Indian Journal of Agricultural Sciences **87** (3): 306–11, March 2017/Article
https://doi.org/10.56093/ijas.v87i3.68604

Assessment of carbon pools in Inceptisol under potato (*Solanum tuberosum*) based cropping systems in Indo-Gangetic plains

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Received: 3 November 2016; Accepted: 19 December 2016

ABSTRACT

Soil carbon pools play a major role in sustaining agro-ecosystems and maintaining environmental quality as they act as a major source and sink of atmospheric carbon. The long-term effect of manuring and fertilization on accessibility of carbon pools of soil in high intensity rice (*Oryza sativa* L.)−potato (*Solanum tuberosum* L.)−wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) −potato−onion (*Allium cepa* L.) cropping systems in Inceptisol of semi-arid sub-tropical India continuing for 10 years was studied. Soil samples were collected (0-15 and 15-30 cm soil depth) from the treatments comprising control (T_1), 100% NPK-Fertilizer (T_2), 100% N-Vermicompost (VC) (T_3), 50% NPK-Fertilizer + 50% N-Vermicompost (VC) (T_4), 100% NPK-Fertilizer + crop residue (CR) (T_5), 100% N-Vermicompost + CR (T_6). Assessment of carbon pools was done by estimating total soil C (TSC), total soil nitrogen (TSN), C:N ratio, carbon mineralization (C_{min}), total polysaccharide (TP) and relationship between these pools. The results showed that the application of 100% N-VC (T_3) and 100% N-VC + CR (T_6) increased the TSC by 94% and 80%, respectively, over 100% NPK in rice-potato-wheat cropping system, while in maize-potato-onion system, 100% N-VC (T_3) increased TSC by 48% over 100% NPK (T_2) at 0-15 cm soil depth. The soil C:N ratios were generally wider in case of treatments receiving organic sources. In both the soil depths, the T_6 treatment (100% N-VC + CR) had resulted higher C mineralization than the other treatments throughout the incubation period. The stable C was lower in maize–potato–onion system than that in the rice–potato–wheat system. The total polysaccharides was higher in organic amended treatments (T_6, T_3) over chemical fertilizer treatments in improving the TP content in soil which was related to greater C input.

Key words: Carbon mineralization, Inceptisols, Potato cropping system, Soil carbon pools

Soil is the largest reservoir of carbon in the terrestrial biosphere. In order to determine the rate or extent of carbon (C) storage and protection in soils an obvious requirement is the need to measure the soil C content. As the soil carbon pool is three times greater than the atmospheric C, a small variation in this C reserves could lead to marked changes in the atmospheric CO_2 concentration (Davidson and Janssens 2006). Soil C decline in an agro ecosystem is mainly due to intensive cultivation. Intensive cultivation changes the quality and quantity of C inputs to soil and soil physical properties that ultimately affects the C decomposition. It takes several decades to reach a new equilibrium of soil C after cultivation. However, adoption of management practices like stubble retention and reduced tillage are found to potentially increase C in agricultural soils. This soil C sink capacity affects both world food security and global climate change (Lal *et al.* 2007). Soil organic matter (SOM) can be observed as a potentially imperative C sink, mitigating global warming by sequestering C removed from the atmosphere by plants. Equally, soils can be a source of CO_2, with microbes and other soil organisms annually releasing 50–75 Pg of CO_2–C to the atmosphere, about 10 times the annual emissions from the burning of fossil fuels (IPCC 1996, Schlesinger and Andrews 2000). Because any net increase in soil CO_2 emissions, possibly in response to environmental changes, can effect global climate, identification of the factors that regulate soil respiration is critical in predicting ecosystem responses to global change. Carbon inputs to the system also may be increased indirectly by fertilization or irrigation treatments that increase crop productivity, biomass and root production (Stewart *et al.* 2007). The changes in soil C and N pools as a result of management practices have been reported by several workers in tropical soils (Bhattacharyya *et al.* 2013). It was observed that the application of inorganic fertilizers in combination with organic manures for four years to a rice–rice tropical agroecosystem resulted in soil carbon build up and increase in crop productivity. The rate at which each C pool responds

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to changes in management considerably between soil types and the nature of organic inputs. In order to examine soil quality dynamics effectively, a range of organic C pools need to measure the varied and overlapping functional rates of different C pools (Purakayastha *et al.* 2008).

