



Soil carbon dynamics, carbon budget and its relationship with crop yield under different cropping systems in Vertisols of Central India

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Received: 28 September 2018; Accepted: 24 June 2019

ABSTRACT

The present study was carried out in the farmers' field during 2014–15 in the agro-ecological sub-region 10.1, covering Sehore and Vidisha of Madhya Pradesh, India. The study was aimed to quantify the annual biomass carbon addition and carbon loss from cultivated Vertisols under different cropping systems and its impact on crop yield. The result indicates that loss of soil organic carbon (SOC) due to intensive crop cultivation was 31.03% and 46.31% as compared to pristine soils of Sehore and Vidisha district, respectively. Among the cropping systems, SOC pool values are relatively higher under legume based cropping system (soybean-wheat and soybean-chickpea) than cereal-cereal cropping system (rice-wheat). The loss of carbon from passive pools was considerably lower (15.72–23.53%) under legume based cropping system as compared to cereal based cropping system (30.20%). The C balance sheet in Sehore and Vidisha districts indicates that the annual loss of C from soil was much less than the annual input of biomass C into the soil, thereby, maintaining a positive C balance in soil to the tune of 1666 (soybean- chickpea system in Sehore) to 2008 kg C (soybean-wheat system in Vidisha) in the soil. Thus, the study concludes that legume based cropping system in Vertisol are soil carbon restorative process as compared to cereal-cereal based cropping system.

Key words: Carbon pools, Central India, Legume crop, Soil carbon

In India, Vertisols cover about 72.9 mha which accounts for 22.2% geographical area of the country; distributed mainly in the central India. These soils contain a high proportion of smectite clay and offers scope for carbon sequestration (Kundu *et al.* 2001). In recent years, crop yields are either stagnating or declining due to poor nutrient and water use efficiency, nutrient mining and soil degradation. A low SOC concentration of cropland soils (0.1 to 0.5%) and quality of carbon is the principal cause of decline in soil quality and crop productivity. Though, the labile C pool has the direct impact on nutrient supply and crop productivity (Mandal *et al.* 2008), highly recalcitrant or passive C pool which contributes to the overall carbon stock also in due course of time by microbial activities influences quality and productivity to soil (Weil *et al.* 2003). Thus, management practices has to be designed in such a way to transfer significant amount of C pools from active to stable pools so as to enhance the SOC content in soil.

There are several evidences to indicate that certain fractions of SOC are more important in maintaining soil quality and crop yield (Kundu *et al.* 2014); and are therefore more sensitive to management practices (Chan 1997).

Tillage practice is likely to affect carbon retention in soil by disrupting soil aggregates which provides better access for the decomposers, leading to a progressive decrease in soil organic carbon content (Bhattacharyya *et al.* 2006). Several researchers across the world reported that perennial horticultural system has always had an edge over annual cropping systems (Bhavya *et al.* 2017, Shrestha and Malla 2016, Janiola and Marin 2016, Chandran *et al.* 2016). In addition to the cropping system impact on SOC pools, many studies also indicated strong positive relationship between the amount of carbon incorporated annually into the soil and soil organic carbon content (Kundu *et al.* 2007). Therefore, carbon budgeting of a given crop production system provides information to indicate whether such production system is carbon restorative process or not. Hence, an investigation was made to quantify annual biomass carbon addition and carbon loss from cultivated Vertisols under different cropping system and its impact on crop yield.

MATERIALS AND METHODS

Soil samples were collected from the agro-ecological sub-region (AESR) 10.1, covering two districts, viz. Sehore (23°12' N; 77°05' E; 1573 m amsl) and Vidisha (22°31' to 23°40' N; 76°22' and 78°08' E; 1646 m amsl) of Madhya Pradesh. Surface soil samples (0-15 cm) were collected from the farmers fields of Sehore (n=120) and Vidisha

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(n=156) district of Madhya Pradesh. The soil samples were processed, sieved through 2 mm sieve and analyzed for physical, chemical and biological attributes following standard methods (Kundu *et al.* 2012). Oxidizable SOC was determined by wet digestion method of Walkley and Black (1934) and total SOC by CHN-analyzer (Thermo Fisher Flash 2000 model). The total SOC was apportioned into different pools by the modified Walkley and Black method as described by Chan *et al.* (2001).

