

Carbon dynamics in tropical rice-rice agro eco-system under different fertilizer treatments

A

**Thesis submitted to the
Orissa University of Agriculture and Technology
in Partial fulfilment of the Requirement
for the degree of
Master of Sciences in Agriculture
(Soil Science and Agricultural Chemistry)**

By

***PRAJNYAMAYEE KAMP
Adm. No. 07AC/13***



**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL
CHEMISTRY
COLLEGE OF AGRICULTURE
ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
BHUBANESWAR, ORISSA-751003
2015**

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2015



CERTIFICATE-II

This is to certify that the thesis entitled “**Carbon dynamics in tropical rice-rice agro ecosystem under different fertilizer treatments**” submitted by Prajnyamayee Kamp to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfilment of the requirements for the degree of Master of Sciences in Agriculture (Soil Science and Agricultural Chemistry) has been approved by the students’ advisory committee and the external examiner.

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It is further certified that the assistance and help received by her from various sources during the course of investigation has been duly acknowledged.

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Place : Bhubaneswar

Dated :

.....

(Prajnyamayee Kamp)

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ABBREVIATIONS

$^{\circ}\text{C}$: Degree celcius
CMI	: Carbon Management Index
C_{mic}	: Microbial Biomass Carbon
C_{min}	: Mineralisable Carbon
$\text{CO}_2\text{-cum}$: Cumulative Carbon Dioxide
CPI	: Carbon Pool Index
CPOC	: Coarse Particulate Organic Carbon
CPOM	: Coarse Particulate Organic Matter
CSP	: Carbon Sequestration potential
DMRT	: Duncan's Multiple Range Test
<i>et al.</i>	: and others
FA	: Fulvic Acid
FPOC	: Fine Particulate Organic Carbon
FPOM	: Fine Particulate Organic matter
FYM	: Farm Yard Manure
GHG	: Green House Gases
GT	: Giga Ton
H	: Humin
HA	: Humic Acid
HF	: Heavy Fraction
HFOC	: Heavy Fraction Organic Carbon
HI	: Harvest Index
$\text{KMnO}_4\text{-C}$: Potassium Permanganate Extractable Carbon
L	: Lability
LF	: Light Fraction
LFOC	: Light Faction Carbon
LFN	: Light Fraction Nitrogen
LFOC	: Light Fraction Organic Carbon
LFOM	: Light Fraction Organic Matter

LI	: Lability Index
LOC	: Labile Organic Carbon
LOI	: Loss-on Ignition
MAC	: Mineral Associated Organic Carbon
MAOM	: Mineral associated Organic Matter
Mg	: Megagram
mM	: milimolar
MQ	: Microbial Quotient
nm	: nanometer
Pg	: Peta gram
POC	: Particulate Organic Carbon
POM	: Particulate Organic Matter
POM-C	: Particulate Organic Matter Carbon
POXC	: Potassium Permanganate Oxidisable Carbon
qCO ₂	: Metabolic Quotient
RMC	: Readily Mineralisable Carbon
rpm	: Revolution per Minute
SG	: Specific Gravity
SOC	: Soil Organic Carbon
SOM	: Soil Organic Matter
SYI	: Sustainable Yield Index
Tg	: Tera gram
TOC	: Total Organic Carbon
TSOC	: Total Soil Organic Carbon
Vis-à-vis	: with reference to
WEOC	: Water Extractable Organic Carbon
WSOC	: Water Soluble Organic Carbon
Y _{max}	: Maximum Yield

ABSTRACT

Soil carbon sequestration is a complex process influenced by agricultural practices, climate and soil conditions. Soil organic carbon (SOC) and its fractions are strong determinants of chemical, physical and biological properties and soil quality. Thus, an attempt is made here to investigate into the dynamics of pools of SOC in relation to crop productivity. Soil sample of post-kharif 2014 were collected from long term fertilizer experiment started in the year 2005-06 in the central farm of OUAT under AICRP in an acidic sandy soil taking swarna (MTU-7029) as a test crop. The experiment was systematically initiated with quadruplicated 12 treatments in a Randomized Block Design. Out of 12 treatments, six treatments were selected for the present study i.e. no fertilization, 100% N, 100% NP, 100% NPK, 150% NPK and 100% NPK+FYM. A fallow treatment was also included to compare the impact of cultivation vis-a-vis no cultivation. The experimental results revealed that cultivation over the years caused a significant decrease in soil organic carbon content by 14% in unfertilized control as compared to uncultivated soil. The balanced fertilization with NPK, super optimal dose of NPK and integration of balanced fertilization with FYM increased the SOC content as well as SOC stocks over the initial year. The carbon sequestration potential (1.77 Mg ha^{-1}) was highest in 100%NPK +FYM treatment. The cumulative C mineralized in 36 days of incubation of surface soil ranged between 1.08 to 2.18 g kg^{-1} , being highest in the 100% NPK + FYM treatment. The biological pool such as $\text{MBC}(\text{C}_{\text{mic}})$ comprised of 3.4 % of the soil organic carbon content. The greater magnitude of C_{mic} and readily mineralisable C (RMC) was found in 100%NPK+ FYM. The greater accumulation of water extractable carbon, $\text{KMnO}_4\text{-C}$, particulate organic carbon and density fraction was recorded in 100%NPK + FYM treatment. A greater amount of C in POC pool was found with the NPK + FYM (3.90 g kg^{-1}) and NPK (3.07 g kg^{-1}) treatments. The Coarse particulate organic C (CPOC) responded to management to a greater extent than fine particulate organic C (FPOC) and may thus be considered a more labile pool of SOC. Among the density fraction, light fraction organic C (LFOC), though accumulated to a small amount (0.5 to 5% of the SOC) as compared to heavy fraction organic C (HFOC), serves as a better indicator for monitoring to soil health. The highest Carbon management index (CMI) was computed in the integrated treatment of 100%NPK with FYM. The microbial quotient (MQ) was highest in 100%NPK+FYM but the respiratory quotient ($q\text{CO}_2$) or metabolic quotient was however, significantly higher under control and only N vis-à-vis other fertilized treatments, the least value being recorded in the NP, NPK, and NPK+FYM treatments. The content of SOC significantly correlated with sustainable yield index (SYI) which support better sustainable productivity. However, LFOC exhibited a strong relationship ($R^2=0.91^{**}$) with mineralisable C compared to CPOC ($R^2=0.89^{**}$). Among the all fractions of SOC, yield and SYI were strongly related with RMC, LFOC, C_{mic} , CPOC and $\text{KMnO}_4\text{-C}$. They accounted for as much as 90, 84, 85, 85, 77 and 69 % variability in rice yield and 70, 73, 82, 70, 54 and 65 % variability in SYI. CMI can be used as a more sensitive indicator of the rate of change of SOC in response to soil management changes. Results suggested that current fertilizer recommendation of 100% NPK+ FYM are adequate for maintaining SOC stock and this practice may help in maintaining the sustainability of rice-rice cropping system.

INTRODUCTION

Under the changing climatic scenario and its effect on crop productivity, the soil nutrient status has assumed greater significance and is of worldwide concern for the environmental sustainability. Rice is the major cereal crop feeding two- third of the global population. Rice occupies one-third of the world's crop land planted to cereals and provides 30-60% of the calories consumed by nearly three billion people (Gurra *et al.*, 1998). Rice production is an important part of Asia's economy. The importance of rice in global concerns regarding food security, poverty alleviation, preserving cultural heritage and sustainable development has been understood very well. More than 90% of the world's rice is grown and consumed in Asia. Between now and 2020, about 1.2 billion new rice consumers will be added in Asia. Rice covers an area of 4023 thousand ha which is 72.74% to the total area in Odisha. Rice production is 9497 thousand MT and productivity is 23.61q ha⁻¹ during the year 2012-13 (Odisha economic survey 2013-14).