Soil carbon (C) mineralization rate is a key indicator of soil functional capacity. Soil incubations are a more direct approach to quantify mineralizable soil C_{min} than various procedures using chemical extraction or organic compound class analysis. Measured C_{min} rates have ranged from less than 0.007 to 35.6% of total soil C using varying incubations times (12–800 days) and soil temperature and moisture conditions (McLauchlan and Hobbie 2004). Total polysaccharides play an important role in soil aggregate formation and its contribution to microorganism nutrition (Martín *et al.* 2011). Therefore, the long-term application of vermicompost alone or in combination with crop residues or integrated use of chemical fertilizer along with vermicompost might influence the carbon pools in potato–based cropping systems of semi-arid India. However, there is a paucity of information available with respect to assessing the carbon pools in various highly managed potato based cropping systems.

MATERIALS AND METHODS

Soil samples were collected from the on-going field experiment involving rice (*Oryza sativa* L.)–potato (*Solanum tuberosum* L.)–wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.)–potato–onion (*Allium cepa* L.) cropping systems continuing at the research station of Central Potato Research Institute Campus, Modipuram, Meerut, Uttar Pradesh, India since the year 2005. The experimental field is located in the upper gangetic alluvial plains (Latitude 28.99°N and Longitude 77.71°E) with an altitude of 300 m amsl and the climate is broadly classified as semi-arid, subtropical with hot dry summers and cold winters. The soil of the experimental site is alkaline in reaction with sandy loam in texture of gangetic alluvial origin, very deep (>2 m), well drained flat, and represents one of the most extensive soil series, i.e. Sobhapur series of northwest India. The composite soil sample was drawn from 0–15 cm soil depth of the experimental field and was analyzed for mechanical composition and important chemical properties (Table 1).The soil samples were collected from 0–15 and 15–30 cm depths with core sampler from the treatments comprising of control (T_1), 100 % NPK-Fertilizer (T_2), 100% N-Vermicompost (VC) (T_3), 50 % NPK-Fertilizer + 50% N-Vermicompost (VC) (T_4), 100% NPK-Fertilizer + Crop residue (CR) (T_5), 100% N-Vermicompost + CR (T_6). The vermicompost was applied during planting of the crops. In T_3, T_6 treatments, 100% of N (180 N kg/ha in potato and onion, 120 N kg/ha in rice, wheat and maize) and in T_4, 50% of N (90 N kg/ha in potato and onion, 60 N kg/ha in rice, wheat and maize) were applied through vermicompost (1% N, 0.75% P_2O_5 and 0.75% K_2O). This corresponds to application rate of vermicompost @18 tonnes/ha (eqv. to 180 N, 135 P_2O_5 and 135 K_2O kg/ha) and 12 tonnes/ha (eqv. to 120 N, 90 P_2O_5 and 90 K_2O kg/ha). In T_5 and T_6, the biomass residues of previous crops were incorporated into the soil for succeeding crop in the cropping sequence. In T_2 and T_5 treatments the full dose of N, P and K and in T_4 the half dose of N, P and K were through DAP, MOP and N was balanced by urea. In onion P was applied through single superphosphate (SSP) for meeting the S requirement of the crop. In potato N was applied in two splits, i.e. ½ N at planting and rest ½ N at the time of earthing up (30 day). In rice ½ N was applied as basal during transplanting and ½ N was applied at the time of top dressing 35 days after transplanting (DAT). In wheat N was applied in three splits, i.e. $1/4^{th}$ as basal, ½ at crown root initiation (CRI) stage and $1/4^{th}$ at panicle initiation (PI) stage. In maize, $1/4^{th}$ N was applied as basal, ½ N was applied at knee height stage and remaining $1/4^{th}$ N was applied at tasseling stage. In onion, ½ N was applied at the time of transplanting and remaining ½ N was applied at 30 DAT. The experiment was laid out in randomized block design with three replications. Total soil carbon (TSC) and nitrogen (TN) was determined by dry combustion method (Nelson and Sommers 1982) in CHNS analyzer. Carbon mineralization (C_{min}) was done by incubation experiment, carbon dioxide (CO_2) flux as measure of C mineralization was determined by the procedure of Parr and Smith (1969). Stable carbon (Stable C) was estimated as the difference between TSC and C_{min}. The total polysaccharides of soil samples were analysed with modified technique from Whistler and Wolfram (1962) by Lowe (1994). Experimental data obtained were subjected to analysis of variance (one way ANOVA) in randomised block design (RBD) using Window based statistical software, SPSS version 16.0. The Duncan's Multiple Range Test at probability 5% was used to segregate significance of difference among the mean values.