Monitoring of CO₂ loss from soil during cropping as well as fallow period was done by CO₂ trapping method from three farmers' fields in each village and one site during the second fortnight of November, February, April, May, July, August, September and October for three consecutive days during 2014–15. For computing annual addition of biomass C to the soil, quantum of FYM added to the soil by the farmers and left over above ground biomass were recorded. Representative samples of FYM and left over biomass were collected for estimating the C content of FYM and biomass C.

After collection of soil samples from the identified farmer's fields, plot size of 10 m × 10 m was earmarked for growing wheat and chickpea in *rabi* season; and soybean and rice in *kharif* season with uniform recommended agronomic package of practices. In Vidisha district all the farmers (156) had soybean-wheat rotation and in Sehore district 82, 22 and 16 farmers had soybean-wheat, soybean-chickpea and rice-wheat rotation, respectively. At the end of each growing season, yield data were collected by harvesting crop from 5 m×3 m area of earmarked plot of 10 m × 10 m. The crop yield data in each farmer's field was transformed to per cent relative yield by dividing with the maximum yield of the respective crops and thereafter mean relative yield (%) of each farmer's field was computed as per following equation.

$$\text{Mean relative yield (\%)} = (R_0/R_m + K_0/K_m)/2 \times 100$$

where, R₀ and R_m are the observed and maximum yield of the *rabi* crop; and K₀ and K_m are the observed and maximum yield of the rainy season crop.

The data analysis was done by the using with SPSS windows, version 11.0. The significance of the treatment effect was determined using F-test, and to compare the significance difference between two treatments, least significance difference (LSD) was estimated at P<0.05.

RESULTS AND DISCUSSION

Soil fertility status of Sehore and Vidisha districts: Around 2.5%, 70% and 27.5% of the soils of Sehore district were having OC content in high, medium and low range while 0.6%, 23.7% and 75.6% of the soils were high, medium and low in OC content in Vidisha district. In both the district more than 80% soils are having available P status in medium range and more than 75% soils are medium in available K status. The results also indicates that due to cultivation of crops (soybean, wheat, gram and rice), the loss of soil organic C (SOC), available Fe and available Mn from the surface (0-15 cm) soil layer were 31.03, 44.6 and

35.8%, respectively in Sehore district; while the loss of SOC, available K and available Fe were 46.3, 47.6 and 19.9% respectively in Vidisha district as compared to pristine soils of the respective districts. It implies that long term improper crop cultivation and poor nutrient management practices increased the extent of deficiency in the Vertisols of AESR 10.1. Several authors have also reported that organic carbon content and microbial biomass had significantly declined in the cultivated soil as compared to uncultivated/reference/baseline soil (Bueno and Ladha 2009). Therefore, compared to natural vegetation adjoining cultivated soils as a result of prolonged agricultural land use has altered the magnitude, diversity, and spatial variability of some soil properties, mostly those related to fertility (Paz-Gonzalez *et al.* 2000).

Distribution of SOC pools: The distributions of different SOC pools in cultivated and pristine vertisols are presented in Table 1. In both the districts, most of the SOC pools and TOC are higher in pristine soils than the cultivated soils. The mean SOC content of the cultivated Vertisols was 5.27 ± 1.52 g C/kg soil, whereas the mean SOC content in the pristine soil was 8.38 ± 2.45 g C/kg soil. Among the carbon pools in the cultivated Vertisols, active pools of carbon (very labile C, VLC and labile C, LC) contributes 43.77% of the total SOC, whereas passive pools of carbon (less labile C, LLC and non labile C, NLC) contribute 56.23% of the total SOC. In contrast, the active pools of carbon in pristine vertisols were 58.16%, whereas passive pool of carbon was 41.84% of total SOC. Mandal *et al.* (2008) also observed that the mean distribution of different pools of SOC, namely VLC, LC, LLC and NLC in Inceptisol was 33.6%, 17.6%, 11.5% and 37.3% of the total SOC. Among the cropping system practised in Sehore district, SOC pools values are relatively higher under legume based cropping system (soybean- wheat and soybean- chickpea) than cereal-cereal cropping system (rice-wheat).

