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Soil organic carbon stock and carbon sequestration potential under different land uses of Marathwada region, Maharashtra

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Abstract : The soils across different land uses (Glyricidia, Grape, Soybean, Sorghum, Pigeon Pea, and Cotton) of Latur, Osmanabad, and Beed districts, were classified as Lithic Ustorthents, Typic Haplustepts, and Typic Haplusterts. Their characteristics vary, with bulk density ranging from 1.35 to 1.63 Mg m^{-3} and saturated hydraulic conductivity ranging from 1.29 to 24.63 cm hr^{-1}. These soils exhibit slightly to moderately alkaline pH levels (ranging from 6.65 to 8.37) and low electrical conductivity (0.11 to 0.90 dS m^{-1}), with organic carbon content ranging from low to medium (0.26 to 1.02%). The cation exchange capacity ranges from 18.55 to 66.78 cmol(p^+) kg^{-1}, with calcium (Ca^{2+}) being the dominant cation, followed by magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+). The maximum soil organic carbon (SOC) stock for the 0-15 cm depth was observed under glyricidia. Soil inorganic carbon (SIC) stock varied from 4.20 to 76.05 t ha^{-1}, with the lowest SIC found under Glyricidia (4.2 to 10.86 t ha^{-1}) and the highest under Soybean (31.36 to 76.05 t ha^{-1}). Total soil carbon stock (TSCS) ranged from 22.76 to 55.66 t ha^{-1} for the 0-15 cm depth, with Pigeon pea exhibiting the maximum TSCS and Grape showing the minimum. The carbon sequestration potential varied with land use, ranging from 0.22 to 1.8 t ha^{-1} $year^{-1}$. Glyricidia demonstrates the highest carbon sequestration potential (1.62 to 1.8 t ha^{-1} yr^{-1}), followed by Soybean, Pigeon Pea, Sorghum, Cotton, and Grape.

Keywords: *Carbon sequestration, Organic carbon, Soybean, Glyricidia*

Introduction

Carbon Sequestration can be defined as the capture and secure storage of carbon that would be emitted into the atmosphere. The idea is first to prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, and second, to sequester carbon from the atmosphere by various means and store it in the soil (Mahdi, 2008). Soil organic carbon sequestration is a process that transfers carbon dioxide from the atmosphere into the soil through crop residue and other organic solids in a form that is not immediately re-emitted (Lal, 2004). The soil organic matter, the seat of soil organic carbon, is the most complex, dynamic and reactive soil component. It contributes to plant growth and development by affecting the chemical, biological, and physical properties of the soil. The CO_2 concentration in the atmosphere has increased from 280 ppm in 1850 to 391 ppm in 2012 (CDIAC, 2012). There has been an increase in atmospheric methane (CO_2) and nitrous oxide (N_2O) concentration over the same period, contributing to global warming (IPCC, 2000).

Restoration of soil health through soil organic carbon (SOC) management is a major concern for tropical soils. Barring its importance for sustainable crop production, the accelerated decomposition of SOC due to agriculture, resulting in loss of carbon to the atmosphere and its contribution to the greenhouse effect, is a serious global problem. The contributions of SOC in sustaining productivity have been appreciated since the

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dawn of human civilisation. Important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use. The effect of a specific land use change or soil management practice on atmospheric CO_2 must be considered within a broader context. There is, however, great potential for increasing soil C sequestration through the adoption of forest land use and mixed vegetation cover land management practices that enhance soil carbon, a win–win strategy of increased C storage and soil fertility, as advocated by Lal (2004) and others.

While the Marathwada region is well known for the cultivation of cotton, soybeans, gram, pigeon peas, and sugarcane, horticulture crops like mangoes and pomegranates are also successfully cultivated in numerous locations throughout the districts. Information on soil organic carbon stocks in various land-use systems is scarce. Therefore, it provides an opportunity to assess the soil organic carbon stock in the identified land use system. The present investigation aims to assess C-stock and its sequestration potential under various land uses, including cotton, soybean, gram, tur, sorghum, grape, Glyricidia, and fallow land, in Latur, Osmanabad, and Beed districts of the Marathwada region.