Table 1 Initial soil characteristics of the experimental field (2005)

Particulars	Value
Soil classification	Typic Haplustept
Taxonomic group	Inceptisol
Texture	
Sand (%)	51.46
Silt (%)	23.02
Clay (%)	25.52
pH	7.5
Walkley Black organic carbon (g/kg)	3.2
Available N (kg/ha)	165
Available P (kg/ha)	66
Available K (kg/ha)	210

RESULTS AND DISCUSSION

Total soil carbon, total soil nitrogen and C:N ratio

In rice–potato–wheat cropping system, the total soil carbon (TSC) content in 0-15 cm soil depth varied from

6.81 g/kg under control (T_1) to 16.1 g/kg under the treatment 100% N-VC (T_3) (Table 2). The T_3 (100% N-VC) and T_6 (100% N-VC + CR) treatments were at par with each other, and increased the TSC content by 136 and 120% respectively, over T_1 treatment. In 15-30 cm soil depth, all the treatments were non-significant to each other with respect to TSC content. Total soil nitrogen (TSN) in 0-15 cm soil layer varied from 0.87 g/kg under control (T_1) to 1.72 g/kg in T_6 treatment. The T_6 and T_3 treatments were at par with each other and increased the TSN by 97.7 and 90.8% respectively, over T_1. Unlike TSC, the TSN increased significantly due to incorporation of CR over 100% NPK treatment (T_5). In the 15−30 cm soil depth, the treatments were non-significant with respect to TSN content. The C:N in 0-15 cm soil layer varied from 7.86 under control (T_1) to 9.73 under T_3. The C:N ratios were generally wider in organic sources treatments . In the 15-30 cm soil depth, the C:N ratio varied from 5.72 (T_5) to 7.60 (T_4) (Table 2). In maize−potato−onion sequence, the TSC content in 0−15 cm soil depth varied from 6.02 g/kg under control (T_1) to 11.46 g/kg in T_3 treatment (Table 2) . The T_3 and T_4 which were at par with each other increased the TSC by 90.2 and 77.9%, respectively, over T_1. Incorporation of CR over 100% NPK did not increased the TSC, while incorporation of CR with 100% N-VC increased the TSC significantly. In the 15−30 cm soil depths, the TSC of all the manuring and fertilization treatments were significantly higher over the control treatment. The TSN in 0−15 cm soil layer varied from 0.65 g/kg under control (T_1) to 1.21 g/kg under the T_4 treatment (50% NPK + 50% N-VC). However, the T_4 and T_3 treatments were at par with each other and increased the TSC content by 86.1 and 73%, respectively, over T_1. Incorporation of CR over 100% NPK significantly increased TSN, while TSN content was not significantly influenced due to incorporation of CR with 100% N-VC. Among the treatments, the TSC content at 15−30 cm soil depth did not vary significantly, while the TSN content was significantly lower in 100% NPK + CR and 100% N-VC + CR over other treatments. The C:N ratio in 0−15 cm soil layer varied from 7.47 under T_5 to 10.7 under T_6.The C:N ratios were generally wider in the organic treatments. In the 15−30 cm soil depth, the C:N varied from 4.06 (T_1) to 5.79 (T_3). The C:N ratio in all the manuring and fertilization treatments were significantly wider than that in the control treatment (Table 2).