Carbon losses in Vertisol: Long-term changes in carbon pools under different agro-ecosystem is very important because it directly affects soil quality and crop productivity (Bandaranayake *et al.* 2003). Among the SOC pools, active pool of SOC is very sensitive and it is greatly influenced by various soil management practices. The results indicated that the loss of total SOC due to cultivation over the years in Sehore district was largely from VLC and LC fraction which together contributed 74.69% of the total SOC (Table 1). Similarly, in cultivated Vertisols of Vidisha district, both VLC and LC fraction accounted 84.28% of the total SOC due to cultivation over the years. The mean SOC content of the cultivated Vertisols was 5.27 ± 1.52 g C/kg soil, whereas the mean SOC content in the pristine soil was 8.38 ± 2.45 g C/kg soil, indicating that the net loss of SOC to the tune of 3.11 g C/kg soil (equivalent to 6.97 t/ha) was due to cultivation of crops over the years. Our earlier investigation also revealed that carbon losses from native SOC during seven year period was at the rate of 0.89% of the initial SOC content (Kundu *et al.* 2001). Soil management practices like tillage, crop cultivation and residue burning or removal might have reduced SOC by

Table 1 Different pools of SOC in soils of Sehore and Vidisha districts under different cropping system

District	Cropping system	SOC Pools (g/kg)							% loss of carbon from	
		VLC	LC	LLC	NLC	TOC	Active pool of C	SOC	Active pool	Passive pool
Sehore	Soybean-Wheat	2.04	1.20	2.70	1.38	7.32	3.24	5.94	45.45	15.88
	Soybean-Chickpea	2.07	1.23	2.48	1.50	7.28	3.30	5.78	44.44	17.94
	Rice-Wheat	1.76	0.99	2.28	1.19	6.22	2.75	5.03	53.70	28.45
	Pristine	3.78	2.16	3.04	1.81	10.79	5.94	8.98	-	-
Vidisha	Soybean-Wheat	1.35	0.83	2.14	0.96	5.28	2.18	4.32	63.91	18.85
	Pristine	3.95	2.09	1.74	2.08	9.86	6.04	7.78	-	-
	CD (P=0.05)	0.28	0.13	0.11	0.07	0.87	0.36	0.88	5.19	4.35

VLC- Very labile carbon; LC-Labile carbon; LLC-Less labile carbon; NLC- Non labile carbon; TOC- Total organic carbon; SOC- Soil organic carbon

reducing inputs to the soil, increasing the decomposition of soil organic materials, or both (Srinivasarao *et al.* 2012). Out of the mean loss of SOC (3.11 g C/kg soil) from cultivated vertisol, the contribution of carbon from active and passive pools was 78.72 and 21.28%, respectively indicating that the decomposability of active pool of carbon was 3.7 times higher than passive pools which are relatively very stable and resistant to decomposition.

Further, it was evident from the result that the loss of carbon from passive pools was considerably lower (from 15.72 to 23.53%) under legume based cropping system as compared to cereal based cropping system (30.20%) indicating the role of passive pools in sustaining soil organic carbon (SOC) and crop productivity. Several authors also reported that long-term fertilizer experiments in India indicate the declining trends in the soil organic carbon under cereal-cereal system and highlighted that inclusion of legumes in the cropping system helps in maintaining soil organic carbon, soil quality and crop productivity (Ganeshamurthy 2009).