There are reports of declining or stagnating crop yields (Ladha *et al.*, 2003) and the sustainability of rice based cropping system is now under threat. The underlying reasons for decline or stagnation of crop yields are not precisely known, though it has been attributed to changes in quantity and quality of soil organic matter (SOM), and a gradual decline in the supply of soil nutrients causing macro and micronutrient imbalances (Bhandari *et al.*, 2002;Ladha *et al.*, 2003).

Following the unprecedented expansion and intensification of agriculture in India, there is clear evidence of a decline in the soil organic carbon (SOC) contents in many soils as a consequenc; while on the other hand, it has been reported that good farming practices such as balanced fertilization and addition of crop residues either maintains or results in build up or depletion of SOC stock (Swarup *et al.*, 2000; Kong *et al.*, 2005). The process of decline of soil organic matter is accelerated by the process of nutrient depletion (Lal, 2002). Soil organic carbon is key attribute of soil fertility and productivity because of its influence on the physical, chemical and biological properties of soils (Nieder and Benbi, 2008). Irrespective of its potential benefits to productivity and profitability, organic carbon might be sequestered by vegetation and soils as a possible

way of reducing the rate of CO₂ enrichment of atmosphere and moderate the global climate change. Soils and managed agricultural soils in particular, represents a potentially significant low to no cost sink for green house gases (GHGs) (Lal, 2004a, Pacala and Socolow, 2004). Increased sequestration of carbon in agricultural soils has the potential to mitigate GHGs emissions to atmosphere (Sampson and Scholes, 2006).

The soil is the largest terrestrial pool of organic carbon, about 1150 Pg compared with about 700 Pg in the atmosphere and 600 Pg in the land biota (Lal and Kimble, 1997). The global potential of soil organic carbon sequestration is estimated at 0.6 to 1.2 GT C yr⁻¹, comprising 0.4 to 0.8 GT C yr⁻¹ through adoption of recommended management practices on crop land soils (Lal *et al.*, 2007). Total SOC pool in Indian soils is estimated at 21 Pg to 30 cm depth and 63 Pg to 150 cm depth. The SOC pool in Indian soils is 2.2% of world pool for 1m depth and 2.6% to 2m depth (Lal, 2004c).

Cropping system and management practices that ensure greater amounts of crop residues returned to the soil are expected to cause a net build up of the SOC stock. Identifying such system or practices is a priority for sustaining crop productivity. To better understand the mechanism by which C is lost or stabilized in the soil, the SOC stock is separated into a labile or actively cycling pool, a slow pool and a stable or passive, recalcitrant pool with varying residence times (Parton and Rasmussen, 1994).

Several physical, chemical and biological methods for determining labile SOC pools have been used with varying degree of success (Rosell *et al.*, 2001; Haynes 2005; von Lutzow *et al.*, 2007). Physical fractionation involves use of size and density floatation techniques to isolate fractions based on the degree of physical protection or occlusion within aggregates and formation of organo – mineral complexes (Cambardella and Elliot, 1993; De Gryze *et al.*, 2004; Benbi and Senapati, 2010; Benbi *et al.*, 2012b). Particulate organic carbon (POC) has been shown to be a sensitive indicator of soil management effects on SOC and is considered to represent the slow pool of SOC (Cambardella and Elliot, 1992; DelGaldo *et al.*, 2003). The labile SOC pool such as water extractable organic carbon; potassium permanganate oxidizable organic carbon contributes to elucidate changes in TOC at early stages of changes in management practices (Gong *et al.* 2009; Purakayastha *et al.*, 2008). The biologically active SOC pools such as soil

microbial biomass carbon (MBC) and mineralisable C (C_{min}) are recognized as sensitive indicators of management induced changes in both SOC and biological properties of soils (Powlson et al., 1987; Anderson and Domsch, 1989; Haynes, 2005). In 1995, the Carbon Management Index (CMI) was derived by combining labile and non-labile C fractions (Blair et al., 1995). Subsequently, the CMI has been widely used as a sensitive indicator of SOC variation rate in response to soil management changes (Blair et al., 2006; Gong et al., 2009; Verma and Sharma, 2007).

Net change in Soc depends not only on the current management practices but also on the management history of the soil. Long term experiments are the primary source of information to determine the effect of cropping systems and other management practices on C and N dynamics in soil (Leigh and Jhouston, 1994). In addition, long term experiments are the best to evaluate the sustainability of agricultural system (Barnett *et al.*, 1995) and to determine the impacts of land use effects on SOC (Paul *et al.*, 1997).

The potential of soil to sequester C, its dynamics and turnover can vary with soil type and climate. Therefore, it is important to determine C dynamics under different climatic regions, in order to draw meaningful conclusions about their contribution (either source or sink) towards global C stock. Very few study have been conducted to understand the organic carbon dynamics in tropical and sub-tropical conditions present in India. Therefore it is proposed to study the carbon dynamics, carbon sequestration and its relation with crop productivity under AICRP on Long term fertilizer experiment of Indian Council of Agricultural Research (ICAR), OUAT, Bhubaneswar with following objectives:-

- 1) To determine the soil organic carbon storage, size of its pools under long term intensive cultivation of rice-rice cropping system.
- 2) To determine soil carbon dynamics and their sequestration potential under different fertilizer programme under long term rice-rice cropping system.
- 3) To study the relationship among sustainable yield indices, SOC, and its fractions and carbon management index(CMI) in rice- rice cropping system.

REVIEW OF LITERATURE

The most important element in the biological realm is carbon upon which the chemistry of all life forms is based. The majority of carbon entering the soil is comprised of plant residues. Microbial and animal cells account for only a minor fraction of the total input of carbon to the soil. Organic C is found in soils in the form of various organic compounds, collectively called soil organic matter (SOM). Soil organic matter includes all living and non living organic material in all stages of decomposition. The soil organic matter is of fundamental importance in soil fertility. It is a store house of all essential plant nutrients and provides energy material for the soil organisms. Several studies on soil organic carbon pool have been done under long term condition. Therefore, an attempt is being made to collect the available information relating to factors influencing carbon sequestration and different carbon pools in relation to crop productivity under rice- rice cropping system.

2.1 Effect of long term manuring on soil organic carbon pools

SOM is not a homogenous substance, but rather is composed of substances with different chemical compositions and different recycling rates (Cambardella and Elliot, 1992).

Wising *et al.*, 2011, observed that Considerable amounts of soil organic matter (SOM) are stabilized in paddy soils, and thus a large proportion of the terrestrial carbon is conserved in wetland rice soils. Liu *et al.*, 2013, in a study found that long-term application of organic manure and inorganic fertilizer increased the SOC content in the soil. The similar results were obtained by Chen *et al.*, 2009.

Mandal *et al.*, 2007, reported in their study that rice-based cropping system has not caused any depletion of Total Soil Organic Carbon (TSOC) rather it has improved it and application of FYM or compost (5.0–10.0Mg ha⁻¹ yr⁻¹) combined with balanced NPK caused a small increase (10.7% over the NPK alone treatment) in TSOC.

