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Navale SD
M. Sc. Student (Soil Science), MPKV, Rahuri, Maharashtra, India

Todmal SM
Assistant Professor, Department of Soil Science, MPKV, Rahuri, Maharashtra, India

Kamble BM
Head, Department of Soil Science, MPKV., Rahuri, Maharashtra, India

V Rajagopal
Soil Scientist, ICAR-NIASM, Baramati, Maharashtra, India

Bandgar VK
Ph.D. Student (Soil Science), MPKV, Rahuri, Maharashtra, India

Corresponding Author:
Navale SD
M. Sc. Student (Soil Science), MPKV, Rahuri, Maharashtra, India

Effect of land use systems and coarse fragments on soil carbon dynamics on the shallow gravelly land

Navale SD, Todmal SM, Kamble BM, V Rajagopal and Bandgar VK

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Abstract
The present investigation entitled 'Effect of different land use systems and coarse fragments on soil carbon dynamics on the shallow gravelly land' was carried out at ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati during 2023-24 to assess the effect of different land use systems *i.e.* horticultural crops (mango, sapota, grapes), field crops (sugarcane, wheat) and perennial grass (napier) on soil carbon pools. Three soil depths *viz.,* D_1 (0-15 cm), D_2 (15-30 cm) and D_3 (30-45 cm) were selected from each land use system with four replications and data analyzed by factorial randomized block design. The significantly highest soil microbial biomass carbon (305.3 mg kg^{-1}), water soluble carbon (266.1 mg kg^{-1}), total organic carbon (3.64 g kg^{-1}), very labile carbon (0.23 g kg^{-1}), labile carbon (0.57 g kg^{-1}) and less labile carbon (1.26 g kg^{-1}) was recorded in mango while non labile carbon (1.64 g kg^{-1}) was recorded significantly highest in grapes. The significantly lowest soil microbial biomass carbon (235.3 mg kg^{-1}), water soluble carbon (199.3 mg kg^{-1}), total organic carbon (2.90 g kg^{-1}), very labile carbon (0.14 g kg^{-1}), labile carbon (0.34 g kg^{-1}), less labile carbon (1.06 g kg^{-1}) and non-labile carbon (1.34 g kg^{-1}) were recorded in wheat. Among all land use systems carbon pools decreased with increase in soil depth.

Keywords: Carbon pools, soil microbial biomass carbon, labile carbon. etc.

Introduction
Shallow gravelly land is those with depth up to 50 cm and large proportion of the land mass is with gravel-sized (2-75 mm in diameter) particles (Huang and Sumner, 2011; Coduto, 1999) [8, 5]. The gravelly land is very widely distributed India and covers approximately 13.6 Mha in India (Reddy and Minhas, 2017) [13]. The Central Deccan Plateau, spanning parts of Maharashtra, Karnataka, and Telangana in India, gravelly land is quite common, particularly in specific sub-regions. In Western Maharashtra region viz., Ahmednagar, Pune, and parts of Solapur have land parcel have higher gravel content, especially in uplands and foothills of Western *Ghats*.

Gravelly land significantly impacts plant growth primarily due to its influence on soil structure, water retention, and nutrient availability. These soils typically have poor water-holding capacity, which can lead to drought stress and reduced plant growth. The presence of gravel restricts root penetration, limiting plants' ability to anchor securely and access deeper water and nutrients (Gyssels *et al*., 2005) [7].

Soil carbon pools are critical components influencing soil health and agricultural productivity. Soil carbon exists in various forms, primarily as organic matter derived from plant residues and microbial biomass. It plays a vital role in soil structure, water retention, and nutrient cycling. Labile carbon is quickly decomposed, fueling microbial activity and nutrient availability in the short term, while stable carbon, such as humus, contributes to long-term soil fertility and resilience (Lal, 2004) [9].

Managing crop residues plays a critical role in soil carbon dynamics. Practices such as leaving crop residues on the soil surface or incorporating them into the soil can enhance SOC levels by providing organic matter for microbial decomposition. This not only improves soil aggregation, water retention, and nutrient availability but also supports microbial communities that aid in nutrient cycling. Conversely, removing crop residues for alternative uses, such as fodder or fuel, depletes SOC and diminishes soil fertility over successive cropping seasons (Lal, 2004) [10].