Seasonal variation in carbon losses under different cropping system: The result on loss of carbon from vertisol under different cropping system due to microbial and root respiration during different months are presented in Table 2. Irrespective of the cropping systems, the loss of carbon from vertisol was maximum in the month of August, ranging from 144.36 mg C/m²/day (soybean-wheat system in Vidisha) to 171.20 mg C/m²/day (rice-wheat system in Sehore),

while the loss of carbon was minimum in the month of May, ranging from 90.03 to 120.46 mg C/m²/day. Similar trend of carbon loss was observed from pristine vertisols, ranging from 50.70 mg C/m²/day (May) to 81.45 mg C/m²/day (August), with a mean value of 68.07 mg C/m²/day. Whereas the mean loss of carbon from vertisol under rice-wheat system was maximum (146.21 mg C/m²/day) followed by soybean-wheat system in Sehore (137.46 mg C/m²/day), and soybean-chickpea system (129.25 mg C/m²/day). Soybean-wheat system in Sehore district showed significantly higher loss of carbon from soil (137.6 mg C/m²/day) due to microbial and root respiration compared to similar system in Vidisha district (126.32 mg C/m²/day) which could be due to higher SOC content in Sehore district (7.32 g/kg soil) as compared to Vidisha district (5.28 g/kg soil). In both the districts mean loss of C from pristine sites through root and microbial respiration were higher than the cropped soil, which could possibly be attributed to higher C content of the pristine sites.

Relationship between carbon pools and crop productivity: The correlation coefficients between different pools of carbon, SOC/TOC and mean relative yield for the combined Sehore and Vidisha districts are presented in Table 3. Among the four C pools, very labile C was highly correlated ($r = 0.9404$) with TOC followed by labile C ($r = 0.8971$), less labile C ($r = 0.8405$) and non labile C ($r = 0.7877$). Similarly with SOC, very labile C was highly correlated ($r = 0.9227$) followed by less labile

Table 2 Carbon loss from Vertisol due to microbial and root respiration under different cropping system.

District	Crop rotation	Carbon loss (mg C/m ² /day)									CD (P=0.05)
		Feb	April	May	July	Aug	Sep	Oct	Nov	Mean	
Sehore	Soybean-Wheat	148.4	138.4	97.2	115.3	162.8	158.4	151.7	126.8	137.4	14.3
	Soybean-Chickpea	136.5	128.4	106.1	118.9	148.8	139.8	140.2	115.3	129.3	16.2
	Rice-Wheat	156.3	132.6	120.5	133.9	171.2	168.6	155.3	131.5	146.2	18.2
Vidisha	Soybean-wheat	132.6	131.6	90.0	121.5	144.4	136.3	132.6	121.4	126.3	12.1

C ($r = 0.9009$), labile C ($r = 0.8826$) and non-labile C ($r = 0.7124$), respectively. The mean crop productivity was better related to SOC ($r = 0.5275$) as compared to TOC ($r = 0.4886$). Among the different C pools, less labile C was highly correlated ($r = 0.5871$) with the crop productivity, followed by very labile C ($r = 0.3893$), labile C ($r = 0.3748$) and non-labile C ($r = 0.2007$). Among the active (very labile + labile C) and passive (less labile + non-labile C) pools of C, the passive pool of C was found to have significantly marked influence on crop productivity ($r = 0.5295$) as compared to active pool of C (0.3920).

Carbon budgeting of a production system: The estimated biomass and biomass carbon inputs to the soil through different crops are presented in Table 4, which showed that biomass carbon inputs ranged from 659 kg C/ha (in rice) to 1118 kg C/ha (in soybean) depending upon the crop type and grain yield. The mean yield ($n = 156$) of wheat and soybean in Vidisha district were 2624 and 1515 kg/ha, respectively, whereas in Sehore district, the observed mean yield of wheat ($n = 98$), gram ($n = 22$), soybean ($n = 104$) and rice ($n = 16$) were 3127, 885, 940 and 2510 kg/ha, respectively (Table 4). The quantum of biomass C entering into the soil annually by the component crops showed that on an average 875 and 1031 kg C/ha was incorporated into the soil by wheat crop in Vidisha and Sehore district, respectively, whereas addition of biomass C through soybean was 1118 and 835 kg C/ha, respectively. The average addition of biomass C through gram and rice crop in Sehore district was 778 and 659 kg C/ha, respectively. It was also observed that average amount of FYM added to the soil annually was less and the quantitative values were 2262 and 2772 kg/ha in Vidisha and Sehore district,

