

Review Article

Impact of different residue management on Carbon dynamics in Rice-wheat cropping system: A Review

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Abstract

Rice-wheat cropping system (RWCS) being the most dominant cropping system of north-west India although providing food security in the country (Parihar et al., 2016) have also led to soil degradation and over exploitation of underground water resources (Hobbs and Gupta 2004; Sharma et al., 2012). Therefore, diversification of RWCS is of paramount importance in mitigating the biotic and abiotic constraints arising in rice-wheat monoculture. The diversification of RWCS with maize-wheat cropping system (MWCS) or pearl millet-wheat cropping system (PWCS) and alternate soil and crop management practices could help enhance system productivity, sustain soil health and environmental quality (Meelu et al., 1979; Parihar et al., 2016), and save irrigation water and labour costs (Aulakh and Grant, 2008). The major problem which cropped up recently with this wheat based cropping system is how to dispose the large quantities of crop residues left over in the field due to use of mechanised combined harvester. In Punjab, Haryana and Western Uttar Pradesh the situation is extremely grave where about 70-80 million tons (MT) of rice and wheat straw are burned annually releasing approximately 140 Mt of CO₂ (Punia et al., 2008, Jain et al., 2014), 8.57 Mt CO, 0.037 Mt of SO_x, 0.23 Mt of NO_x, 0.12 Mt of NH₃ and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter (Jain et al., 2014).

The UN Environment Program now recognizes that Atmospheric Brown Clouds (ABCs) are a major contributor to climate change (UNEP, 2008).

Keywords: residue management, mineralizable carbon, aggregate protected carbon, C Sequestration

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Introduction

Depletion of organic carbon in Indian soils is another worrying factor for unsustainable agricultural productivity and depletion of SOC and overall deterioration of soil health. Long-term studies have shown that practices like improved fertilizer management, manuring and compost application, residue incorporation, crop rotation, green manuring, reduced tillage, adjusting irrigation method enhanced soil carbon build up and storage (Kimble et al., 2002; Purakayastha et al., 2008; Nayak et al., 2012). However, the addition of organic waste materials is a management technique with the potential to increase SOC content and to improve soil quality. This is a feasible option in tropical part of the world where inorganic fertilizer costs are high but organic materials are available adequately. There are few options available to dispose of the crop residues are making manure, in-situ incorporation. In this scenario, biochar, pyrolysed product of biomass offers a significant, multidimensional opportunity to transform large scale agricultural waste streams from a financial and environmental liability to valuable assets. Interestingly if these residues are converted into biochar, 50% of initial biomass C can be recovered as compared to only 3% during open burning and <10–20% after 5–10 years during biomass decomposition (Baldock and Smernik, 2002). Biochar, produced by the pyrolysis of biomass under limited oxygen, is highly stable and resistant to microbial decay. Thus there is considerable interest in the concept of applying biochar to soil as a long-term sink for carbon (C) thereby mitigating climate change (Prayogo et al., 2014). This approach is a win-win strategy as the application of biochar is reported to increase crop yields with a range between 6–144% with few exceptions where yield was reduced (Purakayastha et al., 2017).

Need of residue management

There is lack of scientific knowledge on the long-term effect of various contrasting residue management practices (e.g. crop residue incorporation open burning of residue, biochar and complete removal of residue) on stability and

quality of SOC in three wheat-based cropping systems (rice-wheat, maize-wheat and pearl millet wheat) in Inceptisol of sub-tropical India. Considering the importance of identifying the alternative cropping system to rice-wheat and appropriate residue management strategy

Objectives of residue management

Major objectives of residue application and management is to study the long-term effect of residue management on physical, chemical and biochemical stability of soil organic C. and to identify the long-term impact of residue management on quality of soil organic C and productivity of three cropping systems. With equations to prepare a balance sheet of C input and build-up of soil organic C.

Physical fractionation of soil according to particle-size, combined with derivative chemical techniques was shown to be a potent tool for evaluating land use induced changes on SOM (Guggenberger *et al.* 1994). This fractionation is based on the concept that SOM pools associated with particles of various size classes and mineral composition differ in structure and function, and therefore play different roles in SOM turnover (Christensen 1992).