SOC tended to enrich more in the coarse sand, whereas the highest enrichment of N was found in the clay fraction (Nacro *et al.*, 2004), confirming that partly decomposed plant debris is accumulated preferentially in the sand separates, and the degree of SOM alteration increased from coarser to finer fractions (Yan *et al.*, 2012).

In their study, Tripathi *et al.*, 2014, observed that, continuous cultivation of irrigated rice–rice system in a shallow low land for 41 years without application of FYM and inorganic fertilizer resulted in less accumulation of TOC in soil compared to other treated soil. An application of FYM alone could maintain the TOC while application of inorganic fertilizer and FYM + inorganic fertilizer improved the TOC level in soil. The TOC was 37.1– 47.1% higher in the FYM + inorganic fertilizers treatment compared to unfertilized control. In the FYM + inorganic fertilizer applied plots, most of the soil organic carbon can be supplied through additional C from FYM and increased rice root and stubble biomass as compared to unfertilized control. The higher lignin content in rice stubbles and root biomass and higher input of C may be attributed to increased TOC in the plots treated with FYM + inorganic fertilizers. It was found that in any case aboveground biomass was completely removed; root biomass could also contribute positively to SOC and N accumulation (Yang *et al.*, 2003; Zhu *et al.*, 2007). Blair *et al.*, 2006, showed that synthetic fertilizers can increase SOC and N accumulation but Lal, 2003 and Hai *et al.*, 2010, reported that the application of synthetic fertilizer may have little impact on SOC concentration unless being used in conjunction with no-till and residue management.

Yan *et al.*, 2012, reported that the silt does not have much potential to retain extra SOC; hence the most of the increased SOC is rather remained in coarse sand fractions. Any size group of particles has its saturation capacity for maintaining SOM, but there is a preferential order in sequestering SOM. The fine particles will be firstly saturated with C at lower level of organic input, and then the larger particles will approach saturation gradually with the increase of organic inputs. SOM associated to coarse sand is much more sensitive to fertilization practices. In general, both SOC and N associated with coarse fractions were readily mineralized to supply nutrients for crop growth in long-term cropping systems (Solomon *et al.* 2002; Ashagrie *et al.* 2005).

Changes in tropical land use have profound effects on soil organic matter (SOM) status. It has been suggested that alterations in the different fractions of SOM are more effective in indicating changes in soil use than total soil organic matter content (Daniele Vieira Guimaraes *et al.*, 2013).

Compared to the native forest soil, cultivation increased the proportion of the recalcitrant fraction, and led to a reduction in the labile fraction of SOM. Sustainable management practices should therefore be employed in order to achieve soil stability and biological productivity (Daniele Vieira Guimaraes *et al.*, 2013).

Application of poultry manure and vermicompost along with inorganic sources of NPK resulted in highest grain yield of rice. Soil organic carbon, labile carbon and water soluble organic contents also improved with the application of organic sources in conjunction to chemical fertilizers. The study showed that for better soil management as well as optimizing crop yields and environmental security, organic amendments need to be added along with use of chemical fertilizers (Khurseed *et al.*, 2013).

Cropping with only N–P–K fertilization just maintained SOC content, while N–P–K plus organics increased SOC by 24.3% over the control. A minimum of 3.56 Mg C ha⁻¹ yr⁻¹ was required to be added as organic amendments to compensate for SOC loss from cropping. Balanced N–P–K fertilization along with an adequate amount of FYM is most suitable for the continuous rice–wheat cropping system in the subtropical Indo-Gangetic Plains of India for improving the SOC stock and sustaining crop productivity (Majumdar *et al.*, 2008)

Benbi *et al.*, 2015, reported that differences in soil C pools under row crop production and uncultivated soils may provide information about soil C sequestration. Uncultivated soils had higher total C pool than croplands.

Inorganic and organic amendments increased TOC but NPK seemed to increase more labile fractions and near to the surface, while FYM appeared to increase more resistant SOC fractions especially at depth in the soil (Ghosh *et al.*, 2010).

2.2 Effect of long term manuring on labile pool of Soil organic carbon

Soil labile C and N fractions can change rapidly in response to management practices compared to non-labile fractions (Wang *et al.*, 2014). Soil organic matter labile fractions have been used instead of total SOM as sensitive indicators of changes in soil quality (Bayer *et al.*, 2002; Haynes, 2005), due to the many important interactions of these components in the soil system.

Soil labile organic carbon (LOC), a group of dynamic chemical compounds, is important in global carbon (C) cycling due to its short turnover time and sensitivity to environmental changes (Xia *et al.*, 2010).

Water Soluble Organic Carbon (WSOC) content was the smallest because WSOC typically accounted for less than 2% of SOC in forest soils (Lützow *et al.*, 2007), and was always smaller than LFOC, MBC, and MAC. Soil MBC usually constitutes 1%–5% of SOC (Sparling, 1997). MBC pools were smaller than MAC, implying that MBC was only a portion of MAC, which was consistent with the findings of Zou *et al.*, 2005.

Potassium permanganate was first used to fractionate SOC via oxidation by Loginow *et al.*, 1987. Later Blair *et al.*, 1995, measured labile soil carbon by using varying concentrations of permanganate ($0.03\text{--}0.33 \text{ mol L}^{-1} \text{ KMnO}_4$) to measure labile soil C.

Culman *et al.*, 2012, reported that Permanganate oxidizable C was significantly related to all soil C fractions, including POC, MBC, and SOC. Permanganate oxidizable C was more strongly related to heavier and smaller POC fractions than lighter and larger POC fractions, indicating that it reflects a more processed, stabilized pool of labile soil C. It suggests that POXC may be well suited to track management practices that promote soil C sequestration, making it a particularly useful indicator for soil quality research. The sensitivity of this method and the relative ease of measurement suggest that POXC can be used to routinely evaluate biologically active soil C.

The carbon management index (CMI), which is derived from the total soil organic C pool and C lability, had been extensively used as a sensitive indicator of SOC variation

rate in response to soil management changes (Sparling, 1992 and Blair *et al.*, 1995). The C management index (CMI) can be used to monitor the soil over time, and it also tells whether a new system or practice is declining or rehabilitating the soil. The changes in labile C as a result of differential rates of compost application were also reflected in CMI. Though there is no ideal value of CMI, it provides a sensitive measure of the rate of change in soil C dynamics of systems relative to a more stable reference soil. The CMI could be used to identify management practices that will have positive effects on C sequestration in soil. The use of the CMI can help in differentiating the degrading and aggrading system of nutrient management (Sodhi *et al.*, 2009). The CMI has been proposed as an indicator of soil C rehabilitation; greater values indicate that soil C is being rehabilitated and smaller values suggest that the system is degrading (Blair *et al.* 1995).

Under soybean-wheat, the higher values of carbon management index (CMI) (279 and 286) were associated with the treatments where entire amount of nitrogen was supplied through FYM. Similar results were obtained under rice-wheat, whereas in case of maize-wheat the highest value of CMI was recorded under treatment receiving NPK through chemical fertilizer along with green manure. There was also a significant improvement in CMI under integrated (chemical fertilizer + organics) and chemical fertilizer treated plots. Walkley-Black, KMnO_4 -oxidizable and microbial biomass carbon constituted 1/4, 1/10 and 1/50th respectively of the total soil organic carbon in these intensively cultivated alluvial soils which that CMI is a sensitive and useful index for assessing and monitoring the dynamics of soil organic carbon (SOC) under different management practices and land uses (Verma *et al.*, 2013).