respectively, which in turn supplies around 476 and 525 kg C/ha, respectively. In soybean and gram, the addition of biomass carbon to the soil was through left over trash and roots, whereas in rice-wheat, the biomass addition was through root and left over stubble (after removing the straw). For calculating the biomass carbon entry through below ground root of wheat, rice, soybean and gram, we considered below ground biomass/above ground biomass ratio of 0.302, 0.27, 0.19 and 0.169, respectively based on results obtained from pot culture experiment. It is to mention that while computing biomass carbon inputs, we did not include the inputs through rhizodeposition of carbon from nodules, root turnover and exudates. Several studies also showed that root biomass contributed 31.2% of the above ground biomass in soybean (Kundu *et al.* 2007) and 30% in Indian wheat (Chander *et al.* 1997).

Thus, the C balance sheet under different crop rotation in both the districts indicates that the annual loss of C from soil was much less than the annual input of biomass C into the soil added through FYM and left over biomass, thereby, maintaining a positive C balance in soil to the tune of 1666 (soybean-chickpea, Sehore) to 2008 kg C (soybean-wheat, Vidisha) in the soil profile. Our earlier investigation also indicated that about 887 kg C/ha was required to be added in Vertisols under soybean – wheat rotation to maintain soil organic C at equilibrium level (Kundu *et al.* 2001 and 2007). In case of soybean and gram, the whole trash was returned to the field while in case of wheat and rice, straws were removed as cattle feed leaving some stubbles in the field which was 5 and 4.59% of the straw yield in wheat and rice, respectively. The study clearly suggests that even removing the above ground biomass of rice and wheat crop, the observed crop production levels are sufficient to supply enough C input to the soil to surpass the quantum of C input required to maintain equilibrium soil organic carbon content.

SOC and passive pool was found to have considerable influence on crop productivity as compared to TOC and active pool of carbon. The carbon loss from passive pool of carbon is relatively less in soybean-wheat and soybean-chickpea system (legume based cropping system) and any management practices that conserve slow C-pool or passive pool in soil for longer period should be implemented. Hence it could be concluded that growing soybean– wheat and soybean – chickpea rotations in Vertisol are not only soil organic C restorative process but also help to sequester C into the soil as compared to rice-wheat system.

Table 3 Correlation coefficient of various soil carbon pools and mean relative yield

Parameter	Coefficient value (r value, P=0.05)		
	SOC	TOC	Mean relative yield
Very labile C	0.9227	0.9405	0.3893
Labile C	0.8827	0.8972	0.3748
Less labile C	0.9009	0.8406	0.5871
Non-labile C	0.7125	0.7877	0.2007
Active C pool	0.9268	0.9436	0.3920
Passive C pool	0.9619	0.9429	0.5295
SOC	1.0000	0.9581	0.4886
TOC	0.9581	1.0000	0.5275

Table 4 Balance sheet of C from cultivated Vertisols under different cropping system

District	Cropping	Yield of component crops (kg/ha)		SOC status (g/kg)	C input (kg C/ha/y)	Total C loss (kg C/ha/y)	Carbon balance (kg C/ha/y)
		Kharif	Rabi				
Sehore	Soybean-wheat	940 ±257	3127 ±1032	5.94	2391±526	501.36 ±89.02	1890±337.97
	Soybean-chickpea	940 ±257	885 ±239	5.78	2138 ±470	471.76 ±84.54	1666±310.55
	Rice-Wheat	2510 ±652	3127 ±1032	5.03	2215 ±576	533.66 ±96.05	1681±288.21
Vidisha	Soybean-wheat	1515 ±339	2624 ±918	4.32	2469 ±568	461.06 ±76.54	2008±340.46

ACKNOWLEDGEMENTS

This work is a part of the World Bank Sponsored NAIP Sub-project C-2060 and the authors thankfully acknowledge the support and encouragement received from NAIP (ICAR).

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