The impact of tT_3 and T_6 treatments was spectacular in rice−potato−wheat system than in the maize−potato−onion system. The increased in soil C in rice based cropping system could be due to slow decomposition of carbon under anaerobic condition of rice. The application of organic amendments (farmyard manure, straw, green manure) tends to build up soil organic matter in rice based cropping systems (Mohanty *et al.* 2013). Though it was reported that contribution of carbon carried out through the addition of the crop residues, as they acts as a C source aside from improving physical, chemical and biological properties of soil (Bhaduri *et al.* 2014). The C:N ratio of soil was more wider in VC treatments and it became narrow due to application of CR along with chemical fertilizer (T_5). The application of easily available N through chemical fertilizer might have reduced C:N ratio of crop residues and made the mineralization of crop residues faster. Vermicompost,

Table 2 Long-term impact of manuring and fertilization on total carbon (TSC), total nitrogen (TSN) (g/kg) and C:N ratio of soil under potato based cropping systems

Treatment	TSC	TSN	C:N	TSC	TSN	C:N
	(g/kg)			(g/kg)		
	0-15cm			15-30cm		
Rice–potato–wheat						
Control (T_1)	6.81d§	0.87c	7.86d	3.88a	0.66a	5.87ab
100% NPK (T_2)	8.29cd	1.04c	7.94cd	3.13a	0.54a	5.75b
100% N–VC (T_3)	16.1a	1.66a	9.73a	8.05a	1.01a	7.40ab
50% NPK+50% N–VC (T_4)	11.8b	1.34b	8.83b	7.20a	0.92a	7.60a
100% NPK+CR (T_5)	10.1bc	1.27b	7.99cd	3.92a	0.68a	5.72b
100% N–VC+CR (T_6)	15.0a	1.72a	8.72bc	4.35a	0.72a	5.90ab
Maize–potato–onion						
Control (T_1)	6.02d§	0.65d	9.24ab	3.65a	0.91a	4.06b
100% NPK (T_2)	7.74c	0.81cd	9.48ab	3.70a	0.73ab	5.13ab
100% NPK–VC (T_3)	11.4a	1.13ab	10.1a	4.30a	0.73ab	5.79a
50% NPK+50% N–VC (T_4)	10.7ab	1.21a	8.94ab	4.10a	0.73ab	5.65a
100% NPK+CR (T_5)	8.25c	1.10a	7.47b	3.25a	0.59b	5.51a
100% N–VC+CR (T_6)	9.61b	0.93bc	10.7a	3.73a	0.67b	5.56a

§The values followed by different lowercase letters are significant according to Duncan' Multiple Range Test at P = 0.05, VC – Vermicompost, CR– Crop residue.