Materials and Methods

Soil samples were collected from each land use system during summer 2023-24 at ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati Tehsil, Pune, Maharashtra in order to assess the effect of introduction of different land use system *viz.,* horticultural crops (mango, sapota, grapes), field crops (sugarcane, wheat) and perennial grass (napier) on soil carbon pools. Design selected for experiment is factorial randomized block design with four replications.

Carbon pools

Total organic carbon and organic carbon pools

Different fractions of SOC were estimated through a modified Walkley and Black method as described by Chan *et al.* (2001) [4]. The pools are determined by using 5, 10 and 20 ml of concentrated sulphuric acid that resulted in three acid aqueous solution ratios of 0.5:1, 1:1 and 2:1 (corresponding to 12.0, 18.0 and 24.0 N of H_2SO_4, respectively).

1. Very labile carbon (Pool I) : Organic C oxidizable under 12.0 N H_2SO_4
2. Labile carbon (Pool II) : Difference in SOC extracted between 18.0 N and 12.0 N H_2SO_4
3. Less labile carbon (Pool III) : Difference in SOC extracted between 24.0 N and 18.0 N H_2SO_4
4. Non labile carbon (Pool IV) : Obtained by subtraction of SOC extracted by 24 N H_2SO_4 and TOC

Active and passive pool

Active pools = Very labile + Labile carbon (rapidly decompose and get oxidized easily with any changes in land use practice

Passive pools = Less labile + Non labile carbon (more stable and decomposed slowly by microbial activity)

Results and Discussion

Soil organic carbon

The significantly highest mean soil organic carbon (SOC) content (3.14 g kg^{-1}) was recorded under mango which was on par with sapota (3.06 g kg^{-1}) and grapes (3.00 g kg^{-1}). The lowest mean soil organic carbon (2.27 g kg^{-1}) was observed in the wheat (Table 1). The results indicated that soil organic carbon distribution pattern varied significantly with soil depth. The depth wise comparison indicated that highest content (3.47 g kg^{-1}) was recorded at depth D_1 followed by depth D_2 (11.4 g kg^{-1}) and depth D_3 (2.27 g kg^{-1}). Among soil depths and land use systems lowest soil organic carbon content (2.05 g kg^{-1}) was found at depth D_3 in wheat and highest (3.89 g kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

The higher soil organic carbon recorded in orchards where more residue was added through leaf litter (Bhavya *et al.* 2018) [3]. Reza *et al.* (2014) [14] had also reported that soils under horticulture and forest systems showed greater amounts of soil organic carbon than agriculture land. Lower organic carbon in agricultural crops might be due to exposure of plant residues and organic matter to higher temperature and moisture, frequent tillage operations in agricultural crops which in turn increased oxidation of organic matter. These results are in accordance with Selassie and Ayanna (2013) [16].

Total organic carbon

The significantly highest mean soil total organic carbon (3.64 g kg^{-1}) was recorded under mango which was on par with grapes (3.46 g kg^{-1}) and sapota (3.39 g kg^{-1}). The lowest mean soil TOC (2.90 g kg^{-1}) was observed in wheat (Table 2). The results indicated that TOC varied significantly with soil depth. The depth wise comparison indicated that the highest mean soil TOC (3.85 g kg^{-1}) was recorded at depth D_1 followed by depth D_2 (3.04 g kg^{-1}) and depth D_3 (2.78 g kg^{-1}). Among soil depths and land use systems the lowest TOC (2.50 g kg^{-1}) was found at depth D_3 in wheat and highest (4.34 g kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

Orchards (like mango, grapes, and sapota) had extensive and deeper root systems compared to annual crops. The deeper and more extensive root systems of these trees contributed more organic matter to the soil as roots die off and decompose, leading to higher TOC levels as compared to agricultural crops (Six *et al*., 2000) [19]. Orchards needed less frequent tillage compared to annual cropping systems. Reduced tillage helped to maintain soil organic matter and prevented the rapid decomposition of organic materials (Paul, 2014) [12]. Organic matter tends to accumulate in the upper soil layers where it was most actively added and where biological activity was highest. As you moved deeper into the soil profile, the TOC content generally decreased due to less frequent addition of organic matter. The results are in agreement with Baldock and Skjemstad (2000) [2].