A positive effect of organic fertilizers on the microbial biomass carbon content in soil was observed in long-term field experiments done by Cerny *et al.*, 2008.

Luo *et al.*, 2014, found in their study that, long term P-deficiency fertilization can significantly decrease soil microbial biomass.

The ratio of biomass C to soil organic C (C_{mic}:C_{org}) reflects the contribution of microbial biomass to soil organic carbon (Anderson and Domsch, 1989). It also indicates

the substrate availability to the soil microflora or, in reverse, the fraction of recalcitrant organic matter in the soil; in fact this ratio declines as the concentration of available organic matter decreases.

Eco-physiological indices (metabolic quotients) are generated by basing physiological performances (respiration, growth/death, carbon uptake) on the total microbial biomass per unit time. Any environmental impact which will affect members of a microbial community should be detectable at the community level by a change of a particular total microbial community activity which can be quantified (qCO_2) (Anderson and Domsch, 1990).

Chander and Brookes, 1991, demonstrated that the ratio of biomass C to soil organic C was a sensitive indicator of the effects of heavy metals on the microbial biomass using two different field experiment soils. Powlson *et al.*, 1987 and Wardle, 1992, pointed out that the soil microbial biomass and biomass C/organic C ratio can provide an effective earlywarning of the deterioration of soil quality. Killham, 1985 and Killham and Firestone, 1984, showed that soil microorganisms divert more energy from growth into maintenance as stress increases and thus the ratio of respired C to biomass C (the metabolic quotient or qCO_2) can be a much more sensitive indicator of stress.

Plant litter decomposition studies demonstrate that while qCO_2 usually declines initially, a significant increase in qCO_2 can eventually follow on litter types resistant to decomposition. Correlation analysis of each of 24 previous studies demonstrated that qCO_2 often declines with increasing pH, clay content and amounts of microbial biomass. In particular this index has valuable applications as a relative measure of how efficiently the soil microbial biomass is utilizing C resources, and the degree of substrate limitation for the soil microbial biomass (Wardle and Ghani, 1995).

Application of FYM for 15 years increased microbial biomass carbon concentration by 39% in the 0–10 cm depth, and by 37% in the 10–20 cm depth, as compared to that in the Control. However, application of Inorganic fertilizer did not increase the concentration of MBC compared to that in the Control in the 0–20 cm depth. Apparently, the steady supply of the readily metabolizable C and N in FYM is likely to be the most influential factor contributing to the MBC increase, while microbial activity

is limited by the reduced supply of organic substrates in the inorganic fertilizer and control treatments. (Liang *et al.*, 2012)

Carbon mineralization was lower in the S+HF (soil+heavy fraction) treatment than soil from minimally-disturbed sites and from the wheat plots at the Columbia Basin site, and the proportion of C mineralized from HF during incubation was negligible for most sites. While the C-to-N ratios of WS and HF are similar, the low mineralization of C from HF suggests differences in the quality of SOM in soil and HF. The HF component of soils may contain C that is chemically protected from mineralization, which suggests that the HF could be a major sink for C storage in soils (Whalen *et al.* 2000).

2.3 Effect of long term manuring on active pool of soil organic carbon

Light Fraction Carbon consists mainly of partially decomposed plant debris (Crow *et al.*, 2007), and is considered an intermediate stage between plant residues and stable organic matter (Gregorich and Janzen, 1996).

Owen *et al.*, 2008, in a long term bean rye cropping system found that Light fraction C and N increased with compost amendment, with the C:N ratio significantly lower in composted plots than in synthetically fertilized plots. Light fraction N and C roughly doubled in the compost plots over the three years, compared with synthetically fertilized plots.

Song *et al.*, 2012, found that increased precipitation significantly stimulated soil LFC and LFN by 16.1% and 18.5%, respectively, and increased LFC:HFC ratio and LFN:HFN ratio, suggesting that increased precipitation transferred more soil organic carbon into the quick-decayed carbon pool. In contrast, soil heavy fraction C and N, and total C and N were not significantly impacted by increased precipitation or warming.

Tan *et al.*, 2007, suggested that, there is a greater protection of SOC by aggregates in the light fraction of minimally disturbed soils than that of disturbed soil, and the SOC loss following conversion from forest to agriculture is attributed to reduction in C concentrations in both heavy and light fractions. In contrast, the SOC gain upon

conversion from conventional tillage to no tillage is primarily attributed to an increase in C concentration in the light fraction.

The POM is young, minimally transformed and is less associated with mineral constituents of the soil. Therefore, POM constitutes a dynamic fraction of SOM and is associated with short-term nutrient availability. The MAOM, or humified organic matter, is a fraction that is quite stable over time and is difficult to degrade due to its complex structure and high grade of stabilization by the mineral fraction (Galantini *et al.*, 2004). Moron and Sawchik, 2003, compared the sensitivity of different soil quality indicators based on changes generated by different long term crop rotations, under CT in Uruguay. They found that the C associated with POM (POM-C) greater than 212 μm was the most sensitive size fraction to changes in management practices, followed by, the fraction of POM-C between 53 and 212 μm and, finally, the C associated with MAOM (MAC).

Changes in organic C by land use occurred, mainly, in the particulate fraction (> 53 μm) of organic matter. (Figueiredo *et al.*,2010).

Soil organic matter in coarse-textured soils is more vulnerable to environmental disturbances due to reduced potential for soil organic carbon (SOC) stabilization in aggregates or organo-mineral complexes (Creamer *et al.*,2013).

Aggregate formation was associated with increased carbon storage as C contents increased with aggregate size in most cases and C contents in all aggregate fractions >53 μm were greater than in the silt and clay fraction (<53 μm) (John *et al.*, 2005).The soil amended by FYM contained significantly higher POC in the top 20 cm than that in the inorganic fertilizer or Control treatments. The POC represents the recent C inputs, the left-over crop residues and FYM might contribute to this labile SOC pool in the FYM treated soil (Liang *et al.*, 2012).

Banger *et al.* ,2010, also reported that FYM treatment was the most effective in increasing POM when compared with chemical fertilizer treatments (N, NP, NPK) and Control, after 16 years of fertilization to rice—cowpea rotation system in a sandy loam *Typic Rhodalfs* in semi-arid tropics.

The POC is a very labile fraction depending on dry matter input and the factors influencing their decomposition (climate, material quality and plant origin, and nutrient availability). The higher proportion of plant residues with highest C:N ratio into the system, led to improved POC levels, while levels were lower with less input of residues at soil and higher rate of decomposition . The CPOC (coarse particulate organic carbon) had lower sensibility to management practices than FPOC(fine particulate organic carbon) fractions. Fractions with intermediate dynamics, as FPOC (fine particulate organic carbon) (53–105 μm) and, seem to be better indicators to detect the short- and medium-term management effects than highly dynamics fractions (Duval *et al*, 2013).

Application of NPK fertilizer + FYM was seen to significantly maintain greater amounts of active and slow pools of C at 0–15 cm depth. Thus, the organic pools of C and associated nutrients (particularly N) may be maintained in the rhizosphere zone, thereby sustaining crop productivity and soil quality (Manna *et al.*, 2013).