Materials and methods

Geographically the Latur, Osmanabad and Beed districts are located between 18°05'to 18° 25'N latitude and 76° 25' to 77°25' longitude, 18° 28' to 19° 28'North latitude, 76° 25' to 77°25'longitude and 18° 26' to 19° 26' N latitude and 74° 54' to 76° 57' East longitude, respectively. The total geographical area of Latur, Osmanabad and Beed districts is 7372 km^2, 7512.40 km^2, and 10693 km^2, respectively. The climate of the area is hot and sub-humid with mean annual rainfall of 794 mm, 870 mm and 838 mm and mean maximum and minimum air temperature are 32.70 to 18.10 °C, 33.40 to 18.60 °C, and 33.10 °C and 18.50 °C in Latur, Osmanabad and Beed districts, respectively.

Representative fields were selected under different land use such as cotton, sorghum, soybean, Bengal gram, red gram, grape, glyricidia and fallow land in Latur, Osmanabad and Beed districts of Marathwada region. Seven (7) representative soil profiles were selected and classified as per soil taxonomy (Soil Survey Staff, 1998 & 2006). The horizon wise soil samples were collected, processed and analyzed for physico-chemical properties using standard analytical techniques. Particle size analysis was carried out by international pipette method (Jackson, 1979). Bulk density of soils was determined by clod coating technique (Black, 1965). The pH, EC, organic carbon, $CaCO_3$, exchangeable cations and cation exchange capacity (CEC) were determined by standard procedure (Jackson, 1979). The soils were classified as per keys to soil taxonomy (Soil Survey Staff, 2015). Soil inorganic carbon (SIC) calculation was carried out by using 12 per cent carbon value in $CaCO_3$.

Estimation of carbon stock

The soil carbon stocks were estimated by mass, volume and density relationship (Batjes, 1996). The SOC pool (Mg ha^{-1} for a specific depth) was calculated by multiplying the SOC concentration (g kg^{-1}) with bulk density (Mg m^{-3}) and depth (m).

$$\text{C Stock (Depth)} = TC_i * BD_i * TH_i \tag{1}$$

Where, C Stock (Depth) = Cumulative Soil Carbon Stock, TCi = Total soil C concentration in the i^{th} layer, BD_i = Bulk density of the i^{th} layer, TH_i = thickness of i^{th} layer

Carbon stock for each layer of the dominant land use was calculated by multiplying the C stock obtained by equation 1 by the total area covered by a particular land use. Subsequently, C stock in each soil layer thickness was summed up to determine total C stock contained depth in cm for each land-use type. Difference in soil bulk density caused due to difference in land use or cover affects the calculation of carbon stock by influencing the amount of soil sampled from the same soil depth.

Carbon sequestration potential

Carbon sequestration potential were carried out by following equation

$$Carbon\ sequestration\ potential\ \left(t\ ha^{-1} yr^{-1}\right) = \frac{Carbon\ sequestered\ \left(t\ ha^{-1}\right)}{Number\ of\ experimental\ years}$$

Carbon sequestered (Mg C ha^{-1}) = SOC_f - SOC_i

Where, SOC_f = Current year of carbon stock, SOC_i= Initial year of carbon stock

Results and Discussion

The bulk density of 7 pedons varies from 1.35 to 1.63 Mg m^{-3}. The bulk density of the soils under glyricidia varied from 1.5 to 1.9 Mg m^{-3}, under grape it varied from 1.35 to 1.9 Mg m^{-3} (Table 1). In general, bulk density increases with soil depth. High value of sub surface soil may be due to murrum layer (Ahuja et al., 1988) under very shallow soils. These soils were generally under fallow land, glyricidia and horticultural crop grape. The hydraulic conductivity of the studied soil varied from 1.29 to 24.63 cm hr^{-1}. This variation is attributed to textural difference. The highest hydraulic conductivity in surface soil was noticed under grape (18.45 cm hr^{-1}) and minimum under soybean crop (1.29 cm hr^{-1}).

The results indicated that the lowest soil pH was observed at the surface of the soils (*Lithic Ustorthents*) under land use of glyricidia (Table 2) which could be attributed to organic matter decomposition and the subsequent removal of bases from the surface soil. Conversely, the highest soil pH was observed under *Typic Haplustepts* and *Typic Haplusterts*. The soil pH varied with the land use systems such as sorghum (7.52 to 8.13), soybean (6.8 to 8.37), pigeon pea (7.1 to 7.7) and cotton (7.21 to 7.65). The irregular variation of soil pH down the soil profile is presumed to be due to differential losses of bases over time. Similar findings were also reported by Patil *et al.* (2014) and Pawar *et al.* (2015). Electrical conductivity varied from 0.11 to 0.90 dS m^{-1}. Irregular variation in EC could be due to leaching of salt from surface to down level through the percolation of water, followed by accumulation at places during evapotranspiration resulting in differential salt accumulation along the pedon. Similar observation recorded by Rajkumar (1990) and Vaidya *et al.* (2002).

