Chapter 6

Soil organic carbon pools and productivity in rice based cropping system

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Despite impressive gains in cereal production by India, from 50 m t in 1947 to more than 219 m t in 2000, that remain serious problem. One, expected food demand by 2050 is 300 million tonnes of cereals and must be met from the shrinking land resource base. There are severe problems of degradation of soil and water resources leading to reduction in use efficiency of inputs (e.g., fertilizer, irrigation, tillage), pollution of surface and ground waters, and emission of greenhouse gases (GHGs) from soil/terrestrial/aquatic ecosystems into the atmosphere. Soil organic carbon (SOC) play multifunctional role to improve this degradation. The majority of carbon is held in the form of SOC, having a major influence on soil structure, water holding capacity, cation exchange capacity, the soils ability to form complexes with metal ions to store nutrients, improve productivity, minimize soil erosion, etc. This organic carbon is highly sensitive to changes in land use and management practices such as increased tillage, cropping systems, fertilization, etc., leading to SOC decline. Conversely, land use change and the appropriate management of soils also provide us with the potential to sequester carbon in soils.

It is a well recognized fact that soil organic matter (SOM) is of fundamental importance in soil fertility. It is a storehouse of all essential plant nutrients and provides energy material for the soil organisms. The maintenance of SOM in agricultural soils is primarily governed by climate, particularly annual precipitation, temperature and cropping practices. Although amount of SOM in soils of India is relatively low (ranging from 0.1 to 1.0% and typically less than 0.5%), its influence on soil fertility and physical condition is of great significance. Conversion of land from its natural state to agriculture generally leads to loss of SOM. The maintenance of SOC in tropical soils to a desirable level of 0.5 to 1% is extremely important for sustainable crop production. It may take up to 50 years for the organic matter of soils in the temperate climate to reach a new equilibrium level following a change in management, but this time period is much shorter in the semiarid and tropical environment like India. Intensive cropping and tillage systems have led to substantial decrease in the SOM levels under semiarid and sub-humid regions, through enhanced microbial decomposition, wind and water erosion of inadequately protected soils. This decrease in SOM level has often been accompanied with the decline of soil productivity.

Change in carbon (C) and nitrogen (N) content reflects in change in total SOM. These are slow processes, which are measurable only over the period of decades. Investigation on SOM dynamics therefore, requires long-term experiments with treatments that emulate major regional soil use and management systems. These experiments offer ideal opportunity to define soil quality indicators which are sensitive to changes in SOM. Studies on the quantitative changes in SOM content under rain fed areas are available but investigations on SOM turnover, the mean residence time of different SOM pools and ecological impacts are not available. Therefore, there is a need to examine the SOM dynamics under sub-humid conditions of rice based cropping system.

So far literature on SOM changes in rain fed semiarid and sub-humid regions did not throw much light on the carbon functional pools, which are highly sensitive indicator of soil fertility and productivity. The distribution of soil organic matter into following five functional pools may be made for its true representation.

1. Structural litter fraction: This consists of straw, wood, stems and related plant parts. The C: N ratio varies around 150:1. These are high in lignin content.
2. Metabolic pool fraction: It comprises plant leaves, bark, flower, fruits and animal manure. The C: N ratio ranges from 10 to 25. This fraction gives up mineral nitrogen as it is decomposed with loss of carbon dioxide (CO_2).
3. Active pool of soil carbon: This is microbial biomass and their metabolites. The C:N ratio is around 5 to 15. This fraction gives up mineral nutrients and it gives life to the soil. Besides soil microbial biomass carbon (SMBC), light fraction of organic matter, water-soluble carbon and water -soluble carbohydrates are also active pools of organic matter.
4. Slow decomposable soil fraction: This fraction is comparable to nature of composting having C: N ratio around 20:1. It makes temporary stable humus in soil, which is slowly decomposable.
5. Passive soil organic fraction: This is the highly recalcitrant organic matter with C:N ratio of 7:1 to 9:1. It is resistant to oxidation and is not readily involved in dynamic equilibrium with other types of organic fractions in soil.