Application of organic amendments in rice-wheat system has a major influence on SOC and the relative distribution among various C pools. The LFOC is most sensitive to management, followed by sand-sized HFOC and silt- and clay-sized MAC pool suggesting thereby that these may be considered to represent active, slow and passive pools of SOC, respectively (Benbi *et al*, 2012)

2.4 Effect of long term manuring on passive pool of soil organic carbon

Humic substances are more stable organic matter compounds, which make up a significant portion of the total soil organic C and N (Lal, 1994; Milori *et al.*, 2002). Humic substances can improve soil buffering capacity, increase moisture retention, and supply plants with available micronutrients. Moreover, these compounds can also bind metals, alleviating both heavy metal toxicity and metal deficiency in soils (McCarthy, 2001).

Humins (H) is the insoluble fraction of humic substances; humic acid (HA) is the fraction that is soluble under alkaline conditions; and fulvic acid (FA) is the fraction that is soluble under both alkaline and acidic conditions (Sutton and Sposito, 2005). The chemically reactive and refractory nature of humic substances contributes to their

persistence in soils (Kiem and Kogel-Knabner, 2003; Rovira and Vallejo, 2007), as well as to their important role in nutrient flows through ecological systems, and C emissions to the atmosphere (Lal, 2006).

The content of humus significantly increased with the application of mineral fertilizer (Slepetiene and Slepetys 2005).

Changes in field management practices can alter the chemical properties of soil humic substances (Moraes *et al.*, 2011). Spaccini *et al.*, 2006, reported a progressive decrease in humic substance concentrations in soils that were converted from forest to arable farming. Such decrease is commonly attributed to microbial oxidation of the organic materials previously protected in the soil aggregates destroyed by cultivation. Most studies report a reduction in SOM and in its fractions when forest is converted to other land uses (Navarrete and Tsutsuki, 2008).

Jamala and Oke, 2013, found that the content of humic acid was significantly influenced by land use and soil depth. Highest humic acid content (17.42 g/kg) was recorded under plantation in the soil surface layer (0-15 cm), followed by natural forest (15.16 g/kg), grazing reserve (14.16 g/kg), and fallow land (12.31 g/kg).

Manure application had beneficial effects on SOC stocks in the labile pool (considering both labile pools) and to a greater extent in the recalcitrant pool, suggesting a pronounced change in SOM quality caused by long-term different fertilization treatments (Ding *et al.*, 2012).

2.5 Effect of long term manuring on soil carbon sequestration and C dynamics

Chen *et al.*, 2009, in their twenty-five-years long term studies observed that continuous fertilization of organic manure facilitates aggregation processes and the sequestration of SOC in the Chinese *Mollisols*, indicating that the formation of large macro aggregate from small macroaggregate is essential for the storage of SOC. However, the effect of deaggregation due to long-term mineral fertilizers application was evident and it could increase the risk of soil and nutrient loss through erosion. The combination use of organic manure and mineral fertilizers not only enhance the

sequestration of SOC to some further extent, but also improve the quality of SOM by aggregation effect. Therefore, good soil management practices should preferably include organic manure application to maintain better soil structure and SOM levels in the *Mollisol*. The chemical protection over SOC is limited in large aggregates, but physical protection plays a major role for the sequestration of the increased SOC in the Chinese *Mollisols*. Therefore, when SOC is sequestered along with long-term organic manure application, there is a shift of SOC from the silt + clay fraction to large aggregates. However, when SOC is depleted, it happens preferentially in the physical protected SOC in large aggregates. The combination of organic manure and mineral fertilizers was a better way to further enhance the sequestration of SOC and improve SOM quality by aggregation compared to the pure organic manure.

The organic carbon fractions were observed to decrease with depth. The top layer recorded the highest concentration of these fractions. All the different land use types showed highest accumulation of the various carbon fractions in the surface layer (0-15cm). This result provides valuable information for implementing tillage practices (such as zero tillage) that can favor carbon sequestration and improve soil quality (Jamala and Oke, 2013).

Saree *et al.*, 2012, demonstrated that a shift from upland maize to flooded rice could enhance soil carbon sequestration, and decomposition and incorporation of organic materials (maize and rice straw) into SOC and humic substances (humic acid, fulvic acid and humin) was detectable within a short time period.

Long-term intensive rice-based cropping systems caused a net depletion of SOC that was inversely proportional to the amount of residue C inputs. However, balanced fertilization (with NPK) improved the SOC level even under otherwise unfavorable condition (high summer temperature) in this subtropical region. Such build-up was more with the system having double rice crop or single rice crop with companion crops like wheat, sesame/mustard, etc. producing lower quality (low N content) of crop residues. Organic amendments like FYM or compost *per se* could not appreciably improve SOC stock (10.7%) but encouraged the rate of stabilization of crop residue C to SOC by about 1.6 times more than that in its absence. The amount stabilized constituted only 18% of

the applied C and the rest got lost through oxidation. The system with double rice crop in a year showed remarkable efficiency in stabilizing greater amount of applied C into SOC as compared with the other tested cropping systems (Mandal *et al.*,2007). He also suggested that an understanding of the dynamics of carbon (C) stock in soils, as impacted by management strategies, is necessary to identify the pathways of C sequestration in soils and for maintaining soil organic C (SOC) at a level critical for up-keeping soil health and also for restraining global warming. This is more important in tropical and subtropical region where soils are inherently low in organic C content and the production system is fragile. Long-term application of organic amendments (5–10 Mg ha⁻¹ yr⁻¹) through farmyard manure (FYM) or compost could increase SOC hardly by 10.7% constituting only 18% of the applied C, the rest getting lost through oxidation. They also suggested that not only the quantity but also the quality of the crop residue inputs is important in C sequestration in soils under annual crop production system in the subtropical region. The crops like rice and wheat, which have residues of low N content, are likely to be more efficient in C sequestration in soil than the crops like berseem and jute, which give residue of higher N content under balanced fertilization.

Soil carbon sequestration is enhanced through agricultural management practices viz., increased application of organic manures, use of intercrops and green manures, higher shares of perennial grasslands and trees or hedges, etc., which promote greater soil organic matter (and thus soil organic carbon) content and improve soil structure. Changes in tillage intensity and crop rotations can also affect carbon sequestration by changing the soil physical and biological conditions and by changing the amounts and types of organic inputs to the soil (Bhadoria *et al.*,2012).

Ghosh *et al.*, 2010, in their 19 year old long term experiment found that, management practices such as application of fertilizer and organic amendments played important roles in maintaining soil quality and C sequestration and thereby greenhouse gas mitigation in the Indo-Gangetic plains of eastern India. Addition of organic residues with inorganic NPK fertilizers significantly increased the nutrient content of the soil. Continuous cropping decreased total C as well as its labile and non-labile fractions. The labile C fractions dominated in the near surface soil layers, but decreased significantly in

the deeper layers where the recalcitrant C fraction was significantly dominated down to 0.45 m depth. The result has clearly shown that even in intensive cropping, application of NPK + organic amendments could build up more C as compared to that of fallow and among the organic inputs, FYM is proved more beneficial than Paddy Straw and Green Manure.

Carbon sequestration in Humic Substances was significant under long term fertilization with low and high rates of organic manure with or without inorganic fertilizer. Humin was the main humic fraction responsible for C sequestration under long term fertilization. Additionally, HA, FA and Humin contributed to C sequestration in soil, but HA probably plays an important role in the topsoil (0-20 cm) under long term fertilization. The aliphaticity of HA increased under long term fertilization by manure with or without inorganic fertilizer (Xiang *et al.*, 2014).