SOM and microbial biomass status in paddy soils was improved by application of manure along with inorganic fertilizer. It is therefore important that the traditional use of manure should be strongly promoted in order to maintain long-term soil productivity even where inorganic fertilizer is being used to achieve high yields. Not only will this improve the SOM status but it will also reduce the rates of inorganic fertilizer required, since nutrients will be released from the manures. The incorporation of rice straw is another important way of promoting SOM accumulation and increasing the soil microbial biomass, hence the importance of straw retention also needs to be stressed. Recycling of animal manure and rice straw in paddy agroecosystems can also help to solve environmental and economic problems related to the disposal of these waste materials. (X. H. Hao *et al.*, 2007).study has shown that accumulation of SOM in sandy soils is possible with the continuous application of appropriate quality residues leading to an enhanced microbial stabilization of C and N in soil storage locations (aggregates and resistant POM pools), and efficient microbial nutrient cycling within the soil system(A. Puttaso *et al.*,2010).Recent studies challenged the concept of chemical recalcitrance and demonstrated that the quality of soil OC was not related to its origin, its chemical composition or structure (Dungait *et al.*, 2012). It is suggested that low quality OC is related to the strong chemical inter-molecular interactions of OC with reactive mineral phases (Dungait *et al.*, 2012). Recent studies have shown that OC quality alone does not control the long-term stability of soil OC but that environmental and biologic controls are also important (Berhe and Kleber, 2013). For example, Schmidt *et al.* (2011) reported that old OC can be of high quality while Berhe and Kleber (2013) suggested that the stability of a substrate in a specific ecosystem could change considerably when deposited in a system with different micro-climatic or environmental conditions. In the context of global climate change, understanding the spatial and temporal variability of soil OC quality and erosion-induced lateral fluxes of OC between systems characterized by different environmental conditions are thus important to predict present-day and future soil OC stability (Doetterl *et al.*, 2012). Berheet *et al.* (2012) demonstrated that soil erosion can lead to reconfiguration of organo-mineral associations influencing the distribution of soil OC pools along a hillslope. Berhe *et al.*, 2012 showed that eroded OC at the catchment-scale was buried and stabilized at the depositional site, but argued that the rate of replacement of eroded OC is likely not be equally distributed over different OC pools. However, these studies focused on natural ecosystems, which are characterized by very low erosion rates and high Net Primary Production relative to disturbed agro-ecosystems. Based on physical fractionation methods, Doetterl *et al.* (2012) studied the distribution of OC pools along an agricultural hillslope taking into account short-term stabilization processes such as aggregation. At present, the combined geomorphic and pedogenic effects on OC quality distribution and OC stabilization by organomineral associations on agricultural land remain poorly quantified. The mechanisms responsible for stabilization of SOM can be categorized as physical, chemical and biochemical. Storage (accumulation) and stabilization (slow decomposition rate, long turnover) of eroded SOC in different depositional settings depend on a number of variables in the soil system including physical protection (removal from near surface environments by burial and aggregation), chemical associations with the mineral fraction (mineralogy), and biochemical stability/recalcitrance of their organic constituents (Kahle *et al.*, 2003; Six *et al.*, 2002; Torn *et al.*, 1997).

Changes in soil management practices influence the amount, quality and turnover of soil organic matter (SOM; Tiessen and Stewart 1983). Many studies have been carried out to investigate the influence of land use changes on tropical (Guggenberger *et al.* 1995) and temperate soils (Guggenberger *et al.* 1994). Little is known, however, about the effects of deforestation followed by intensive pasture installation on SOM in high mountain ecosystems. Particulate organic matter (POM) is assumed to be associated with the sand fraction, SOM with medium term turnover within the clay fraction, and SOM with long-term turnover within the silt fraction (Guggenberger *et al.* 1995). Microbial biomass C and N tend to follow the trend among treatments in whole and light fraction organic matter. Soil under CG and CL and the barley/forage rotation had the higher amounts of aliphatic-C (indicating

