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SOIL ORGANIC CARBON STOCK AND CARBON SEQUESTRATION POTENTIAL UNDER DIFFERENT LAND USES OF MARATHWADA REGION, MAHARASHTRA

C.B. Wagh[1], P.H. Vaidya[2] and S.S. Shilewant[3]

ABSTRACT

The soils across different land uses, including glyricidia, grape, soybean, sorghum, pigeonpea, and cotton in Latur, Osmanabad, and Beed districts during 2019-2020, were classified as Lithic Ustorthants, Typic Haplustepts and Typic Haplustert. Their characteristics vary, with bulk density ranging from 1.35 to 1.63 Mg m^{-3} and saturated hydraulic conductivity from 1.29 to 24.63 cm hr^{-1}. These soils exhibited slightly to moderately alkaline pH levels (ranging from 6.65 to 8.37) and low electrical conductivity (0.11 to 0.90 dSm^{-1}), with organic carbon content ranging from low to medium (0.26P to 1.02%). The cation exchange capacity ranged from 18.55 to 66.78 cmol (p^{+}) kg^{-1}. The maximum soil organic carbon (SOC) at the surface and 0-15 cm depth was observed under glyricidia. Soil inorganic carbon (SIC) 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} at the 0-15 cm depth with pigeonpea exhibiting the maximum TSCS and grape showing the minimum TSCS. The carbon sequestration potential varied with land use, ranging from 0.22 to 1.8 t ha^{-1} year^{-1}. Glyricidia showed the highest carbon sequestration potential (1.62 to 1.8 t ha^{-1} year^{-1}) followed by soybean, pigeonpea, sorghum, cotton, and grape.

(Key words: Carbon sequestration, organic carbon, soybean, glyricidia)

INTRODUCTION

Carbon sequestration can be defined as the capture and secure storage of carbon that would be emitted in the atmosphere. The idea is to first prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, and second secure carbon from the atmosphere by various means and store in to the soil, (Mahdi and Kaisi, 2008). Soil organic carbon sequestration is process of transferring carbon dioxide from the atmosphere into the soil trough crop residue and other organic solids and in a form that is not immediately reemitted (Lal, 2004a). 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 through its effect on the chemical, biological, and physical properties of soil. The CO_2 concentration in the atmosphere has increased from 280 ppm in 1850 to 391 ppm in 2012 . There has been increase in atmospheric methane (CO_2) nitrous oxide (N_2O) concentration over same period to global warming (Anonymous, 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 their productivity are being appreciated since the dawn of human civilization. Important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use. The effect of a certain land use change or soil management practice on atmospheric CO_2 needs thus to be considered in a broader context. There is, however, great potential for increasing the soil C sequestration through adoption of forest land use and mixed vegetation cover land management practices that will increase soil carbon, the win–win strategy of increased C storage and soil fertility advocated by (Lal, 2004b).

Marathwada region is well known for cultivation of cotton, soybean, gram, pigeonpea, sugarcane, horticulture crops like mango, pomegranate crops can successfully cultivated in numerous locations throughout the districts. Information on soil organic carbon stock in various land use system is scanty. Therefore, it provides scope for assessing soil organic carbon stock in identified land use system. Present investigation was aimed to assess

1. P.G. Student, Dept. of Soil Science, College of Agriculture, VNMKV, Parbhani
2. Head, Dept. of Soil Science, College of Agriculture, VNMKV, Parbhani
3 Jr. Res. Assistant, Dept. of Soil Science, College of Agriculture, VNMKV, Parbhani

C-stock and its sequestration potential under different land use such as cotton, soybean, gram, tur, sorghum, grape, glyricidia and fallow land in Latur, Osmanabad and Beed district of Marathwada region.