The maximum amount of organic carbon content (0.91 to 1.02%) was observed in glyricidia plantation , in general, these soil contain more organic carbon than agriculture land use because of no tillage and pedo-turbation at soil surface addition of biomass and deep root system. The surface soil under soybean has the highest amount of organic carbon (0.28 to 0.85%) followed by in pigeon pea (0.26 to 0.78%), sorghum (0.28 to 0.69%) and cotton (0.53 to 0.63%). This indicated that the leguminous crop soybean and pigeon pea added more organic matter in soil than the cereal crop sorghum and cash crop cotton. The maximum calcium carbonate was notice under sorghum (10.3 to 17.0%) which is coinciding with soil type *Typic Haplustert* (P5) and *Typic Haplustept* (P6).

The minimum calcium carbonate was observed under land use of glyricidia (3.4 to 3.9 %) fallowed by fallow land (3.6 to 5.3 %) and grape (3.2 to 4.7 %) which correspond to soil type *Lithic Ustorthent* (P1 to P3). The calcium carbonate content in *Lithic Ustorthent* was lower than the *Typic Haplustept* and *Typic Haplustert* and it may be due to the leaching of bicarbonate which get precipitated down to slope as well as at lower horizon. CEC of *Lithic Ustorthent* soil varied from 18.55 to 32.61 cmol (p+) kg^{-1}, *Typic Haplustepts* varied from 34.75 to 63.45 cmol (p+) kg^{-1}and *Typic Haplusterts* varied from 36.39 to 69.45 cmol (p+) kg^{-1}. This indicated that CEC varies with soil type. Similar result was also reported by Adkine *et al.* (2018), Pawar (2015) and Mane (2013).

The maximum SOC was noticed under Glyricidia (P1), and the minimum SOC was noticed under sorghum (P5) at the surface. However, the maximum SOC at a soil depth of 0-15 cm was observed under glyricidia, ranging from 24.22 to 24.48 t ha^{-1}. This may be due to the addition of a large amount of organic matter and a minimum in grape (11.74 t ha^{-1}). The depth-wise SOC stock was found to have decreased because the SOC in soil is closely associated with organic carbon content in soil. At the same time, the SIC varied from 4.20 to 76.05 t ha^{-1}. The minimum SIC was found under glyricidia (4.2 to 10.86 t ha^{-1}), whereas the maximum SIC was noted under soybean (31.36 to 76.05 t ha^{-1}) crop, followed by pigeon pea (37.61 to 68.44 t ha^{-1}). However, it was also observed that the maximum SIC occurred in *Typic Haplusterts*, while the minimum SIC was found in *Lithic Ustorthents*. The minimum SIC stock in Gliricidia may be attributed to the decomposition of organic matter,

Table 1: Soil Physical and physic-chemical properties under different land use of Latur, Osmanabad and Beed district of Marathwada region of Maharashtra