enrichment in carbohydrate, proteins and peptides, thus improving organic matter quality) than soil under CB. These results indicate the positive contribution of forage crops to sequester carbon and improve soil quality (Arshad *et al.*, 2011). The SOC, TN and labile SOM fractions were affected by management systems and N fertilization. Management systems had greater effects on total SOM and its fractions than did N fertilization. Compared with traditional farm-ing practices, the two ISSM systems increased SOC, TN, labile SOM fractions and CMI. Appropriate N fertilization application (N150) resulted in higher SOC and TN. Though N application increased DOM-N, it was prone to decrease most of the other labile SOM fractions (POM-C, POM-N, DOM-C, MBN, KMnO₄-oxidizable C), especially under higher N rate. Our study indicates that those recently developed integrated soil-crop sys-tem management in rice rapeseed rotation was suitable for improving soil organic matter. N rate is a key factor in affecting labile SOM fractions. There need to evaluate the long-term integrated soil-crop management and N fertilization for the environmental effects (e.g. green-house gas production) in rice-rapeseed rotations (J. Tian *et al.*, 2013). Changes in soil organic carbon (SOC) due to management practices are difficult to quantify as these changes occur slowly, are relatively small compared to the vast SOC pool size, and vary both spatially and temporally (Paustian *et al.*, 1997). Some of the soil carbon fractions, such as microbial biomass carbon (MBC), (Nannipieri *et al.*, 1990), particulate organic carbon(POC), and potential mineralizable carbon (Pawlson and Jenkinson, 1981) and KMnO₄oxidizable carbon (Blair *et al.*, 1995) are likely to be more sensitive to management practices than the total SOC (Campbell *et al.*, 1997). Thus these soil carbon fractions may serve as indicators of future changes in total SOC that are presently undetectable (Janzen *et al.*, 1997). Particulate organic carbon (POC) has been recognized as a sensitive indicator of soil management effects on SOC and is referred to as slow pool of SOC (Camberdella and Elliot., 1992) having an intermediate turn- over time between the active and passive pools of SOC (Parton *et al.*, 1987). Although, this fraction of organic matter represents only a small fraction of soil mass, its short turn over time makes it an important source of carbon and nutrients. Microbial biomass carbon (MBC) is a relatively small (1-4% of total SOC pool), labile fraction that quickly responds to carbon availability (Smith and Paul., 1990). Further very few studies, indicated that labile carbon is more sensitive to the changes in cultivation or agricultural management practices, compared to total SOC (Blair *et al.*, 1995).

Carbohydrates represent an important fraction of soil organic carbon (SOC), whereby in cultivated soils the carbohydrate-C accounts for approximately 10% of total OC on average (Cheshire, 1979). The soil carbohydrate pool is composed of polysaccharides derived from various sources, i.e. plant and animal tissues, plant mucilage, cellular tissues and extracellular products of soil microbes. The presence of carbohydrates in soil has manifold effects on biological, physical and chemical soil properties, reflecting the diverse properties and functions of polysaccharides in soil (Greenland and Oades, 1975). They represent the major carbon and energy source for soil organisms, thus governing biological activity. Polysaccharides, mainly those of microbial origin. Act as binding agents between soil particles. Thus influencing soil structure / aggregation. Since polysaccharides interact with metal cations, they may also affect soil chemical properties. Carbohydrates are usually considered to be readily degradable compounds. The non-cellulosic and cellulosic fractions in plant residues are degraded at a much higher rate than lignin for example (Martin *et al.*, 1980; Martin and Haider. 1986). Microbially synthesized polysaccharides were also found to be attacked rather rapidly, although saccharides of some microbial species may be relatively resistant against decomposition (Martin *et al.*, 1966). On the other hand, carbohydrates account for a considerable proportion of SOC. Based on model experiments, different mechanisms of sugar stabilization have been proposed (Cheshire, 1977): i) a close association c polysaccharides with mineral colloids, ii) an interaction of polysaccharides with meta ions (Fe, Cu, Zn) through uronic acid and mannose units, iii) an interaction of sugars will tannins. It was proposed that enzymes may show a reduced affinity toward; polysaccharide-metal complexes as compared with pure polysaccharides (Martin *et al.*, 1966). A reduced degradation of polysaccharides in the presence of tannins was explained by a reduced availability of the sugars to enzymes/microbes, and by an enzyme inhibition through tanning, respectively. A further protection against rapid degradation may arise from the special role of polysaccharides as "bridges" between mineral particles, being directly involved in the build-up of stable (micro) aggregates. The promotion of aggregation occludes the polysaccharides themselves within aggregates and consequently reduces accessibility to decomposer organisms (Puget *et al.*, 1999).