The specific relationship of management practices and biologically active SOM with soil process is not well characterized. The structure of SOC sub-model is illustrated in Century Model (Fig. 1) (Parton et al., 1987). This model includes respiration C losses associated with dynamics of organic pools. Similarly, the N- sub models have the same basic structure of SOM and also include the flow of nutrients in different mineral form. Moreover, SOC turnover is dependent on soil moisture, radiation, temperature, cropping, rooting and plant residue, etc. Combine effect of all these factors on the dynamics of SOM is not yet established in tropics. Studies therefore, need to be conducted to develop a model of SOM for rain fed rice-based cropping systems which will include different parameters such as physical properties of soil, nutrient status, light fraction of SOC, hot water -soluble carbon, soil microbial biomass carbon (SMBC), activity of enzymes, etc. Such model may be of great practical importance from management point of view and as an indicator of soil quality in climatic change scenario.

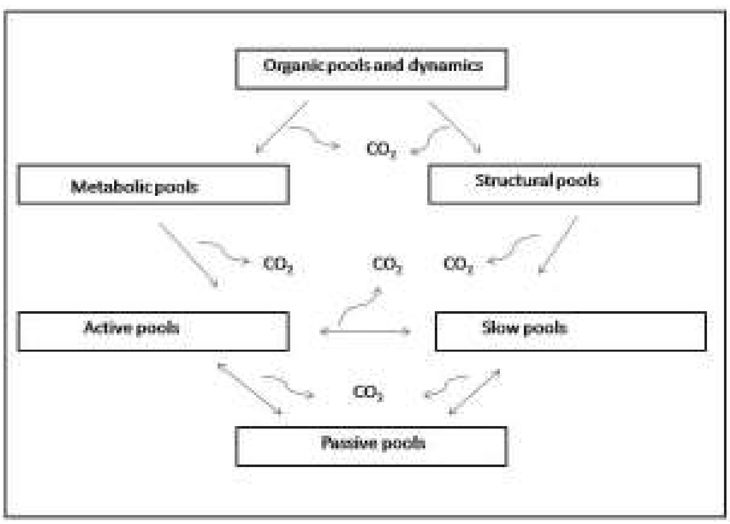

FIGURE 1. *Soil organic carbon sub-model in Century*

Long term fertilizer experiments conducted in India have clearly brought out the fact that the balanced use of plant nutrients is important to sustain crop productivity and soil fertility. Under intensive cropping with imbalanced fertilizer use particularly N alone, SOM content showed a decline irrespective of cropping systems and soil types. So far little information is available under different soil crop management systems on different pools of carbon, which is highly sensitive indicator of soil fertility and productivity.

Thus, one needs to understand how land use and management practices such as fertilization and tillage in rice based cropping systems can potentially enhance C-pools, C-sequestration and SOC storage equilibrium over a period of cultivation and these aspects are discussed in this chapter.

Soils carbon pool

In general, SOC concentration increases with increase in clay content and rainfall, and decreases with increase in mean annual temperature. Some of these soils have been cultivated for centuries, and often with low off-farm input, based on systems that involve removal of crop residue and cow dung for fuel and other purposes. Diverse soils are also characterized by a wide range of SOC concentration, which is generally related to clay content (Ali et al., 1966) and climate (Jenny & Raychaudhary, 1960). The data in Table 1 show that SOC concentration of most soils is less than 10 g kg^{-1}, and is generally less than 5 g kg^{-1}. Because of the low clay contents, the SOC concentration is especially low in alluvial soils of the Indo-Gangetic Plains, coarse-textured soils of southern India, and arid zone soils of northwestern India. The low levels of SOC concentrations are attributed to excessive tillage, imbalance in fertilizer use, little or no crop residue returned to the soil, and severe soil degradation.