MATERIALS AND METHODS

Geographically the Latur, Osmanabad and Beed districts are located in between 18^0 05'to 18^0 25 ̇N latitude and 76^0 25' to 77^0 25' longitude, 18^0 28' to 19^0 28'North latitude , 76^0 25' to 77^0 25'longitude and 180 26' to 190 26' N latitude and 740 54' to 760 57' East longitude respectively. The total geographical area of the Latur, Osmanabad and Beed districts are 7372 sq. km and 7512.40 sq. km and 10693 sq. km 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 32.7^0 to 18.1^0 C, 33.4^0 to 18.6^0C and 33.1^0 C and 18.5^0 C of Latur, in Latur, Osmanabad and Beed district respectively. Representative field was selected under different land use such as cotton, sorghum, soybean, gram, tur, grape, glyricidia and fallow land in Latur, Osmanabad and Beed district of Marathwada region. Seven (7) representative soil profiles were selected and classified as per soil taxonomy (Anonymous, 2015). 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 (Anonymous, 2015). Soil inorganic carbon (SIC) was calculated by using 12 per cent carbon value in $CaCO_3$.

Estimation of carbon stock/pool

The soil carbon stocks were estimated by mass, volume and density relationship (Batjes, 1996) and reported in Table 3. 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).

C Stock Depth = TC (i) * BD (i) * TH (i) * 10^{-3} mg kg^{-1} * 104 m^2 ha^{-1} ....eqn[1]

Where, C Stock (Depth) = Cumulative Soil Carbon Stock (Mg ha^{-1})

TC (i) = Total soil C concentration in the *i*th layer (g C kg^{-1})

BD (i) = Bulk density of the *i*th layer (Mg m^{-3})

TH (i) = Thickness of *i*th layer (m)

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

$$\textbf{Carbon sequestration potential (t ha}^{-1}\textbf{ yr}^{-1}) = \frac{\text{Carbon sequestered (t ha}^{-1})}{\text{Number of year's experiment}}$$

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

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

RESULTS AND DISCUSSION

The bulk density of 7 pedons varied from 1.35 to 1.63 Mg m^{-3}. The data in the Table 1 represent that the bulk density of the soils under different land use in glyricidia varied from 1.5 to 1.9 Mg m^{-3} and in grape from 1.35 to 1.9 Mg m^{-3}.In general bulk density showed increase from surface to subsurface soil. High value of sub surface soil might be due to murrum layer under very shallow soils Entisol. These soils generally found under fallow land, glyricidia and horticultural crop grape. The data detected in the Table 1 indicated that the hydraulic conductivity of the studied soil varied from 1.29 to 24.63 cm hr^{-1}. This variation attributes to textural difference. The highest hydraulic conductivity in surface soil was noticed maximum under grape (18.45 cm hr^{-1}) and minimum in soybean crop (1.29 cm hr^{-1}).

The data regarding pH in Table 2 shows that the lowest soil pH was observed at the surface in glyricidia soil (Lithic Ustorthents). It might be due to organic matter decomposition and the subsequent removal of bases from the surface soil. Conversely, the highest soil pH was observed under TypicHaplustepts and TypicHapluster. These soils came under the land use sorghum with pH 7.52 to 8.13, soybean 6.8 to 8.37, pigeonpea 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. Patil *et al.* (2013) found soil pH in the ranged from 6.8 to 8.3 of Osmanabad tahsil. Electrical conductivity of the studied soil varied from 0.11 to 0.90 dSm^{-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. The maximum amount organic carbon content in soil was observed at glyricidia plantation 0.91 to 1.02 per cent. In general these soil contain more organic carbon than agriculture land use because of no tillage and pedoturbation at soil surface addition of biomass and deep root system. The surface soil under soybean had high amount of organic carbon 0.28 to 0.85 per cent followed by in pigeonpea 0.26 to 0.78 per cent, sorghum 0.28 to 0.69 per cent and cotton 0.53 to 0.63 per cent. This indicated that the leguminous crop like soybean and pigeonpea added more organic matter in soil than the cereal crop sorghum and cash crop cotton. Similar decreasing trend of organic carbon with increasing depth of soil reported by Rejak and Kundu (2023), they found organic carbon in between low to medium category. The maximum calcium carbonate was notice under sorghum