Ligninolyticbasidiomycetes produce large quantities of hydrophobic polysaccharides, glycolipids or glycoproteins that bind to and stabilize soil particles in water-stable aggregates (Caesar-Tonhat and Cochran, 2000). However, many of the polysaccharides produced by microbial degradation will glue aggregates together quickly but are water-soluble and ephemeral and do not to contribute to the long-term stability of aggregates (Chaney and Swift, 1986; Six *et al.*, 2001). Without the protection of hydrophobic coatings, soil aggregates may be disrupted by rainfall because of slaking, the differential swelling of clays, mechanical dispersion by the kinetic energy of raindrops, and physiochemical dispersion. The aliphatic molecules involved in aggregate formation increase water stability and long-term survival of aggregates, because attractive forces between these molecules are much stronger internally than

externally (Degens, 1997; Piccolo and Mbagwu, 1999; Chenu et al., 2000). Soil organic matter containing high concentrations of aliphatic groups, such as humic acid, may increase aggregate stability and the long-term stabilization of organic materials (Piccolo and Mbagwu, 1999). These aliphatic hydrophobic groups and polymers are the major contributors to the water-stability of aggregates. They increase the contact angle for water penetration, which restricts infiltration and slaking, lowers water potential, and increases the internal cohesion of aggregates (Chenu et al., 2000).

Glomalin contributes to the stabilization of aggregates by sloughing off hyphae onto the surrounding organic matter, binding to clays (probably via cation bridging by iron), and providing a hydrophobic coating (Wright and Upadhyaya, 1999). This is demonstrated in a number of experiments, where total and, especially, immune reactive concentration of glomalin are positively correlated with percent water-stable soil aggregates in both agricultural and native soils (Rillig et al., 2003; Wright and Anderson, 2000; Wright and Upadhyaya, 1998; Wright et al., 1999).

Cropping systems that include grass and/or legume forage crops had better soil structure (i.e., more stable aggregates) than soil under continuous barley. Soil under continuous bromegrass (CG) and continuous forage legume (CL) were higher in soil and light fraction organic matter than the other two treatments. Rotation cropping that alternate 3 years of barley production with 3 years of forage production had intermediate levels of soil structure and organic matter content. Soil under CG had the highest and under continuous barley (CB) the lowest amounts of acid-hydrolysable sugars amongst the treatments.

Collection of soil samples

- Soil samples will be collected from three depths viz., 0-15 cm, 15-30 cm, 30-60 cm from the above treatments and cropping systems.
- Each soil sample will be divided into two parts, one part will be kept in the refrigerator for analysis of microbial biomass carbon (MBC) and the other part will be air dried and stored in ambient temperature for analysis of other parameters.
- Laboratory studies will be conducted to accomplish the set of objectives and their details are given below:

Stability of carbon in aggregated soil fractions

Thermal stability of carbon in the various aggregate fractions will be studied estimating the activation energy (AE) by carbon mineralization at three temperatures 25°C, 30°C and 35°C. Thermal stability of aggregate protected carbon will be done at three different temperatures at field capacity by alkali trap method (Anderson, 1982) and carbon content of aggregates will be measured at 15, 30, 60 and 90 days period. By using the data temperature sensitivity of C loss will be calculated by using Arrhenius equation ($k=A \cdot \exp(-E_a/RT)$) and Q_{10} values (Knorr et al., 2005):