TABLE 1. *Depletion of soil organic carbon concentration of cultivated compared with that in undisturbed soils (adapted from Jenny & Raychaudhary, 1960; Swarup et al., 2000)*

Region	SOC content		Percent reduction
	Cultivated (g kg^{-1})	Native (g kg^{-1})	
1. Northwest India			
Indo-Gangetic Plains	4.2 ±0.9	10.4 ± 3.6	59.6
Northwest Himalaya	24.3 ± 8.7	34.5 ± 11.6	29.6
2. Northeast India	23. 2 ± 10.4	38. 3 ±23. 3	39.4
3. Southeast India	29.6 ± 30. 1	43.7 ± 23.4	32.3
4. West coast	13.2 ±8.1	18.6±2.1	29.1
5. Deccan Plateau	7.7 ±4.1	17.9 ±7.6	57.0

The principal cause of decline in SOC pool in degraded soils is a reduction in biomass productivity and the low amount of crop residue and roots returned to the soil. A typical example of the low SOC pool is in salt-affected soils of Haryana, Andhra Pradesh, Odisha and West Bengal. Even in the surface 0 - 15 cm layer, the SOC pool may be lower than 5 g kg^{-1}.

Accelerated soil erosion depletes the SOC pool severely and rapidly. The SOC fraction is preferentially removed by surface runoff and wind because it is con-centrated in the vicinity of the soil surface and has low density (1.2 to 1.5 Mg m^{-3} compared with 2.5 to 2.7 Mg m^{-3} for the mineral fraction). The effectiveness of several techniques for SOC sequestration has been discussed by Swarup (1998) and Swarup et al. (2000), and is outlined in Table 2. Swarup (1998) reported the impact of integrated nutrient management, including application of NPK and manuring (8 - 10 Mg $ha^{-1}y^{-1}$), on SOC concentration in surface layer of soils from long term rice based experiments established in different ecoregions of India. Assuming a plough depth of 20 cm and soil bulk density of 1.4 Mg m^{-3}, the rate of SOC sequestration was calculated for NPK + manuring over that of the control. The results showed low rates of C change over, 15 to 120 kg C $ha^{-1}y^{-1}$. The low rates are attributed to low soil water, high soil temperature and high rate of oxidation (Table 2).

TABLE 2. *Effect of soil fertility management on SOC concentration in a long term manuring experiment (recalculated from Swarup. 1998) (assuming plough depth of 20 cm and bulk density of 1.4 Mg m^{-3})*

Location	Soil	Initial (g kg^{-1})	Control (g kg^{-1})	NPK (g kg^{-1})	NPK + FYM (g kg^{-1})	Period (yrs)	Rate of change over control (kg C $ha^{-1}y^{-1}$)
Barrackpore (Rice-wheat-jute)	Eutrochrept	7.0	4.1	5.0	5.4	24	15
Bhubaneswar (Rice-rice)	Haplaquept	2.6	3.7	5.7	8.1	21	59
Hyderabad (Rice-rice)	Tropaquept	5.0	4.6	5.3	8.0	23	41
Pantnagar (Rice-rice)	Hapludoll	13.0	5.0	8.3	15.0	24	117

Yield trends and soil organic carbon

The yield trends and total organic carbon over 30 years of multiple rice-based cropping systems in an Inceptisol of West Bengal are given in Table 3. Linear regression analysis showed negative yield trends of rice based cropping system was due to repeated application of imbalance fertilizer in a long run. Similarly, the declining trends were also observed in total organic matter content in these treatments over the initial value (Table 4). It is interesting to note that though positive trends of total organic carbon (TOC) were observed in NPK and NPK+FYM treatments but improved yields were not obtained over the years.

TABLE 3. *Long term effect of manure and fertilizers on yield trends in rice based cropping system*

Locations	Treatments	Rate of yield change			Initial value[a]	Sustainable
		Magnitude (Mg $ha^{-1}yr^{-1}$)	*t*-stat	*p*-value	(Mg ha^{-1})	yield index (SYI)
Barrackpore						
Rice	Control	-0.028	-3.410	0.002	1.93	0.16
	N	-0.087	-6.032	0.000	4.49	0.33
	NP	-0.081	-4.972	0.000	4.75	0.38
	NPK	-0.090	-5.753	0.000	5.03	0.40
	NPK+FYM	-0.060	-3.958	0.000	4.81	0.47
	LSD 5%	-	-	-	-	0.04
Wheat	Control	-0.013	-3.067	0.005	0.95	0.14
	N	-0.036	-4.550	0.000	2.50	0.41
	NP	-0.021	-2.225	0.034	2.55	0.49

Contd....