Water management affected the allocation and dynamics of recently assimilated C within the rice-soil system and also changed the relative contribution of rhizodeposition to C transferred belowground (Tian *et al.*, 2013). They also found that the highest shoots and roots biomass were observed under flooded condition, while the non-flooded treatment had the lowest shoots and roots biomass. At a given C input, the C sequestration efficiency was greater in paddy soil than in upland soil, which may be attributed to lower microbial activity but greater chemical (i.e., oxalate-soluble Fe) and physical stabilizations (i.e., soil structure) in paddy field. Paddy soil may sequester more SOC, with higher efficiency, than upland soil does (Yan *et al.*, 2013).

Intensive cultivation of an irrigated and optimally fertilized rice-wheat system led to C sequestration due to improved crop productivity and greater C transport to the soil. A one tone increase in productivity of the rice-wheat system improved SOC by 0.38 g kg⁻¹ soil. Therefore, intensive cultivation is a viable strategy for biotic C sequestration in agricultural soils and for mitigating CO₂ emissions to the atmosphere (Benbi and Brar, 2009). Sakin, 2012, suggested that areas containing low carbon should be preferred for use in carbon storage rather than areas containing high carbon stocks.

Carbon sequestration in tropical soils has potential for mitigating global warming and increasing agricultural productivity. Compared to the control treatment the NPK + FYM treatment sequestered $0.33 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ whereas the NPK treatment sequestered $0.16 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ (Pathak *et al.*, 2011).

Improvement in the physico-chemical properties of soil with addition of organic matter as FYM, thereby improving water and nutrient use efficiency were the reasons for higher yield in the NPK + FYM treatment compared to the NPK treatment (Ladha *et al.*, 2003; Hati *et al.*, 2006, 2007). In long-term rice–wheat systems increased yield with addition of organic matter was due to correction of unrecognized nutrient deficiency, indirect effect of nutrient addition such as effect of potassium on resistance to lodging (Swarup *et al.*, 2000; Duxbury, 2001; Manna *et al.*, 2005) and control of soil borne pathogens (Regmi *et al.*, 2002).

FYM application was a ‘win–win’ technology increasing farm income and also sequestering C. The technologies of SOC sequestration, therefore, need to be promoted by providing incentives, technological know-how, required resources and policy support to the farmers (Pathak *et al.*, 2011).

The soil system represents the dominant terrestrial reservoir of carbon in the biosphere. Deforestation, poor land management, and excessive cropping lead to a decrease in soil carbon stocks, but intensive cropping can reverse this trend. Minasny *et al.*, 2012, discussed long-term soil organic carbon data from two major rice-growing areas: Java (Indonesia) and South Korea. Soil organic carbon content in the top 15 cm for both countries has increased in recent decades. In South Korea, the top 15 cm of soils store about 31 Tg (1012 g) of carbon (C) with a sequestration rate of 0.3 Tg C per year. In Java, the agricultural top soils accumulated more than 1.7 Tg C per year over the period of 1990–2010. They attribute the increase in measured SOC mainly to increases in above- and below- ground biomass due to fertilization. Good agronomic practices can maintain and increase soil carbon, which ensures soil security to produce food and fiber.

Topsoil C-sequestration increased with organic manure addition rates with an order of OM3, organic manure added at $22.5 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ plus chemical fertilizer (10.5

Mg ha⁻¹) > OM2 organic manure added at 15 Mg ha⁻¹ yr⁻¹ plus chemical fertilizer; (8.4 Mg ha⁻¹) > OM1 organic manure added at 7.5 Mg ha⁻¹ yr⁻¹ (7.2 Mg ha⁻¹). A positive relationship between C sequestration and organic manure input indicates that the soil has not reached its maximum capacity of C sequestration (Ding *et al.*, 2012).

Application of organic manure with chemical fertilizer was found to produce greater size of both labile and recalcitrant pools than application of mineral fertilizers alone. In most cases, the increases in these C fractions were greater when organic manure was supplied at higher rates. Moreover, increase in recalcitrant C (10.5–29.5%) was significantly higher than labile C (5.6–10.2%) in manure treated plots as compared with no amendment plot. This indicated that a majority of organic C sequestered due to C inputs was accumulated and stabilized in recalcitrant C pool (Ding *et al.*, 2012).

Nayak *et al.*, 2012, found that application of 50% NPK + 50% N through FYM in rice and 100% NPK in wheat, sequestered 0.39, 0.50, 0.51 and 0.62 Mg C ha⁻¹ yr⁻¹ over control (no N–P–K fertilizers or organics), respectively at Ludhiana, Kanpur, Sabour and Kalyani using the mass of SOC in the control treatment as reference point.

Rudrappa *et al.*, 2006 in their long term experiment showed that application of graded doses of NPK from 50 to 150% of recommendation NPK significantly enhanced other organic C fractions like, microbial biomass C (MBC), particulate organic C (POC) and KMnO₄ oxidizable C (KMnO₄-C). Integrated use of farmyard manure with 100% NPK (100% NPK + FYM) emerged as the most efficient management system in accumulating largest amount of organic C (72.1 Mg C ha⁻¹) in soil. Nevertheless, this treatment also sequestered highest amount of organic C (731 kg C ha⁻¹ yr⁻¹). Microbial metabolic quotient (qCO₂) was significantly lower in 100% NPK + FYM over other treatments to indicate this to be the most efficient manuring practice to preserve organic carbon in soil where it facilitates aggradations of more recalcitrant organic C in soil. As compared to POC, total TOC proved to be a better predictor of MBC as it strongly correlated with the total carbon mineralized from soil.

2.6 Effect of long term manuring on crop productivity

Soil organic matter (SOM) plays an important role in maintaining the productivity of tropical soils because it provides energy and substrates, and promotes the biological diversity that helps to maintain soil quality and ecosystem functionality. SOM directly influences soil quality, due to its effect on soil properties (Wendling *et al.*, 2010).

Analysis of the yield of the five years data showed the highest significant grain yield (7.9 t/ha) from the treatment that received recommended doses of NPK along with 10 ton FYM /ha and was significantly higher in all the years. Same treatment also produced the highest straw yield of 7.1 t/ha. In the longer run, soil fertility is not sustained from the balanced fertilizer application alone while application of FYM helps to boost up crop yield (Lal and Mathur, 1989a, Kabeerthumma *et al.*, 1993) and improve physical soil status (Lal and Mathur, 1989b, Kumar and Tripathy, 1990).

Ren *et al.*, 2014, showed that if no organic manure is applied, SOC concentration, especially for stable organic carbon, will decline significantly. Therefore, integrating nutrient management, including optimized N fertilizer input, as well as enhanced the soil organic matter content, should be considered to maintain soil fertility and productivity.

The yield was lower when plots received mineral NPK fertilizers alone (no organic fertilizer) compared with plots that received OM or SM applied to complement the mineral fertilizer input.(Kismanyoky and Toth,2013).

Combination of inorganic and organic fertilizer can substantially increase SOC and crop yields. The crop yields increased further with more fertilizer being added. However, SOC decreased with less inorganic fertilizers application and SOC increased with the addition of corn stalks. Fertilizer was an effective way of SOC storage. There was a trend that the crop yields had a relationship with SOC. More than twenty years of continuous winter wheat–summer corn rotation cultivation revealed a significant correlation at $p < 0.05$ level between crop yields and SOC. The mineralization amount of SOC had a significant correlation at $p < 0.05$ level with wheat yield which can confirm the result of crop yield related to SOC. (Yang *et al.*, 2015).