Very Labile Carbon and labile Carbon

The significantly highest mean soil very labile carbon (0.23 g kg^{-1}) was recorded under mango which was on par with sapota (0.22 g kg^{-1}) and grapes (0.20 g kg^{-1}). The lowest mean soil very labile carbon (0.14 g kg^{-1}) was observed in wheat (Table 3). The results indicated that very labile carbon varied significantly with soil depth. The depth wise comparison indicated that the highest mean soil very labile carbon (0.22 g kg^{-1}) was recorded at depth D_1 followed by depth D_2 (0.18 g kg^{-1}) and depth D_3 (0.16 g kg^{-1}). Among soil depths and land use systems lowest very labile carbon (0.12 g kg^{-1}) was found at depth D_3 in wheat and highest (0.25 g kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

The significantly highest mean soil labile carbon (0.57 g kg^{-1}) was recorded under mango which was on par with grapes (0.56 g kg-1) and sapota (0.56 g kg^{-1}). The lowest mean soil labile carbon (0.34 g kg^{-1}) was observed in wheat (Table 4) The results indicated that labile carbon varied significantly with soil depth. The depth wise comparison indicated that highest mean labile carbon (0.53 g kg^{-1}) was recorded at depth D_1 followed by depth D_2 (0.47 g kg^{-1}) and depth D_3 (0.41 g kg^{-1}). Among soil depths and land use systems the lowest soil labile carbon (0.29 g kg^{-1}) was found at depth D_3 in wheat and highest (0.63 g kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

Higher soil carbon active pool (very labile carbon and labile carbon) in horticultural land use systems could be attributed to undisturbed litter additions for long periods. In contrast, disturbances caused by cultivation and low additions of organic matter were reasons for low soil very labile carbon and labile carbon in field crops (Sahoo *et al*. 2019) [15]. Soil very labile carbon and labile carbon was more in surface soil than the subsurface soil potentially due to higher amounts of added root biomass and exudation coupled with surface crop residues. These results are aligned with Padbhushan *et al*., (2015) [11].

Less labile carbon and non-labile carbon

The significantly highest mean soil less labile carbon (1.26 g kg^{-1}) was recorded under mango followed by grapes (1.18 g kg^{-1}), sapota (1.16 g kg^{-1}) and sugarcane (1.14 g kg^{-1}). The lowest mean soil less labile carbon (1.06 g kg^{-1}) was observed in wheat (Table 5) The results indicated that soil less labile carbon varied significantly with soil depth. The depth wise comparison indicated that highest mean soil less labile carbon (1.28 g kg^{-1}) was recorded at depth D_1 followed by depth D_2 (1.15 g kg^{-1}) and depth D_3 (1.01 g kg^{-1}). Among soil depths and land use systems the lowest soil less labile carbon (0.93 g kg^{-1}) was found at depth D_3 in wheat and highest (1.41 g kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

The significantly highest mean soil non labile carbon (1.64 g kg^{-1}) was recorded under grapes which was on par with sapota (1.57 g kg^{-1}). The lowest soil non labile carbon (1.34 g kg^{-1}) was observed in wheat (Table 6). The results indicated that soil non labile carbon varied significantly with soil depth. The depth wise comparison indicated that the highest amount of soil non labile carbon (1.73 g kg^{-1}) was recorded at depth D_1 followed by depth D2 (1.38 g kg^{-1}) and depth D3 (1.29 g kg^{-1}). Among soil depths and land use systems the lowest soil non labile carbon (1.18 g kg^{-1}) was found at depth D_3 in wheat and highest (1.95 g kg^{-1}) in grapes at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

The passive pool (less labile and non-labile carbon content) was found higher under horticulture compared to agriculture land use system. Grapes orchard found higher content of non-labile pool compared to all other LUS. This might be due to larger addition of plant residue in the soil by litter fall since long time and their stabilization by the humification process. These results are in agreement with Datta *et al*. (2015) [6].

Soil microbial biomass carbon (SMBC) and water-soluble carbon (WSC)

The significantly highest mean soil microbial biomass carbon (305.3 mg kg^{-1}) was recorded under mango which was on par with grapes (287.1 mg kg^{-1}), sapota (280.3 mg kg^{-1}) and sugarcane (272.2 mg kg^{-1}). The lowest mean SMBC (235.3 mg kg^{-1}) was observed in wheat (Table 7). The results indicated that SMBC varied significantly with soil depth. The depth wise comparison indicated that highest mean SMBC (341.6 mg kg^{-1}) was recorded at depth D_1 followed by depth D_2 (260.3 mg kg^{-1}) and depth D_3 (209.8 mg kg^{-1}). Among soil depths and land use systems lowest SMBC (190.3 mg kg^{-1}) was found at depth D_3 in wheat and highest (392.1 mg kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