Locations	Treatments	Rate of yield change			Initial value[a]	Sustainable
		Magnitude (Mg ha^{-1}yr^{-1})	*t*-stat	*p*-value	(Mg ha^{-1})	yield index (SYI)
	NPK	-0.017	-1.913	0.066	2.56	0.52
	NPK+FYM	-0.021	-2.209	0.035	2.67	0.55
	LSD 5%	-	-	-	-	0.034
Jute	Control	-0.118	-2.318	0.028	3.20	0.20
	N	-0.040	-6.827	0.000	2.90	0.47
	NP	-0.038	-8.254	0.000	2.35	0.51
	NPK	-0.032	-7.576	0.000	2.47	0.61
	NPK+FYM	-0.011	-2.382	0.024	2.30	0.70
	LSD 5%	-	-	-	-	0.04

[a] Intercept value is considered as initial value (Manna et al., 2005a)

TABLE 4. *Long term effect of manure and fertilizers on SOC trends in rice based cropping system*

Location	Treatment	Rate of SOC change			Initial value (g kg^{-1})[a]
		Magnitude (g kg^{-1} yr^{-1})	*t*-stat	*p*-value	
Barrackpore	Control	-0.028	-0.364	0.025	5.30
(Rice–wheat-jute)	N	-0.044	-5.770	0.000	6.35
	NP	-0.017	-1.540	0.123	4.98
	NPK	0.078	5.880	0.000	4.64
	NPK + FYM	0.066	5.250	0.000	5.05

[a] Intercept value is considered as initial value

Active pools of carbon

The active fractions of SOC (Soil microbial biomass carbon (SMBC), Water soluble carbon (WSC), Acid Hydrolysable Carbohydrates (AHC)) changed significantly and substantial amount of these parameters decreased under N or NP treatments as compared to balanced NPK use. Most of the researches specifically emphasized upon SOC and its pool fractions (active and slow pools), which lead to improved soil fertility, sustainability and environmental quality. More information is also required whether collapsing of active fraction of C and N of SOM hamper the nutrients supply in long run. In the imbalanced fertilized plots (N and NP), SMBC decreased about 1.1-3 folds compared to NPK+FYM application in rice based cropping system. Acid hydrolysable carbohydrate is a labile C fraction and has been found to change more rapidly in response to changes in management than SOC contents. The biological activity of soil causes the large amount of soil microbial biomass is soil and also more labile component of SOM fractions (soluble phase of carbon and carbohydrates) than most other fractions.

Yield declining/ or stagnating in long-term experiments could occur because of many factors such as decline of SOM and associated nutrients, imbalanced fertilizer application, climate, insect pest and crop management practices. It is also evident that yield declined in NPK despite the fact that total organic carbon (TOC) was maintained in this treatment (Table 3). This study clearly indicates that TOC stock is not necessarily related to yield decline. After 31 years of continuous cultivation (1971-2001) study on the active pools of C and N indicated a gradual decline over initial level. Continuous N, NP or NPK fertilizer application were prone to large N losses because of alternate wetting (anaerobic) and drying (aerobic) conditions during rice cultivation. Total organic C improved in NPK and NPK plus FYM treatment. The total C and N pools in these treatments however, were maintained suggesting that regular application of organic matter with NPK is critical for their maintenance in the rice-based cropping system.