(10.30 to 17.00%) which was coinciding with soil type TypicHapluster (P5) and TypicHaplustept (P6). The minimum calcium carbonate was observed under land use. Glyricidia (3.4 to 3.9 %)followed by fallow land (3.6 to 5.3%) and grape (3.2 to 4.7 %) which were corresponded to soil type Lithic Ustorthent (P1 to P6). The calcium carbonate content in Lithic Ustorthent had very low value than the TypicHaplustepts and TypicHaplusterts, it might be due to the leaching of $(HCO_3)_2$ which get precipitated down to slope as well as at lower horizon. CEC of LitichUstorthent soil varied from 18.55 to 32.61 C mol (P+) kg^{-1}, CEC of TypicHaplustepts varied from 34.75 to 63.45 C mol (P+) kg^{-1} and TypicHaplusterts varied from 36.39 to 69.45 C mol (P^+) kg^{-1}. This indicated that CEC varied with soil type. The minimum CEC was noticed under glyricidia followed by grape. (Table 1), whereas maximum CEC was observed under pigeionpea (P6) followed by soybean (P4), sorghum (P5) and cotton (P7). Adkine *et al.*(2018) recorded CEC from 24.56 to 78.18 cmol (p^+) kg^{-1} in soils of Krishna Valley and Mane *et al* .(2015) reported that CEC of TypicHaplustepts ranged from 30.9 to 62.0 C mol (P^+) kg^{-1} .

The soil organic carbon stock were estimated by mass, volume and density relationship (Batjes, 1996) and results are reported in Table 2.The maximum SOC was noticed under glyricidia (P1) and minimum SOC was noticed under sorghum (P5) at surface. However, the maximum SOC at 0-15 cm soil depth was noticed under glyricidia i.e. 24.22 to 24.48 t ha^{-1}, this might be due to addition of large amount of organic matter and minimum in grape i.e. 11.74 t ha^{-1}. The depth wise SOC stock was found decreased because the SOC in soil is closely associated with organic carbon content in soil. Whereas 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} followed by pigeonpea (37.61 to 68.44 t ha^{-1}). However, it was also observed that the maximum SIC occurred in TypicHaplusterts, while the minimum SIC was found in Lithic Ustorthents.The minimum SIC stock in Gli ricidia may be attributed to the decomposition of organic matter, which solubilized the $CaCO_3$ and caused it to move down through the soil solum. Depth-wise SIC stock was found to increase due to the higher amount of $CaCO_3$ content in the subsoil, which increased with depth (Table 2). Bhattacharya *et al.* (2009) reported that SOC stock in 48 soil series was 24.3 Pg.

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 centimeters. The total soil carbon stock (TSCS) varied significantly across different soil types. TypicHaplusterts showed the highest TSCS values, ranging from 149.15 to 464.35 t ha^{-1}, whereas the lowest values were found in Lithic Ustorthant soils, ranging from 27.1 to 68.43 t ha^{-1}. Based on these findings, it is evident that Vertisol exhibited the maximum TSCS at 464.35 t ha^{-1}, followed by Inceptisol and Entisols. Vekanna *et al.*(2014) reported that the Vertisols and associated soils contained greater total C stocks, followed by Inceptisols and Alfisols.

The data presented in Table 3 demonstrated that the highest carbon sequestration potential was observed under glyricidia (1.62 and 1.80 t ha^{-1}) $year^{-1}$ followed by legume crop soybean (1.6 t ha^{-1} $year^{-1}$). The carbon sequestration potential under cereal crop sorghum was found in between 0.53 t ha^{-1} $year^{-1}$ whereas under cash crop, cotton it was 1.08 t ha^{-1} $year^{-1}$ and horticulture crop grape it was 0.22 t ha^{-1} $year^{-1}$. The results indicated that the soil under glyricidia had the highest carbon sequestration potential, followed by soils under legume crops (soybean and pigeonpea), cereals (sorghum), cash crops (cotton), and horticultural crops (grapes). This suggests that soils under horticultural crops and cash crops like cotton experience the greatest loss of soil organic carbon (SOC), followed by sorghum, pigeonpea, and soybean. Therefore, these lands require improved soil management practices, such as balanced fertilizer 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. The soil carbon total stock found highest in the cotton cropping pattern (calcic Haplusterts), lowest total carbon stock was under red gram cropping pattern (Lithic Ustorthents) (Tadi,2021). Soil carbon stock and equivalent CO_2 lowest value recorded in cultivated land was reported by Singh *et al.* (2023).