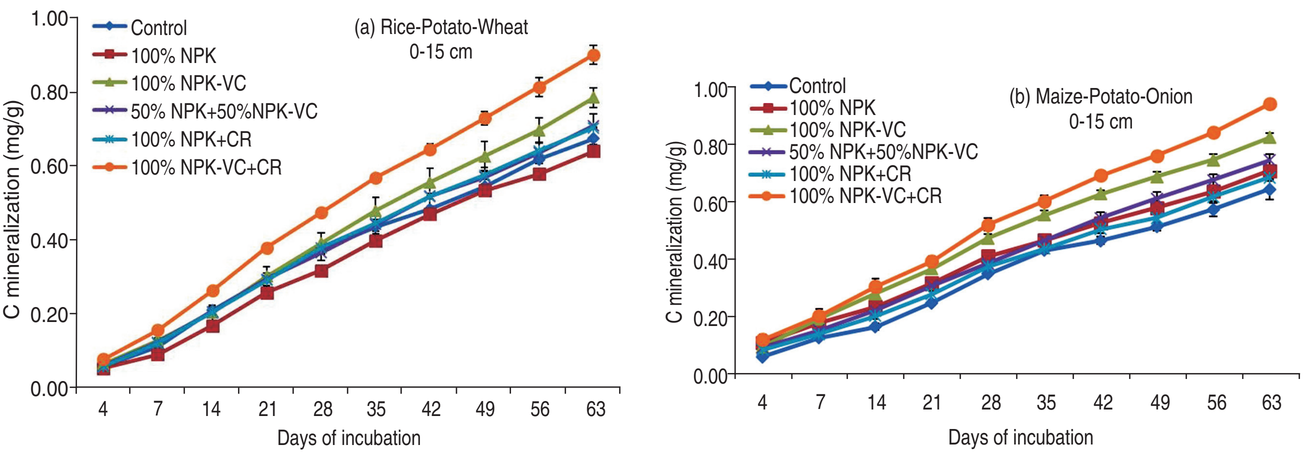

Fig 1 Long-term impact of manuring and fertilization on cumulative carbon mineralization from (a) 0–15 cm and (b) 0–30 cm soil depth under potato based cropping system

being a stabilized product, may not get decomposed at faster rate thus showing wider C:N ratio in soil. Under VC treated soil the wider C:N ratio could be one of the reason for the higher stability of C in soil.

Carbon mineralization

The cumulative carbon mineralization (C_{min}) continued up to 63 days varied significantly between the treatments in 0–15 and 15–30 cm soil depths (Table 3) (Fig 1). In both the soil depths, the T_6 treatment (100% N-VC + CR) registered higher C_{min} than the other treatments throughout the incubation period. The T_3 treatment (0.78 g/kg) was second to T_6 (0.89 g/kg) with respect to C_{min} in 0–15 cm soil depth, while in 15–30 cm soil depth the combined application of NPK and VC was second to T_6 treatment. In 0–15 cm soil depth, the C_{min} was lower in 100% NPK treatment, while in 15–30 cm soil depth, it was at par between the control and 100% NPK treatment especially during the initial period of incubation but in the later stage the former showed lower C_{min} than the latter treatment. Total C_{min} over 63 day period both in 0–15 and 15–30 soil depth was significantly higher in 100% N-VC + CR than the rest of the treatments. The control, 100% NPK, 50% NPK + 50% N-VC and 100% NPK + CR which were statistically at par with each other showed lower C_{min} (Table 3). In 0–15 cm soil depth, the cumulative C_{min} in maize–potato–onion cropping system followed almost the similar trend as that of rice–potato–wheat cropping system, while in 15–30 cm soil depth the 100% N-VC treatment showed higher C_{min} than the rest of the treatments which were at par with each other (Table 3). The lowest rate of soil C_{min} in the unfertilized plot might be due to the nutrients depletion under continuous cropping. The balanced fertilized plots might have created favourable condition with better supply of labile C substrate which trigger the microbial activity and thus have more rate of C_{min} (Sayre *et al.* 2005). A very interesting phenomenon was evident mainly in 0-15 and 15-30 cm soil layers that the respiration rate was initially high and later it became very low. This was obviously due to the fact that the depletion of easily mineralizable substrates occurs initially at a great pace.

Table 3 Long-term impact of manuring and fertilization on C_{min} and stable C (g/kg) under potato based cropping systems