Although active pool is a small fraction of SOM, it is considered as buffering agent and found useful in replenishment mechanisms like desorption from soil colloids, dissolution from litter, and exudation from plant roots. The contribution of water-soluble fractions in the inorganic fertilized treatment was less because aboveground biomass was neither used nor returned to the soil in any form in rice based cropping system. The reduced amount of active pools of C and N after long term cultivation of fertile virgin soil leads to depletion of soil fertility in three ways i.e. through reduced labile sources of nutrients; reduced rate of mineralization, and lower bioavailability of nutrients. Furthermore, continuous cultivation with cereal based cropping reduced total amount of nutrients as well as soil microbial biomass, which could lead to biological degradation of soil. Similarly, continuous application of inorganic fertilizer and removal of aboveground biomass significantly reduced not only total amount of nutrients but also the active pools of C and N resulting in decline of crop yields. It is often difficult to maintain or enhance the organic matter and N in cultivated soil unless a cover/legume crop is included in the rotation or a heavy application of manures and crop residues is made. Therefore, balanced plant nutrition (fertilizer in combination with manure) every year may contribute more labile fraction of C, which acts as a source of bioenergy and helps to improve mineralization process.

Soil TOC and total nitrogen (TN) concentration in bulk soil samples of the unfertilized control from the topsoil (0-15 cm) lost approximately one-third of its original TOC and two-third of its initial total N concentration (7.12 g TOC kg^{-1} and 960 mg N kg^{-1} soil, 1971) (Table 1). Microbial biomass is an essential component of labile C. Sometimes it is used as a surrogate for labile C pools, because it can readily be determined through physical and biochemical method. The MBC and microbial biomass nitrogen (MBN) in the treatment receiving FYM with fertilizer NPK were about 35 to 52 % and 32.8 to 44 % more than in N, NP and NPK treatments and approximately 1.5 and 1.3 times higher than fallow soils. The results showed that MBC ranged from 3.3 to 7.3 % of total organic carbon and MBN from 1.1 to 2.3 % of total N in the surface layer. The water soluble fraction is considered the most active part of TOC and on an average the WSC and water soluble nitrogen (WSN) accounted for 0.2 to 1.4% of TOC and 1.0 to 2.6% of TN, whereas hydrolysable carbohydrates accounted for 9.2 to 11.3% TOC in the top surface layer (Table 5).

TABLE 5. *Long term effect of manure and fertilizer application on active fractions of soil organic carbon under Inceptisol (Rice-wheat-jute) at 0-15 cm soil depth*

Location	Treatment	SMBC ($g\ m^{-2}$)	SMBN ($g\ m^{-2}$)	AHC ($g\ m^{-2}$)	WSC ($mg\ kg^{-1}$)	% POM in SOC
Inceptisol	Control	33.8	2.28	105.2	10.7	10.6
(Rice-wheat-jute)	N	32.4	2.14	116.0	12.6	16.5
	NP	41.8	2.20	121.8	26.3	22.4
	NPK	65.4	2.20	137.8	69	20.0
	NPK+FYM	97.2	4.04	169.0	80.4	27.0

SMBC: Soil microbial biomass carbon; WSC: Water soluble carbon; AHC: Acid Hydrolysable Carbohydrates (Manna et al., 2005b)

Slow pool of carbon

In general, the aggregates size distribution was dominated by micro-aggregates (53 - 250 μm) followed by small macro-aggregates (250 to 2000 μm) in most of the rice–based cropping systems in Inceptisols. Alternate wetting (anaerobic) and drying (aerobic) condition resulted after continuous intensive conventional tillage operations and removal of aboveground residues induced a rapid mineralization of aggregates associated SOM which collapsed the aggregates (>2-mm diameter size class). The correlation between reduction in aggregates and loss of SOM with cultivation has been used to explain aggregate hierarchy theory by many authors (Camberdella and Elliott, 1993; Six et al., 2000). Increasing cultivation intensity with repeated application of inorganic fertilizers (N, NP and NPK) caused reduction of macro-aggregates (Manna et al., 2005b, 2007a and 2007b). It is because of no significant release of water-soluble carbon and hydrolysable carbohydrates (which acted as binding agents) from belowground biomass decomposition upon microbial action. This perhaps resulted in loss of soil aggregates.