Where k = reaction rate, E_a = activation energy, A = factor, R = Universal gas constant, T = Absolute temperature
Taking the natural logarithm of Arrhenius' equation yields:

$$\ln(k) = \frac{-E_a}{R} \frac{1}{T} + \ln(A)$$

This has the same form as an equation for a straight line:

$$y = mx + b$$

So, when a reaction has a rate constant that obeys Arrhenius' equation, a plot of $\ln(k)$ versus T^{-1} gives a straight line, whose gradient and intercept can be used to determine E_a and A . This procedure has become so common in experimental chemical kinetics that practitioners have taken to using it to define the activation energy for a reaction. That is the activation energy is defined to be $(-R)$ times the slope of a plot of $\ln(k)$ vs. $(1/T)$

$$E_a = -R \left[\frac{\partial \ln k}{\partial (1/T)} \right]_p$$

Long-term impact of residue management on quality of soil organic C and productivity of three cropping systems

Water extractable organic matter C and N (WEOM-C, WEOM-N) in soil samples will be extracted by treating soil with distilled water, shaken overnight, centrifuged at 1400g for 10 min, and then filtered through a 0.45µm membrane filter (Agnelli et al., 2016) and WEOM-C (Snyder and Trofymow, 1984) WEOM-N (Bremner, 1970) will be

estimated by digestion and diffusion procedure. The contents of hexose and pentose sugars in the WEOM and hot water extractable part will be colorimetrically estimated (Hofman and Dušek, 2003) by using the anthrone and orcinol methods, respectively. The UV–VIS spectra of the WEOM solutions will be measured in the 200–600 nm wavelength range in a 1 cm quartz cuvette with a UV-VIS spectrophotometer.

The dissolved organic matter (DOM) in the WEOM solutions will also be characterized by absorbance determined at 254 nm (Abs₂₅₄) which is considered as an acceptable representation of the content of aromatic structures in the overall DOM. The specific UV absorbance at 254 nm (SUVA, L mg C⁻¹ m⁻¹) will be calculated as follows: SUVA = 100 × Abs₂₅₄/(DOC) where L is the optical path length (cm) and DOC is in mg L⁻¹ (Sharma et al., 2017). For soil organic C, in an incubation experiment on carbon mineralization will be studied in closed jars by alkali trap method (Anderson, 1982) over two months period. Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) will be estimated at the last week of incubation and microbial metabolic quotient (C_{min}/MBC) will be used to judge the quality of SOM. available nitrogen, phosphorus and sulphur contents will be assessed before digestion. Light fraction organic matter fraction (LFOMF) will be separated from the soil and its C, N (CHNS analyser) and C:N ratio.

Prepare the balance sheet of C input and build-up of soil organic C by modeling

The amount of C from plant residues that is returned to the soil will be estimated using both secondary, as well as primary databases generated out of C analysis of leaves, roots and stems of rice, wheat, maize, pearl millet in the cropping system.

The amounts of crop residues left over in the fields by different crops will be directly measured. The rhizodeposition C of these crops will be calculated following the relationship of root C:rhizodeposition C as established by Shamoot *et al.* (1968) for rice (0.76:1), wheat (0.81:1) and maize (0.72:1) and pearl millet (0.75:1). Using all the above databases and measurements, an estimate of plant derived C inputs into the soils by different crops and each of their components from the three systems will be made.