The significantly highest mean soil water soluble carbon (266.1 mg kg^{-1}) was recorded under mango which was on par with grapes (254.3 mg kg^{-1}) and sapota (248.5 mg kg^{-1}The lowest mean soil WSC (199.3 mg kg^{-1}) was observed in wheat (Table 8). The results indicated that WSC varied significantly with soil depth. The depth wise comparison indicated that highest soil WSC (305.4 mg kg^{-1}) was recorded at depth D_1 followed by depth D_2 (215.9 mg kg^{-1}) and depth D_3 (180.7 mg kg^{-1}). Among soil depths and land use systems lowest soil WSC (162.2 mg kg^{-1}) was found at depth D_3 in wheat and highest (350.5 mg kg^{-1}) in mango at D_1 depth. The interaction between land use systems and soil depths was found statistically significant.

Microbial biomass carbon and water-soluble carbon were most active and mobile form of organic matter in soils. It believed to be derived from plant roots, litter and soil humus, known as labile substrate for microbial activity. It decomposes within few weeks or months. (Stevenson 1982) [20]. Low concentration of microbial biomass carbon and water-soluble carbon in agricultural land use system attributed to intensive tillage practices (Shrestha *et al*., 2006) [18]. Tillage reduced microbial biomass carbon content by affecting the moisture content. It enhanced soil aeration and through exposure of organic matter, protected aggregate to microbial attack, accelerated organic carbon oxidation (Beare *et al*. 1994) [2]. These results are in conformity with Sharma *et al*. (2014) [17] and Katti *et al*. (2020) [9]. Among the soil depths the surface layer showed higher microbial population and decreased with depth.

Table 1: Effect of land use systems on soil organic carbon

Land use systems	Soil organic carbon (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	3.89	3.12	2.42	3.14
Grapes	3.78	3.02	2.38	3.06
Sapota	3.85	2.82	2.32	3.00
Sugarcane	3.40	2.52	2.16	2.69
Napier	3.12	2.43	2.20	2.58
Wheat	2.65	2.12	2.05	2.27
Mean	3.47	2.67	2.27	
	S.E(m)±	C.D. at 5%		
LUS	0.07	0.21		
Depth	0.07	0.20		
LUS X Depth	0.148	0.42		

Table 2: Effect of land use systems on total organic carbon

Land use systems	TOC (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	4.34	3.40	3.18	3.64
Grapes	4.15	3.26	2.97	3.46
Sapota	4.04	3.21	2.92	3.39
Sugarcane	3.62	2.81	2.56	3.00
Napier	3.51	2.79	2.54	2.95
Wheat	3.43	2.76	2.50	2.90
Mean	3.85	3.04	2.78	
	S.E(m)±		C.D. at 5%	
LUS	0.11		0.31	
Depth	0.18		0.50	
LUS X Depth	0.22		0.62	

Table 3: Effect of land use systems on very labile carbon

Land use systems	Very labile carbon (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	0.25	0.23	0.21	0.23
Grapes	0.23	0.19	0.17	0.20
Sapota	0.24	0.21	0.20	0.22
Sugarcane	0.22	0.17	0.15	0.18
Napier	0.19	0.15	0.13	0.16
Wheat	0.16	0.13	0.12	0.14
Mean	0.22	0.18	0.16	
	S.E(m)±		C.D. at 5%	
LUS	0.01		0.03	
Depth	0.007		0.02	
LUS X Depth	0.007		0.02	

Table 4: Effect of land use systems on labile carbon

Land use systems	Labile carbon (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	0.63	0.60	0.49	0.57
Grapes	0.62	0.57	0.50	0.56
Sapota	0.60	0.56	0.52	0.56
Sugarcane	0.52	0.40	0.35	0.42
Napier	0.4	0.34	0.30	0.37
Wheat	0.42	0.32	0.29	0.34
Mean	0.53	0.47	0.41	
	S.E(m)±		C.D. at 5%	
Land use	0.007		0.02	
Depth	0.02		0.05	
Land use X Depth	0.02		0.07	