As cultivation continued with N, NP and NPK fertilization, there was a extensive depletion of organic matter associated with particulate organic matter carbon (POMC), light fraction carbon (LFC) and light fraction nitrogen (LFN). Light fraction carbon and LFN originating from stubbles biomass and root biomass in cultivated soil were mostly affected by both residue input and soil micro-climatic conditions. Free-light fractions are more labile organic matter slow pools but constitutes partially decomposed organic matter. The free LFC and N seems to be the POM fraction that is especially affected by residue input, whereas other fractions are affected by aggregation and aggregate mineralization. The free LF decomposition rate has been influenced by soil moisture, temperature, crop residue, quality and quantity of input whereas POM disruption rate is primarily affected by only soil aggregations. Particulate organic matter carbon is mostly used as an indicator of soil quality caused by land use management and tillage. Particulate organic matter carbon made up of 16.4 to 28% of TOC and tended to increase under NPK plus FYM than NPK treatment (Table 6). The percentages of soil C present in the free light fraction and POM in the top 0 to15cm depth of cultivated soils were 1.6 to 2.5 and 16.4 to 28.0% of TOC, respectively. Particulate organic matter nitrogen comprised 5.1 to 15.9% of TN. Therefore, 69.5 to 82.4% of TOC was present in the mineral associated organic matter in these treatments. It was observed that continuous application of N, NP or NPK for 30 years reduced the POMC by 5.3 to 10.7% of TOC and 5.3 to 29.5% of TN compared to fallow soil. The results clearly revealed that improvement of POM, could be associated with improvement of soil physical properties, microbial activities and better supply of plant nutrients. The C mineralization was lower than N mineralization either

TABLE 6. *Effect of manure and fertilizer on LF-C, LF-N, POM-C, POM-N and mineral associated-C and mineral associated-N (0-15cm depth)*

Treatments	LF-C (mg kg^{-1})	LF-N (mg kg^{-1})	LF-C/ LF-N	POM-C (g kg^{-1})	POM-C/ TOC	POM-N (g kg^{-1})	POM-N/ TN	Mineral Associ-ated-C	Mineral Associ-ated-N
Fallow	120	11.5	10.3	1.53	25	118.48	10.3	4.4	0.492
Control	61	8.2	7.6	0.54	9	24.60	5.1	4.6	0.388
N	91.5	9.8	9.1	0.94	13.8	84.7	12.1	4.7	0.570
NP	99	11.3	9.6	1.41	22.4	96.3	13.7	4.8	0.630
NPK	120	10.9	11.2	1.48	20.0	112.3	11.7	5.8	0.747
NPK+FYM	212	15.6	13.8	2.19	27.38	141.2	15.9	5.5	0.770

POMC: Particulate organic matter carbon; LFC: Light fraction carbon; LFN: Light fraction nitrogen (Manna et al., 2005b) from slow pools (aggregate size classes) or from mineral–associated organic matter (silt + clay) fraction (Manna et al., 2005b). Further, they reported that less mineralization rate in micro-aggregates may be due to transformation of labile materials to more stable fractions during continuous cultivation. The treatments variation of decay rate constant was due to quantity of LFC and LFN as well as POMC present in each aggregates size classes. However, more research is required to explain whether significant fraction of labile materials are transformed to stable fraction during different land use management system that may eventually effect nutrient supply to plants. The best approach should be the integrated use of manure and fertilizer in the highly intensive rice based cropping system to maintain SOC. The practice of residue incorporation during transition period of two crops is difficult. For example, after harvest of rice the transitional gap is only 20 to 25 days prior to wheat sowing. There is scope of further investigation to explain as to how residue can be managed in a short period without scarifying the next crop so that regular addition of residue along with balance fertilizer maintain active and slow pools of C and N under high intensive cropping system in a long run. Perturbations to the soil system such as conversion of native vegetation to arable agriculture cause large changes in SOM content in soil. Particulate organic matter carbon is the precursor for formation of soil microbial biomass carbon, soluble fraction of carbon, humic and non-humic fraction of carbon in soil and thus it is a key attribute of soil quality. It is the major source of cellular C and energy for the heterotrophic microorganisms. The POM accumulation is also the major pathway by which nutrients are recycled from crop residues back to the soil and release nutrients by mineralization during decomposition of POM. The large amount of microbial community associated with the decomposing POM produces binding agent such as exocellular mucilaginous polysaccharides. It acts as a major food and energy for endogenic soil fauna. Thus, POM is associated with a multitude of soil process and functions and is therefore, a key attribute of soil quality.

