-arid	Hot-arid
Soil type	Brownish-black soil	Laterite soil	Red loamy soil	Red loamy soil	Sandy loam soil
Dominant crops and productivity (Mg ha^{-1})	*Oryza sativa* (2.50), *Vigna radiata* (2.14), *Eleusine coracana* (0.72), *Cajanus cajan* (0.63), *Arachis hypogaea* (0.44)	*Zea mays* (5.17), *Triticum aestivum* (1.52), *Oryza sativa* (1.21), *Pennisetum americanum* (0.76)	*Oryza sativa* (2.7), *Arachis hypogaea* (1.6)	*Oryza sativa* (4.0), *Zea mays* (2.3), *Eluesine coracana* (1.6)	*Oryza sativa* (4.1), *Zea mays* (2.4), *Triticum aestivum* (0.98), *Pennisetum americanum* (0.82), *Arachis hypogaea* (0.4)
Dominant trees (%)	*Tectona grandis* (25.79), *Azadirachta indica* (19.28), *Zizyphus mauritiana* (14.58), *Mangifera indica* (13.90), *Syzygium cumini* (12.23), *Acacia nilotica* (9.49)	*Acacia nilotica* (20.12), *Azadirachta indica* (20.08), *Syzygium cumini* (19.52), *Leucaena leucocephala* (11.25), *Mangifera indica* (10.43)	*Mangifera indica* (41.91), *Tectona grandis* (13.23), *Azadirachta indica* (12.28), *Cocos nucifera* (8.09), *Acacia nilotica* (7.75)	*Areca catechu* (39.92), *Cocos nucifera* (29.26), *Azadirachta indica* (7.95), *Mangifera indica* (7.54), *Tectona grandis* (6.07)	*Acacia nilotica* (42.13), *Azadirachta indica* (12.43), *Bambusa dendrocalmus* (8.39), *Tectona grandis* (7.14), *Cocos nucifera* (6.70)

Table 2. Depth-wise distribution of mean (± standard deviation) soil organic carbon (%) in Maharashtra, Andhra Pradesh and Karnataka

	Thane		Nashik		Chittoor		Tumkur		Bellary	
Depth (cm)	AF	Crop	AF	Crop	AF	Crop	AF	Crop	AF	Crop
0–15	1.02 (± 0.15)	0.96 (± 0.31)	0.95 (± 0.30)	0.74 (± 0.38)	0.55 (± 0.29)	0.46 (± 0.16)	0.64 (± 0.26)	0.40 (± 0.09)	0.57 (± 0.22)	0.51 (± 0.26)
15–30	0.89 (± 0.34)	0.70 (± 0.37)	0.67 (± 0.32)	0.60 (± 0.26)	0.50 (± 0.22)	0.40 (± 0.14)	0.61 (± 0.29)	0.38 (± 0.09)	0.47 (± 0.18)	0.45 (± 0.13)
30–60	0.47 (± 0.29)	0.64 (+0.28)	0.52 (± 0.39)	0.79 (± 0.91)	0.23 (± 0.13)	0.18 (± 0.07)	0.24 (± 0.06)	0.18 (± 0.05)	0.20 (± 0.06)	0.19 (± 0.09)
60–90	0.47 (± 0.40)	0.44 (+0.36)	0.56 (± 0.16)	0.40 (± 0.19)	0.17 (± 0.07)	0.15 (± 0.03)	0.18 (± 0.08)	0.13 (± 0.03)	0.14 (± 0.06)	0.16 (± 0.05)

AF, Agroforestry.