Treatment	Cmin	Stable C	Cmin	Stable C
	(g/kg)		(g/kg)	
	0-15 cm		15-30 cm	
Rice–potato–wheat				
Control (T_1)	0.67c§	0.61d	0.51c	0.33a
100% NPK (T_2)	0.64c	0.76cd	0.55bc	0.25a
100% N–VC (T_3)	0.78b	1.53a	0.59bc	0.74a
50% NPK+50% N–VC (T_4)	0.70c	1.11b	0.63ab	0.66a
100% NPK +CR (T_5)	0.71c	0.94bc	0.56bc	0.33a
100% N–VC+CR (T_6)	0.89a	1.41a	0.69a	0.67b
Maize–potato–onion				
Control (T_1)	0.62d§	0.54d	0.53b	0.30a
100% NPK (T_2)	0.68c	0.70c	0.55b	0.31a
100% N–VC (T_3)	0.80b	1.06a	0.64a	0.36a
50% NPK+50% N–VC (T_4)	0.72c	0.99a	0.57b	0.35a
100% NPK +CR (T_5)	0.66cd	0.75bc	0.55b	0.27a
100% N–VC+CR (T_6)	0.91a	0.86b	0.57b	0.31a

§The values followed by different lowercase letters are significant according to Duncan's Multiple Range Test at P = 0.05, VC –Vermicompost, CR–Crop residue, Cmin–Mineralized carbon.

Stable soil carbon (Stable C)

The stable C was also estimated by deducting the mineralizable C over 63 day incubation from the TSC value. The stable soil C significantly differed across various treatments in both the soil depths under rice-potato-wheat cropping system (Table 3). The stable C varied from 6.1 g/kg in control (T_1) to 15.3 g/kg in 100% N-VC (T_3) treatment in 0–15 cm soil depth and from 3.31 g/kg in control (T_1)

to 7.4 g/kg in 100% N-VC (T_3) treatment in 15–30 cm soil depth. The stable C in T_3 and T_6 increased by 150 and 131%, respectively, over control. The stable C was significantly higher in 100% N-VC (T_3) and 100% N-VC + CR (T_6) over rest of the treatments in 0–15 cm soil depth. Incorporation of CR residue either over 100% NPK or 100% N-VC did not influence the stable C. In 15–30 cm soil depth, the 100% N-VC and 50% NPK + 50% N-VC being statistically at par with each other showed higher stable C.

The stable soil C was significantly higher in 100% N-VC and 50% NPK + 50% N-VC in 0–15 cm soil depth and in 15–30 cm soil depth, all the treatments remained at par under maize–potato–onion cropping system (Table 3). The stable C varied from 5.4 g/kg in control (T_1) to 10.6 g/kg in 100% N-VC (T_3) treatment in 0–15 cm soil depth and from 2.71 g/kg in control (T_1) to 3.6 g/kg in 100% N-VC (T_3) treatment in 15–30 cm soil depth. The control treatment invariably showed lowest amount of stable C. The stable C was lower in maize–potato–onion system than that of the rice–potato–wheat system. This was confirmed from the study that the stable C was greater in 100% N–VC treatment than 100% N–VC + CR and 100% NPK+ CR treatments. This was further evident from the correlation matrix that stable C correlated significantly with carbon mineralization. However, the treatment behaviour with respect to C_{min} and stable C was almost similar.

Total polysaccharides (TP)

Total polysaccharide (TP) content in soil significantly differed across various treatments at 0-15 and 15-30 cm soil depths under both the potato based cropping systems (Table 4). In rice-potato-wheat cropping system, treatment 100% N-VC + CR (T_6) resulted in highest TP content (8.62 g/kg) followed by100% N-VC (T_3) which was statistically at par with T_6 (100% N-VC + CR). All these treatments improved the TP status of soil significantly over the control (T_1) (1.52g/kg). Addition of vermicompost and crop residue (T_6) did maintain 4.4 times higher TP than the control (Table 4). In 15–30 cm soil depth, the (TP) content in soil followed almost the similar trend as surface layer in rice–potato–wheat cropping system. But the (TP) content was decreased in lower depth. In case of maize–potato–onion cropping system, 100% N-VC + CR (T_6) resulted in the highest TP content (8.52 g/kg) followed by 100% N-VC (T_3) (7.30 g/kg). All these treatments improved the TP status of soil significantly over the control (T_1) (1.41 g/kg). Addition of Vermicompost and crop residue (T_6) did maintain 5.0 times higher TP than the control (Table 4). The ability of organic inputs to increase the amount of labile polysaccharides (LP) in soil was well evidenced from the study. In 15–30 cm soil depth, the (TP) content in soil followed almost the similar trend as surface layer in maize–potato–onion cropping system. But content of the (TP) was decreased in lower depth.