Carbon sequestration rate and efficiency in rice based cropping system

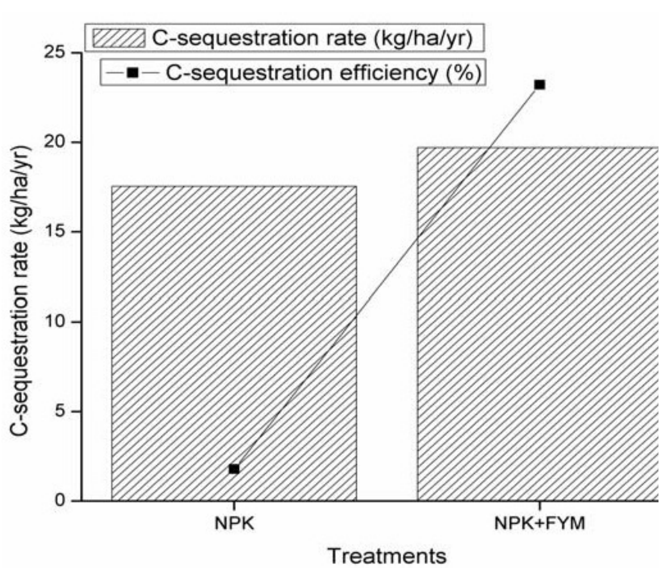

FIGURE 2. *Carbon sequestration rate and efficiency in Inceptisol (Manna et al., 2012)*

It was observed that all the long term imbalanced fertilizer treatments were not encouraged for carbon sequestration rate and carbon sequestration efficiency in rice based cropping system. For example, in Inceptisol at Barrackpore the treatments with NPK and NPK+FYM showed lower carbon sequestration rate and it was varied from 17 to 22 kg ha^{-1}yr^{-1} and C-sequestration efficiency was varied from 0.42 to 0.45 % in these treatments (Fig. 2).

Carbon steady state and carbon turnover

Using a non-linear regression model, the steady state SOC_e and loss rate k of the surface (0-15 cm) over 30 years of continous cultivation were calculated (Table 7). While calculating carbon steady state, it was assumed that the maximum amount of biomass C from leaf fall, stubbles and root remained on the surface layer. The values of SOC_o (calculated) were not close to mean SOC values of the initial samples (measured) for Inceptisol. Because, initially the total C decreased rapidly in the first 10 years and then stabilized in later stage in Inceptisols. If the above situation occurs in any system, the SOC_e value of cultivated soils happens to be similar to the SOC_o value in the model. After fitting the model the negative k values indicate the tendency of positive C over a period, with a new equilibrium. Higher SOC_e values indicate a decline in the total SOC whereas higher negative k values means decline occur in the shorter period. The SOC loss rate in different treatments varied considerably from 0.020 to 0.129 per year in Inceptisol (Table 7). This study clearly indicates that application of NPK+FYM had the lowest turn over period (t=1/k, 7.7 years in Inceptisol) when compared to other treatment under a high intensive cropping system in long run.

TABLE 7. *Initial status of organic carbon and equilibrium values for different treatments after 31 years of cultivation (Barrackpore)*

Treatment	Initial SOC ($g\ kg^{-1}$)	SOC_o ($g\ kg^{-1}$)	Steady state mean ($g\ kg^{-1}$)	Loss rate SOC_e ($g\ kg^{-1}$)	$t_{1/2}$ (yr^{-1})	R^2
N	7.12	4.99 ± 0.025	4.8 ± 0.018	-0.020	50.3	0.10
NP	7.12	4.99 ± 0.065	5.0 ± 0.022	-0.067	14.9	0.22
NPK	7.12	5.0 ± 0.038	5.1 ± 0.04	-0.095	10.7	0.39
NPK + FYM	7.12	5.4 ± 0.022	5.6 ± 0.017	-0.129	7.7	0.62**

** Value is significant at $p< 0.05$; ± standard error (Manna et al., 2012)

Passive pools of carbon

In rice based cropping system the changes in humic acid (HA) concentrations and HA/fluvic acid (FA) ratios were higher in the surface soil (0-15cm) and decreased with increase in depths (Manna et al., 2005b). On the contrary, FA-concentrations were higher at lower depth compared to surface soil. The HA and FA content did not vary due to treatments. Similarly, HA and FA ratios also did not vary due to treatments. Acid hydrolysable-N of humic substances was lower in HA-N than FA-N irrespective of treatments indicating that more time frame is required to improve passive fraction of C.