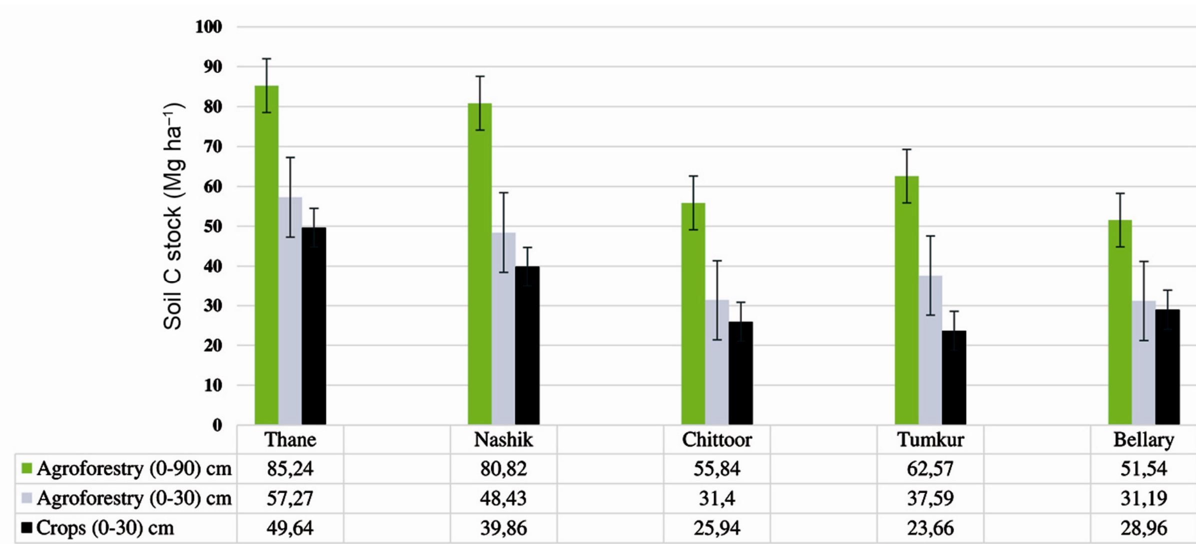

Figure 1. Soil organic carbon stock (Mg ha^{-1}) under agroforestry and sole crop in Maharashtra, Andhra Pradesh and Karnataka.

depth, SOC stock was 85.24, 80.82, 55.84, 62.57 and 51.54 Mg C ha^{-1} under agroforestry system in Thane, Nashik, Chittoor, Tumkur and Bellary respectively. SOC stock in the top 0–30 cm depth was 57.27 Mg C ha^{-1} compared to control (sole crop) with 49.64 Mg C ha^{-1} in Thane (Figure 1). This value is about 1.15 times higher than that of the control. These values are comparable to those in the Mediterranean region (25–50 Mg C ha^{-1})[13,14] and better than 27 Mg ha^{-1} of SOC stock in 0–60 cm layer for agroforestry systems in Central India[15]. In case of Nashik and Chittoor, the SOC stock under agroforestry system was 1.21 times more than the sole cropping in 0–30 cm soil layer. While in Karnataka, it was 1.58 times more in case of Tumkur district and 1.07 times more for Bellary district respectively. In the 0–90 cm soil depth studied, especially the top 0–30 cm contributed almost 67% of the SOC stock in Thane and around 60% in Nashik, 56% in Chittoor and 60% each in Tumkur and Bellary. This might be due to the fact that trees along with herbaceous layer of crops add a lot of organic matter to the soil, which is recognized as an efficient measure to sequester carbon and mitigate climate change. Improved carbon storage of the agroforestry system can also be explained by greater capture of resources such as solar radiation and water combining different components for enhanced biomass that is partly returned to the soil through above- and belowground litter. The agroforestry system existing in the farmer's field not only provides food, fuel, and improves soil health, and helps in water management, but also acts as a major sink for atmospheric CO_2.

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A new insight into age and environments of intertrappean beds of Mohgaon Kalan, Chhindwara District, Madhya Pradesh using palynology, megaflora, magnetostratigraphy and clay mineralogy

The megaflora-rich intertrappean cherts near the village Mohgaon Kalan in Chhindwara District, Madhya Pradesh (Figure 1 *a*) has been known since 1934 when K. P. Rode[1] first reported dicotyledonous woods from this intertrappean. Sahni and Rode[2] carried out pioneering work on megaflora of this horizon and during the following seven decades numerous additional megafloral remains, representing pteridophytes, gymnosperms, angiosperms, algae and fungi have been reported. However, despite numerous records of megafloral remains from this megafossil Lagerstatten[3,4], the age, whether Maastrichtian or Palaeocene[5] has been difficult to pin down in the absence of unequivocal age marker fossils or any precise radiometric dating.

During the current field investigations for palynological study, multiple intertrappean sediments at different stratigraphic levels within the Deccan volcanic sequence in Chhindwara area have been studied. The previous study[6] has shown that in the Mohgaon Kalan locality there are two intertrappean beds at two stratigraphic levels associated with three flows. The two upper flows (MKF2 and MKF3) are exposed and the lower most flow (MKF1) occurs only as subcrops in the well sections (Figure 1 *b*). The sediments of the lower intertrappean, including the one studied earlier[7–9], occur between MKF1 and MKF2 in the well section. We designate the lower intertrappean as Mohgaon Kalan Well Section (MKWS) and the upper one as Mohgaon Kalan Fossil Forest (MKFF). The present study is aimed to understand the palynofloral composition in the MKWS and MKFF sediments for the