Table 4 Long-term impact of manuring and fertilization on total polysaccharide (g/kg) under potato based cropping systems

Treatment	Total polysaccharide (g/kg)			
	Rice-potato-wheat		*Maize-potato-onion*	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Control (T_1)	1.52d §	0.33c	1.41e	0.44d
100% NPK (T_2)	3.55c	0.86c	2.43d	0.99cd
100% N–VC (T_3)	8.11a	3.49a	7.30b	3.22a
50% NPK+50% N–VC (T_4)	6.39b	2.40b	5.37c	2.12b
100% NPK +CR (T_5)	5.37b	1.82b	4.46c	1.46c
100% N–VC+CR (T_6)	8.62a	3.84a	8.52a	3.25a

§The values followed by different lowercase letters are significant according to Duncan's Multiple Range Test at P = 0.05, VC –Vermicompost, CR–Crop residue.

The ability of organic inputs to increase the amount of the (TP) in soil was well evidenced from the present study. Organic amended treatments had an edge over chemical fertilizer treatments in improving the TP content in soil. Higher TP content in T_3 and T_6 was related to greater C input, which could directly provide more polysaccharide materials or favor greater microbial activity that would produce microbial extracellular polysaccharides. Superiority of organic sources and aggregation in increasing the TP content of soils was also reported earlier (Yuan *et al.* 2012). A continuous application of chemical fertilizers without organic sources can be attributed for the lowest TP content in T_2 in case of both the soil depths. Similar results were also observed by Haynes *et al.* (1991). Among the nutrient treatments, higher TP contents were found in T_6 and T_3 indicating that both the quantity and quality of added organic sources played an important role in determining the TP content in soils.

Correlation among various C pools

The data pertaining to the correlation of total soil carbon (TSC), total soil nitrogen (TSN), stable carbon and carbon mineralization in potato based cropping systems at 0–15 cm depth have been presented (Table 5). The TSC strongly correlated with stable C (r = 0.99), TSN (r = 0.97) and C_{min} (r = 0.75) in case of rice–potato–wheat cropping system. But in case of maize–potato–onion cropping system, TSC strongly correlated with stable C (r = 0.99), TSN (r = 0.78) and C_{min} (r = 0.66). Stable C had better correlation with C_{min} in case of rice–potato–wheat cropping system than maize–potato–onion cropping system. It might be possible that as the duration of the C mineralization study was less, due to this, C from the labile component of SOM matter was not fully realized. So the C mineralized over 63 day period was insufficient to correlate.

Keeping in view of the experimental results discussed above, it may be concluded that organic recycling either with vermicompost or with crop residue incorporation significantly improved various soil carbon pools. Thus, due to application of organic amendments like vermicompost and crop residues there are ample chances of better soil

Table 5 Long–term impact of manuring and fertilization on correlation among various pools of carbon under potato based cropping system

	TSC	TSN	Stable C	Cmin	TSC	TSN	Stable C	Cmin
	Rice–potato–wheat				*Maize–potato–onion*			
TSC	1				1			
TSN	0.97**	1			0.78**	1		
Stable C	0.99**	0.97**	1		0.99**	0.79**	1	
Cmin	0.75**	0.81**	0.74**	1	0.66**	0.60**	0.57*	1

TSC- Total soil carbon, TSN-Total soil nitrogen, Cmin–Mineralized carbon, VC–Vermicompost, CR– Cropresidue, * Significant at 0.05 level; ** Significant at 0.01 level.

quality with respect to labile carbon fractions.

ACKNOWLEDGEMENT

We sincerely acknowledge Indian Council of Agricultural Research and Indian Agricultural Research Institute, New Delhi for financial support and Central Potato Research Institute Campus, Modipuram, Meerut, Uttar Pradesh for providing assistance in conducting this research.

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