Horizon	Depth (cm)	BD ($Mg\ m^{-3}$)	HC ($cm\ hr^{-1}$)	pH	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC [$cmol\ (p^+)\ kg^{-1}$]
Pedon 1 - Borphadi, Beed (*Lithic Ustorthent*) land use Glyricidia								
Ap	0-19	1.6	16.88	6.65	0.19	1.02	3.7	23.12
Cr	19-32	1.8	22.54	6.95	0.20	0.87	3.9	21.22
Pedon 2 - Shend, Latur (*Lithic Ustorthent*) land use Glyricidia								
Ap	0-7	1.5	14.87	6.75	0.14	0.99	3.4	31.45
Cr	8-20	1.9	21.32	7.12	0.11	0.91	3.7	18.55
Pedon 3 - Alni, Osmanabad(*Lithic Ustorthent*) land use Grape								
Ap	0-25	1.35	18.45	6.95	0.33	0.58	4.1	32.61
Cr	25-40	1.9	20.67	7.4	0.38	0.42	4.5	21.65
Pedon 4 - Ter, Osmanabad (*TypicHapluster*)land use Soybean								
Ap	0-17	1.53	1.29	7.91	0.20	0.85	10.3	60.44
Bw_1	17-36	1.54	1.53	8.12	0.20	0.89	11.2	66.78
Bw_2	36-60	1.59	1.54	8.22	0.20	0.53	11.6	66.59
Bss_1	60-92	1.68	1.59	8.37	0.30	048	10.1	42.48
Bss_2	92-130	1.69	1.68	7.77	0.60	0.32	11.2	56.94
Bss_3	130-160	1.56	1.69	7.86	0.90	0.28	12.8	56.48
Pedon 5 - Khasapur, Osmanabad (*Typic Haplustept*)land use Sorghum								
Ap	0-8	1.63	2.93	7.82	0.18	0.48	12.52	54.64
Bw_1	8-15	1.65	4.05	7.90	0.19	0.52	13.82	51.89
Bw_2	15-26	1.71	4.45	8.13	0.20	0.41	14.81	31.43
Cr	26-42	1.82	10.09	7.72	0.22	0.28	14.21	30.75
Pedon 6 - Shekhapur, Osmanabad (*Typic Haplustept*)land use Pigeon pea								
Ap	0-27	1.54	14.18	7.13	0.18	0.78	13.72	48.65
Bw_1	27-50	1.56	15.70	7.11	0.19	0.72	14.08	47.54
Bw_2	50-64	1.59	17.34	7.38	0.21	0.39	14.10	43.17
Cr	64-80	1.68	24.63	7.37	0.22	0.26	16.63	38.66
Pedon 7 - Umrai, Beed (*Typic Haplustert*) land use Cotton								
Ap	0-23	1.43	1.32	7.3	0.35	0.62	8.8	63.45
Bw_1	23-41	1.5	3.24	7.65	0.16	0.52	8.5	63.22
Bw_2	41-64	1.35	5.79	7.32	0.15	0.58	8.9	58.12
Bss_1	64-84	1.6	11.22	7.60	0.14	0.53	10.5	61.24
Bss_2	84-106	1.63	12.52	7.21	0.14	0.41	11	55.64
Bss_3	106-150	1.8	13.61	7.3	0.14	0.21	11.6	53.21

Table 2: Soil organic carbon, soil inorganic carbon and carbon stock of soils under different land use of Latur, Osmanabad and Beed district of Marathwada region of Maharashtra

Horizon	Depth (cm)	SOC ($t\ ha^{-1}$)	SOC ($t\ ha^{-1}$) 15 cm depth	SIC ($t\ ha^{-1}$)	SIC ($t\ ha^{-1}$) 15 cm depth	Total Carbon stock($t\ ha^{-1}$)	Total Carbon stock ($t\ ha^{-1}$)
Pedon 1 - Borphadi, Beed (*Lithic Ustorthent*) land use Glyricidia							
Ap	1-19	31.08	24.48	06.30	10.56	35.04	68.43
Cr	19-32	20.35		10.70			
Pedon 2 - Shend, Latur (*Lithic Ustorthent*) land use Glyricidia							
Ap	0-7	10.39	24.22	4.2	9.8	34.02	46.19
Cr	8-20	20.74		10.86			
Pedon 3 - Alni, Osmanabad(*Lithic Ustorthent*) land use Grape							
Ap	0-25	19.57	11.74	16.53	11.02	22.76	63.46
Cr	25-40	11.97		15.39			
Pedon 4 - Ter, Osmanabad (*TypicHapluster*)land use Soybean							
Ap	0-17	22.10	19.50	31.36	28.22	47.72	464.35
Bw_1	17-36	26.04		39.20			
Bw_2	36-60	20.22		53.04			
Bss_1	60-92	25.80		65.04			
Bss_2	92-130	20.55		76.05			
Bss_3	130-160	13.35		71.60			
Pedon 5 - Khasapur, Osmanabad (*Typic Haplustept*)land use Sorghum							
Ap	0-8	6.140	12.14	19.22	38.36	50.05	149.15
Bw	8-15	6.000		19.14			
Bw	15-26	07.71		33.42			
Cr	26-42	08.15		49.37			
Pedon 6 - Shekhapur, Osmanabad (*Typic Haplustept*)land use Pigeon pea							
Ap	0-27	30.06	17.78	68.44	37.88	55.66	222.08
Bw	27-50	28.70		60.27			
Bw	50-64	08.40		37.61			
Cr	64-80	06.90		53.49			
Pedon 7 - Umrai, Beed (*Typic Haplustert*) land use Cotton							
Ap	0-23	20.00	13.29	34.73	22.43	35.72	295.87
Bw1	23-41	14.04		27.54			
Bw2	41-64	18.00		33.16			
Bss1	64-84	16.96		40.32			
Bss2	84-106	14.70		47.33			

which solubilised the $CaCO_3$ and caused it to move down through the soil solum. Depth-wise, the SIC stock was found to increase due to the higher amount of $CaCO_3$ content in the subsoil, which increased with depth (Table 2). These findings are consistent with those observed by Wilkson et al. (2017) and Bhattacharya et al. (2009).