Based on these analyses, the total amount of organic C applied to the soil at all the treatments through organic amendments will be calculated on dry weight basis. C budgeting for the studied systems will be done as follows:

$$\text{C build - up (\%)} = \frac{\text{C}_{\text{fert + organic}} - \text{C}_{\text{cont}}}{\text{C}_{\text{cont}}}$$

$$\text{C build - up rate (Mg C/ha/yr)} = \frac{\text{C}_{\text{fert + organic}} - \text{C}_{\text{cont}}}{\text{Years of experimentation}}$$

The stabilization rate of exogenous organic C into SOC in the entire 0–60 cm depth was calculated as follows:

$$\text{C stabilization (\%)} = \frac{\text{C}_{\text{fert + organic}} - \text{C}_{\text{cont}}}{\text{Total C input}}$$

where C_{fert+org} represents C in fertilizer NPK+organics FYM or compost treatments and C_{fert} and C_{cont} are the C in fertilizer NPK and control treatments, respectively.

$$\text{C sequestered (Mg C/ha)} = \text{SOC}_{\text{current}} - \text{SOC}_{\text{initial}}$$

Where SOC_{current} and SOC_{initial} indicate the SOC stocks in 2017 (current) and that at the initiation of the long-term experiments (initial) i.e. in 2010. Positive and negative values indicate SOC gains and losses respectively for the cropping systems.

Decay constant, “k” of soil belonging to a particular site will be estimated by plotting the data between change in SOC over time (dC_t/dt) versus C inputs data and equating the relationship with dC_t/dt = hA – kC_t (y = mx + C) where slope represents humification rate constant, “h” of the straight line curve and intercept represents “kC_t”. By substituting the decay rate constant (k) in the following equation, it is possible to calculate the maximum carrying capacity of soil (C_m).

$$\frac{dC_t}{dt} = I \left(1 - \frac{C_t}{C_m} \right) - kC_t$$

Where dC_t/dt is change in C content over time, I represents average annual C input, k is decay rate constant, C_t is C content at time t.

Annual C inputs (A) enter pool F where labile C is rapidly decomposed and respired as CO_2 (mineralization) and where a fraction, h (the humification rate constant), enters pool S each year. A fraction, k (decay rate constant), of SOC in pool S is also decomposed each year. The change in SOC over time t is: $dC_s = dt \frac{1}{4} hAkC_s \delta 1P$ where C_s is the SOC in pool S in the year 2003, and A is the average annual C input between the year 1994 and 2003. Solving Eq. (1) for $C_s = C_0$ when $t = 0$ gives: $C_s \frac{1}{4} hA = k \int \delta P C_0 hA = k ekt \delta 2P$ where C_0 is the initial SOC in pool S in the year 1994. The h was calculated through optimization of parameter. The k value of our soil was known as 0.001 (Vennila, 2003).

The predicted C_s was calculated from the Eq. (2) by using the values of C_0 , h, k, A and t. Carbon inputs required to maintain C_0 .

Conclusion

The study would identify the best residue management practice and cropping system alternative to rice-wheat system for long-term C sequestration and yield sustainability. The study would also assess the C sequestration efficiency of the different management practices for recommendation.

Table Soil parameters and methodology to be used for the study

Parameters	Methodology	Reference
Soil organic C	Dry combustion method	Nelson and Sommers (1982)
very labile, labile, less labile and non-labile C	Modified walkeley and black method	Chan et al., (2001)
Macro/micro/silt-clay fractions	wet sieving method	Cambardella and Elliott (1992)
chemical stability of soil organic C	Sodium hypochlorite	(Siregar et al., 2005)
Resistant C	333mM $KMnO_4$	(Blair et al., 1995)
SOM characterization	IR spectroscopy	(Bernier <i>et al.</i> , 2013).
Glomalin	Glomalin extraction	Wright and Upadhyay (1999)
Lignin, carbohydrates&Polyphenol	<i>Reducing sugar</i> - DNS method (Spectrophotometry)	Halvorson et al.(2009)
Water extractable organic matter C and N	digestion and diffusion procedure.	Agnelliet al. (2016)
Sodium hypochlorite (NaOCl) oxidisable C.	Varying concentration of NaOCl.	Siregaret al.(2005)
Carbon mineralization	Alkali trap method	Anderson (1982)
Total Organic C	Combustion method (CHNS analyser) (Elementar, Vario TOC Cube).	Dumas (1831)
Microbial biomass carbon (MBC)	Substrate induced respiration method.	Bailey <i>et al.</i> , (2007)

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