MATERIALS AND METHODS

In order to achieve the objectives of the present investigation , the long term fertilizer experiment (LTFE) of the All India Co-ordinated Research Project (AICRP) of ICAR conducted at Orissa University of Agriculture and Technology(OUAT), Bhubaneswar with effect from 1994 and with modified set of treatments from 2005-06 was used.

3.1 Field experiment

The long term fertilizer experiment at Bhubaneswar was started in 1994 and after conducting three years of uniformity trial with kharif rice each year systematic study with a set of new treatments was however started from rabi 2005-06 with a rice-rice cropping system. The present investigation was made on the kharif rice grown during 2014.

3.1.1 Materials

3.1.1.1 Location of experimental site

The experimental plot is located in the 'E' block of the Central Research station, Bhubaneswar which lies between longitude of 85⁰ 48' N and 85⁰ 49' E and latitude at 20⁰16' N and 20⁰ 17' N.

3.1.1.2 Climate

The climate of Bhubaneswar is humid tropical with dry season from October to June and wet season from July to September. Three important climatic situations prevailing during kharif-2014 is presented in appendix I.

3.1.1.3 Soil

The soil of the experimental field belongs to lateritic *Inceptisols* (*UdicUstocrept*). The initial physic-chemical properties of the soil as measured during 2005 are listed table 1.

Table 1: Physico-chemical properties of the initial surface soil

Serial no	Properties	Value
1	Mechanical composition	
	Sand (%)	71
	Silt (%)	12
	Clay (%)	17
2	Textural class	Sandy loam
3	Bulk density (Mg m^{-3})	1.55
4	Particle density (Mg m^{-3})	2.68
5	pH (1:2)	5.8
6	EC (dS m^{-1})	0.12
7	OC (g kg^{-1})	4.3
8	CEC ($\text{cmol p}(+) \text{kg}^{-1}$)	3.75
9	Available nutrients (kg ha^{-1})	
	Available N(alkaline KMnO_4)	187
	Available P (Olsen's)	19.4
	Available K (NH_4OAc Extractable)	43.4

3.1.1.4 Test crop

The popular rice cultivar Swarna (MTU-7029) of 145 days duration with a yield potential of 5 t ha^{-1} at a standard level of management practice was used as the test crop.

3.1.1.5 Sources of nutrient

3.1.1.5.1 Organic source

Only one organic source i.e. Farm Yard Manure (FYM) was used @ 5 t ha^{-1} the study. The nutrient contents and C:N ratio of FYM is presented below in table 2.

Table 2: Chemical composition and C:N ratio of FYM used during kharif-2014

Serial no	Properties	Value
1	Carbon (%)	20.3
2	Nitrogen (%)	0.79
3	Phosphorus (%)	0.50
4	Potassium(%)	0.80
5	C:N Value	25.70

3.1.1.5.2 Inorganic sources

Common fertilizer such as Urea, DAP and MOP were used to supply the nitrogen, phosphorus and potassium at 100% Recommended Dose (RD) of 80-40-60 kg ha⁻¹.

3.1.2 Methods**3.1.2.1 Treatments and design**

Out of the total 12 treatments 6 treatments as given in table 3 below were used for the study. The experiment was laid out in randomised block design (RBD) with treatments replicated 4 times in plots of size 15m x 10m with rice-rice cropping sequence.

Table 3: Manurial Schedule of the treatments for kharif rice-2014

Treatments	Details
T ₁	Control
T ₂	100% N
T ₃	100% NP
T ₄	100% NPK
T ₅	150% NPK
T ₆	100% NPK + FYM

3.1.2.2 Methods and time of application of manures and fertilizer

Nitrogen was applied in 3 splits i.e. 25% as basal, 50% at 15 days after transplanting and 25% at panicle initiation stage. Total phosphorus was applied as basal. Potash was applied as 50% basal and 50% at panicle initiation stage. The required amount of FYM was incorporated one week before transplanting.

3.1.2.3 Field preparation and planting

After applying 50mm of water, the field was first worked with power tiller. Two more puddlings were done at 5 days interval and finally the plots were leveled. Standing water of 3cms was maintained throughout. Thirty days old seedlings of Swarna (MTU-7029) were transplanted @ 2-3 plants /hill at a spacing of 15cmx 10cm in third week of July.

Irrigation was provided to the plots intermittently as and when required in order to maintain 3-5 cm of standing water until 2 weeks before harvesting. Normal intercultural operations and plant protection measures were undertaken.

Crops were harvested on whole plant basis at maturity at ground level (leaving short stubble of 15-20 cm) manually with sickle and removed from the fields for biomass yield determination. To study the impact of cropping on SOC a soil sample from an adjacent uncultivated site, maintained as a buffer area around the experimental field, where disturbance from agricultural activity was minimal was collected. The uncultivated soil sample was a composite of four random locations. The rice yield was reported at 14% grain moisture content.

3.2 Soil sampling

After 10 years of rice-rice cropping in December, 2014, three representative soil samples from each replicated plot were collected randomly from 0-15 cm depth with the help of a screw type auger after 10 days of harvesting of rice. After hand crushing and passing through a 2.0 mm sieve, field-moist soil sample were stored at 4⁰C and were used later afresh for estimation of soil microbial biomass carbon, mineralisable carbon and water extractable carbon. A second set of soil sample was air dried and passed through a

2mm sieve for determination of SOC, KMnO₄-extractable Carbon, particulate organic carbon, heavy fraction, light fraction, mineral associated fraction and humic acid content. Additional triplicate samples were taken using a core sampler (5.3 inner diameter and 5 cm length) for measurement of bulk density of the soil.

3.3 Estimation of gross C- input

The gross C-input in soil was calculated on the basis of observed and derived values of C content in root, rhizodeposition and stubble biomass of crops. Root samples were taken from an area of 1m x 1m to a depth of 30 cm with a narrow flat bladed shovel and hand saw. Root samples were then washed with water. Roots and stubbles were dried at 65⁰c at a constant temperature and weighed sub-samples were passed through 0.15 mm sieve for carbon analysis. Carbon concentration of root and stubble biomass was estimated by dry combustion method as described by Poincelot, 1972. While calculating total rhizodeposition derived from rice crop in the present study, we considered similar values as it was mentioned by Bronson *et al.*,1998. Root exudates therefore represented 15% of aboveground biomass at maturity with a C concentration of 36% and 33% in unfertilized and fertilized treatments respectively. During the crop growth, weeds were removed and incorporated in to the soil. However, no weed biomass was recorded and therefore the value of C input through weed biomass was ignored while constructing C input in this system.

To estimate the annual rate of changes in SOC, it is necessary to know the amount of organic C present in the soil at the beginning of the experiment. In order to establish relationship between C addition (external C addition plus crops C inputs) and SOC storage in a given soils were fitted in simple linear regression equation.

$$dC_s/dt = ax-b$$

where, dC_s/dt are the losses or gains from initial value over time (t) in 0-15 cm soil depth, x is the annual C input, the slope of this equation is decay rate constant (a) and the intercept (b) represents the annual loss of C from the native SOC. We assumed that the whole amount of biomass C from stubble, root mass C and rhizodeposition remained in

the 0-15 cm surface layer. Carbon content (Mg ha^{-1}) of 0-15 cm depth was calculated by multiplying C concentration (g kg^{-1}) soil with bulk density (Mg m^{-3}) and soil depth (m).