Conclusions

Rice based cropping systems are predominant in the Indo-Gangetic Plains of India and other South Asian countries. The annual rotation such as rice -wheat, rice-wheat-jute and rice-rice are dominant cropping system in India. Most of long term experiments with rice based cropping system, the yield trends of rice were negative in imbalanced fertilized plots due to loss of active and slow pools of carbon, quantity and quality of soil organic matter pools with associate nutrients and deterioration of physical properties of soil. Further, extensive tillage operation significantly reduced macro-aggregates in imbalanced fertilized plots and resulted in significant reduction of light fraction of particulate organic carbon and heavy fraction of particulate organic matter carbon. These fractions were improved by NPK+FYM treatment. Carbon sequestration efficiency and C-sequestration rate were also improved in NPK+FYM treatment under rice based cropping system. Various results suggest that the integrated use of NPK and FYM is important for sustaining this cropping system.

References

Ali, M.H., Chaterjee, R.K., & Biswas, T.D. (1966). Soil moisture tension relationship of some India soil. *Journal of the Indian Society of Soil Science,* 14, 51-62.

Camberdella, C.A., & Elliott, E.T. (1993). A carbon nitrogen distribution in aggregates from cultivated and native grass land soils. *Soil Science Society of the American Journal,* 57, 1071-1076.

Jenny, H., & Raychaudhuri, S.P. (1960). *Effect of climate and cultivation on nitrogen and organic matter reserves in Indian soils*. (pp. 1-125). New Delhi: Indian Council of Agricultural Research.

Manna, M.C., Swarup, A., Wanjari, R.H., Ghosh, P.K., Singh, K.N., Singh, Y.B., Tripathi, A.K., & Saha, M.N. (2005a). Soil organic matter in a West Bengal *Inceptisol* after 30 years of multiple cropping and fertilization. *Soil Science Society of America Journal*, 70, 121-129.

Manna, M.C., Swarup, A., Wanjari, R.H., Ravankar, H.N., Mishra, B., Saha, M.N., Singh, Y.V., Sahi, D.K., & Sarap, P.A. (2005b). Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Research*, 93, 264-280.

Manna, M.C., Swarup, A., Wanjari, R.H., Mishra, B., & Sahi, D.K. (2007a). Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil and Tillage Research*, 94, 397-409.

Manna, M.C., Swarup, A., Wanjari, R.H., & Ravankar, H.N. (2007b). Long-term effect of NPK fertilizer and manure on soil fertility and a sorghum-wheat farming system. *Australian Journal of Experimental Agriculture*, 47, 700-711.

Manna, M.C., Sahu, A., & Subba Rao, A. (2012). Impact of long-term fertilizers and manure application on C-sequestration efficiency under different cropping systems. *Journal of Soil and Water Conservation (In press).*

Parton, W.J., Schimel, D.S., Cole, C.V., & Ojima, D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grassland. *Soil Science Society of America Journal,* 51, 1173-1179.

Six, J., Paustian, K., Elliott, E.T., & Combrink, C. (2000). Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregates-associated carbon. *Soil Science Society of America Journal*, 64, 681-689.

Swarup, A., Manna, M.C., & Singh, G.B. (2000). Impact of land use management practices on organic carbon dynamics in soils of India. In R. Lal et al. (Eds.), *Global climate change and tropical ecosystems*: *Advances in soil science (USA).* pp. 261-281.

Swarup, A. (1998). Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. In *Long-term soil fertility management through Integrated Plant Nutrient Supply System.* (pp1-335). Proceedings of National workshop. April 2-4. Bhopal, India: Indian Institute of soil Science.

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