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 ranged from low to very high. The high CEC is attributed to the high amount of clay content in soil. The maximum SOC and minimum SIC at surface and 0-15 soil depth was noticed at glyricidia. The total carbon stock also varied with soil type. Maximum TSCS was noted at TypicHaplusterts and minimum at Lithic Ustorthent. The maximum SOC stock and carbon sequestration potential was found under glyricidia followed by leguminous crop, (soybean and pigeonpea), cereal crop (sorghum), cash crop (cotton) and lowest at horticultural crop (grape).

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)	B D ($Mg\ m^{-3}$)	H C ($cm\ hr^{-1}$)	pH	Ec (dSm^{-1})	O.C (%)	$CaCO_3$ (%)	CEC [cmol (p^+) Kg^{-1}]
Pedon 1 Borphadi ,Tq. Beed, Dist. Beed *(Lithic Ustorthent)* land use Glyricidia								
Ap	0-19	1.60	16.88	6.65	0.19	1.02	3.70	23.12
Cr	19-32	1.80	22.54	6.95	0.20	0.87	3.90	21.22
Pedon 2 Shend, Tq. Latur, Dist. Latur *(Lithic Ustorthent)* land use Glyricidia								
Ap	0-7	1.50	14.87	6.75	0.14	0.99	3.40	31.45
Cr	8-20	1.90	21.32	7.12	0.11	0.91	3.70	18.55
Pedon 3 Alni, Tq. Osmanabad , Dist. Osmanabad *(Lithic Ustorthent)* land use Grape								
Ap	0-25	1.35	18.45	6.95	0.33	0.58	4.10	32.61
Cr	25-40	1.90	20.67	7.40	0.38	0.42	4.50	21.65
Pedon 4 Ter, Tq. Osmanabad, Dist. 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, Tq. Bhoom, Dist. Osmanabad *(TypicHaplustept)* 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, Tq. Paranda, Dist. Osmanabad (TypicHaplustept) 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 ,Tq. Beed , Dist. Beed *(TypicHapluster)* 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 ,Tq. Beed, Dist. 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, Tq. Latur, Dist. Latur*(Lithic Ustorthent)* land use Glyricidia							
Ap	0-7	10.39	24.22	4.20	9.80	34.02	46.19
Cr	8-20	20.74		10.86			
Pedon 3 Alni, Tq. Osmanabad , Dist. 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, Tq. Osmanabad, Dist. 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, Tq. Bhoom, Dist. Osmanabad*(TypicHaplustept)* land useSorghum							
Ap	0-8	6.14	12.14	19.22	38.36	50.05	149.15
Bw	8-15	6.00		19.14			
Bw	15-26	07.71		33.42			
Cr	26-42	08.15		49.37			
Pedon 6 Shekhapur, Tq. Paranda,Dist. Osmanabad*(TypicHaplustept)* 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 ,Tq. Beed , Dist. Beed*(TypicHapluster)* 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			

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} $year^{-1}$)	Initial year organic carbon stock (t ha^{-1} $year^{-1}$)	Carbon sequestration potential (t ha^{-1} $year^{-1}$)
Pedon 1 Borphadi ,Tq. Beed, Dist. Beed*(Lithic Ustorthent)* land use Glyricidia				
Glyricidia	0-32	51.35	42.34	1.8
Pedon 2 Shend, Tq. Latur, Dist. Latur*(Lithic Ustorthent)* land use Glyricidia				
Glyricidia	0-20	31.13	22.87	1.62
Pedon 3 Alni, Tq. Osmanabad , Dist. Osmanabad*(Lithic Ustorthent)* land use Grape				
Grape	0-40	31.54	30.44	0.22
Pedon 4 Ter, Tq. Osmanabad, Dist. Osmanabad*(TypicHapluster)* land use Soybean				
Soybean	0-160	134.27	125.90	1.6
Pedon 5 Khasapur, Tq. Bhoom, Dist. Osmanabad*(TypicHaplustept)* land useSorghum				
Sorghum	0-42	28	25.34	0.53
Pedon6 Shekhapur, Tq.Paranda,Dist.Osmanabad*(TypicHaplustept)* land use Pigeon pea				
Pigeon pea	0-80	76.01	71.45	0.91
Pedon 7 Umrai ,Tq. Beed , Dist. Beed*(TypicHapluster)* land use Cotton				
Cotton	0-150	98.66	93.23	1.08

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