Table 5: Effect of land use systems on less labile carbon

Land use systems	Less labile carbon (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	1.41	1.21	1.17	1.26
Grapes	1.35	1.20	1.0	1.18
Sapota	1.29	1.18	1.02	1.16
Sugarcane	1.27	1.15	1.00	1.14
Napier	1.20	1.10	0.95	1.08
Wheat	1.17	1.08	0.93	1.06
Mean	1.28	1.15	1.01	
	S.E(m)±		C.D. at 5%	
LUS	0.021		0.06	
Depth	0.014		0.04	
LUS X Depth	0.028		0.08	

Table 6: Effect of land use systems on non-labile carbon

Land use systems	Non labile carbon (g kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	1.75	1.45	1.32	1.51
Grapes	1.95	1.55	1.42	1.64
Sapota	1.85	1.50	1.36	1.57
Sugarcane	1.61	1.32	1.23	1.39
Napier	1.60	1.26	1.21	1.36
Wheat	1.62	1.21	1.18	1.34
Mean	1.73	1.38	1.29	
	S.E(m)±		C.D. at 5%	
LUS	0.028		0.08	
Depth	0.081		0.23	
LUS X Depth	0.035		0.10	

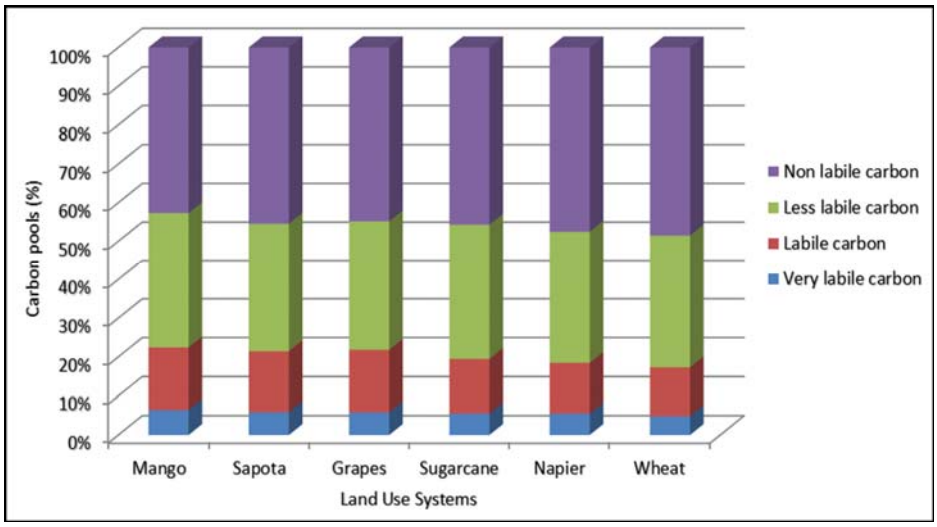

Fig 1: Percent contribution of soil organic carbon pools in different land use systems

Table 7: Effect of land use systems on soil microbial biomass carbon

Land use systems	SMBC (mg kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	392.1	296.5	226.5	305.3
Grapes	365.6	275.6	220.2	287.1
Sapota	356.2	269.4	215.2	280.3
Sugarcane	345.6	260.5	210.5	272.2
Napier	300.1	234.6	196.2	243.6
Wheat	290.2	225.6	190.2	235.3
Mean	341.63	260.37	209.80	
	S.E(m)±		C.D. at 5%	
LUS	12.4		35.2	
Depth	22.51		63.5	
LUS X Depth	17.73		50.0	

Table 8: Effect of land use systems on water soluble carbon

Land use systems	WSC (mg kg^{-1})			
	D_1 (0-15 cm)	D_2 (15-30 cm)	D_3(30-45 cm)	Mean
Mango	350.5	252.2	195.5	266.1
Grapes	332.2	240.6	190.2	254.3
Sapota	323.0	236.2	186.4	248.5
Sugarcane	293.5	199.3	179.4	224.1
Napier	275.2	190.0	170.7	212.0
Wheat	258.4	177.2	162.2	199.3
Mean	305.4	215.9	180.7	
	S.E(m)±		C.D. at 5%	
LUS	8.51		24.00	
Depth	11.1		31.5	
LUS X Depth	14.9		42.1	

Conclusion

The significantly higher total organic carbon and other carbon pools observed in orchard crops as compared to field crops and grassland due to high intensity of litter fall and organic residues in orchards. The proportion of passive carbon pools (less labile carbon and non-labile carbon) was higher than active carbon pool (very labile carbon and non-labile carbon), in all land use systems suggesting that it consisted of stable organic matter that was resistant to decomposition and could remain in soil for hundreds to thousands of years.

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