The total soil carbon stock (TSCS) exhibited considerable variation across different land use systems, ranging from 46.91 to 464.35 t ha^{-1}. Among these systems, the highest TSCS was recorded under sorghum (P5), while the lowest was observed under grape cultivation, particularly at a depth of 15 cm. The total soil carbon stock (TSCS) varies significantly across different soil types. *Typic Haplustert* show the highest TSCS values, ranging from 149.15 to 464.35 t ha^{-1}, whereas the lowest values are found in *Lithic Ustorthent* soils, ranging from 27.1 to 68.43 t ha^{-1}. Based on these findings, it is evident that Vertisols exhibit the maximum TSCS at 464.35 t ha^{-1}, followed by Inceptisol and Entisols. Similar conclusions were also reported by Vekanna et al. (2014) and Makumba et al. (2007).

The data presented in Table 3 demonstrate that the highest carbon sequestration potential was observed under Glyricidia (1.62 and 1.80 t ha^{-1} $year^{-1}$), followed by the legume crop soybean (1.6 t ha^{-1} yr^{-1}). The carbon sequestration potential under cereal crop sorghum was found to be between (0.53 t ha^{-1} yr^{-1}), whereas under cash crop, cotton (1.08 t ha^{-1} yr^{-1}) and horticulture crop, grape (0.22 t ha^{-1} yr^{-1}). The results indicated that the soil under Glyricidia has the highest carbon sequestration potential, followed by soils under legume crops (soybean and pigeon pea), cereals (sorghum), cash crops (cotton), and horticultural crops (grapes). This suggests that soils under horticultural crops and cash crops, such as cotton, experience the greatest loss of soil organic carbon (SOC), followed by sorghum, pigeon pea, and soybean. Therefore, these lands require improved soil management practices, such as balanced fertiliser application, residue management, crop rotation and conservation agriculture practices. These practices can reduce carbon losses and are the best options for enhancing soil organic carbon (SOC) sequestration under these land uses. A similar result was also reported by Singh *et. al.* (2023).

Table 3: Organic carbon stock and carbon sequestration potential of soils under different use of Latur, Osmanabad and Beed district of Marathwada region of Maharashtra.

Horizon	Depth (cm)	Current year organic carbon stock (t ha^{-1} yr^{-1})	Initial year organic carbon stock (t ha^{-1} yr^{-1})	Carbon sequestration potential (t ha^{-1} yr^{-1})
Pedon 1 - Borphadi, Beed (*Lithic Ustorthent*) land use Glyricidia				
Glyricidia	0-32	51.35	42.34	1.8
Pedon 2 - Shend, Latur (*Lithic Ustorthent*) land use Glyricidia				
Glyricidia	0-20	31.13	22.87	1.62
Pedon 3 - Alni, Osmanabad(*Lithic Ustorthent*) land use Grape				
Grape	0-40	31.54	30.44	0.22
Pedon 4 - Ter, Osmanabad (*TypicHapluster*)land use Soybean				
Soybean	0-160	134.27	125.90	1.6
Pedon 5 - Khasapur, Osmanabad (*Typic Haplustept*)land use Sorghum				
Sorghum	0-42	28	25.34	0.53
Pedon 6 - Shekhapur, Osmanabad (*Typic Haplustept*)land use Pigeon pea				
Pigeon pea	0-80	76.01	71.45	0.91
Pedon 7 - Umrai, Beed (*Typic Haplustert*) land use Cotton				
Cotton	0-150	98.66	93.23	1.08

Conclusion

The bulk density of the studied soils varied from 1.35 to 1.90 Mg m^{-3}. The pH levels of these soils ranged from slightly acidic to moderately alkaline. Organic carbon content ranges from low to very high. The high CEC is attributed to the high amount of clay content in the soil. The maximum SOC and minimum SIC were observed at the surface and the 0-15 soil depth in Glyricidia. The total carbon stock also varies with the type of soil. The maximum TSCS was noted at *Typic Haplustert*, and the minimum at *Lithic Ustorthent*. The maximum SOC stock and carbon sequestration potential was found under glyricidia, followed by leguminous crop (soybean and pigeon pea), cereal crop (sorghum), cash crop (cotton) and lowest at horticultural crop (grape).

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