Relative to the initial value of SOC ($\text{SOC}_{\text{initial}}$) at the start of the long-term experiment in the year 2005, the apparent C sequestration was determined as

$$C_{\text{sequestered}} (\text{Mg C ha}^{-1} \text{ soil}) = \text{SOC}_{\text{current}} - \text{SOC}_{\text{initial}}$$

Where, $\text{SOC}_{\text{current}}$ indicates the SOC stocks in 2014. Positive and negative value indicates the SOC gains and losses, respectively for the cropping system.

3.4 Methods of analysis

3.4.1 Soil organic carbon

Soil organic carbon was determined by wet digestion with potassium dichromate along with H_2SO_4 (Walkley and Black, 1934).

3.4.2 Microbial biomass carbon (C_{mic})

The microbial biomass carbon (C_{mic}) was determined by chloroform fumigation–extraction method as described by Vance *et al.*, 1987. Twenty gm of fresh rhizospheric soil sample was taken and fumigated with ethanol free chloroform in a vacuum desiccators for 24 hours. Then it was extracted with 0.5 M K_2SO_4 and filtered. Ten ml of filtrate was taken in a 250ml conical flask and was treated with 10 ml of 0.035 N $\text{K}_2\text{Cr}_2\text{O}_7$ and 20 ml of conc. H_2SO_4 . The content was digested on a hot plate at 150° - 170°C for 30 minutes and cooled. After addition of 25ml of distilled water and 5ml of phosphoric acid it was titrated against 0.04 N FAS using diphenylamine indicator. A non-fumigated set was done by following all the steps except fumigation. Carbon content was calculated using titration value. MBC was calculated by subtracting the extracted C in unfumigated samples from that measured in fumigated samples and dividing it by a K_c value of 0.45 (Joergensen, 1996). The value of MBC was represented in $\mu\text{g g}^{-1}$ dry soil.

Readily Mineralizable Carbon (RMC) or K_2SO_4 - extractable carbon content of the soil samples was estimated after extraction with 0.5 M K_2SO_4 (Inubushi *et al.*, 1991) followed by wet digestion of the soil extract with dichromate (Vance *et al.*, 1987).

3.4.3 KMnO₄ extractable carbon

The KMnO₄-C content was determined as described by Blair *et al.* 1995. In a 50 ml centrifuge tube after taking of 2g of soil 20 ml of 20mM KMnO₄ was added and a blank was run without taking soil. The content was shaken for 15 minutes and centrifuged at 2000 rpm for 5 minutes. After that 2 ml of supernatant aliquot was transferred in to a 50ml volumetric flask and volume was made up by distilled water. The absorbance was read at 565 nm and concentration of KMnO₄ was determined from a standard curve. A standard curve was prepared by taking 0, 0.5, 1.0, 1.5, 2.0 ml of standard KMnO₄ solution in different 50 ml volumetric flask and diluted with distilled water. Absorbance was taken at 565 nm and a standard calibration curve was plotted.

The proportion of C not oxidized, referred to as non labile carbon and was calculated as the difference between SOC and KMnO₄-C.

3.4.4 Carbon management index (CMI)

CMI was calculated for each treatment using a reference sample value for the calculation according to the method of Blair *et al.*, 1995). The mean of the four control samples (unfertilized control plot) was used as the reference in the experiment (Gong *et al.*, 2009). Based on changes in SOC between the reference site and sample site, a carbon pool index (CPI) was calculated as follows.

$$\text{CPI} = (\text{sample SOC}) / (\text{SOC of reference soil})$$

Based on changes in C Lability [L=KMnO₄-C/ (SOC-KMnO₄-C)]

Lability index (LI) was determined as follows

$$\text{LI} = (\text{Sample L}) / (\text{L of reference soil})$$

These two indices were used to calculate CMI as follows

$$\text{CMI} = \text{CPI} \times \text{LI} \times 100$$

3.4.5 Water extractable organic carbon

Water extractable carbon (WEOC) was performed as per the method given by [Mc Gill *et al.* 1986](#). To a 5 g of field moist soil sample, 10 ml of distilled water was added and kept for one hour. The content was centrifuged at 10000 rpm for 30 minutes and supernatant was filtered through whatman no 1 filter paper. From the filtrate 5 ml was taken in a conical flask and was treated with 5 ml of 0.07 N $K_2Cr_2O_7$, 10 ml of conc. H_2SO_4 and 5ml of ortho-phosphoric acid.

The content was then mixed carefully and digested at $150^{\circ}C$ for 30 minutes on a hot plate and cooled. The content was titrated against 0.035N FAS in 0.4 M H_2SO_4 using 1ml of diphenylamine indicator. Simultaneously a blank was run and from titration value, water soluble organic carbon was calculated and it was represented as $g\ kg^{-1}$ of dry soil.

3.4.6 Mineralisable carbon

Organic C mineralization (C_{min}) was studied in the laboratory by conducting aerobic incubation under controlled conditions as per the method described by [Hopkins, 2007](#). Fifty g of each soil was wetted to 50% water filled pore space; placed in a 500ml conical flask along with vials containing 10 ml of 0.1 N NaOH to trap evolved carbon dioxide and incubated for 36 days at $25\pm 1^{\circ}c$. Alkali traps were replaced frequently and the evolved carbon dioxide was determined by titrating the alkali in the traps with 0.1 N HCl using phenolphthalein as indicator. The cumulative carbon dioxide evolved in 36 days of incubation was used as mineralisable C (CO_2 -cum).

3.4.7 Particulate organic matter carbon (POM-C)

Particulate organic matter was separated from 2 mm soil following the method described by [Cambardella and Elliott \(1992\)](#). Briefly a 10 g sub-sample was dispersed in 30 ml of 0.5 % Sodium hexameta phosphate by shaking for 15 hours on a reciprocating shaker. The soil suspension was poured over a series of 250 and 53 μm sieves. The material retained on the 250 μm sieve consisted of coarse particulate organic matter (CPOM) and sand (250-2000 μm). The material retained on the 53 μm sieve comprised fine particulate organic matter (FPOM) and sand (53-250 μm). After rinsing several times

with water, the material retained on the sieve was dried at 50°C in a hot air oven overnight. The coarse particulate organic matter was separated from sand by hand picking. CPOM and FPOM carbon content was determined following loss-on-ignition (LOI) using a muffle furnace (Schulte and Hopkins, 1996). The slurry that passed through 53µm sieve comprising silt and clay particles and mineral associated organic matter was centrifuged and the solution was decanted. The mineral matter was dried at 70°C, weighted and labeled as mineral associated organic matter. The carbon fraction in the mineral associated SOM is calculated by taking the difference between their corresponding contents in total and particulate SOM.

3.4.8 Density fractionation

Uncomplexed light fraction organic matter (LFOM) was isolated as per the method described by Janzen *et al.*, 1992. Twenty five gram of soil was weighed in a 250 ml polythene bottle. After adding 40 ml sodium iodide (NaI) solution (SG=1.72), the suspension was gently shaken for 30 minutes on an end to end shaker. The material was then transferred to a 100 ml beaker. The beakers were covered and the suspension was allowed to equilibrate for 48 hours at room temperature. The floating and suspended material was removed and transferred directly to a moisture filtration unit with whatman filter paper. The light fraction was washed under 3 succession aliquots of 0.01M CaCl₂ and twice aliquots of distilled water. After drying overnight at 70°C one LF was scraped and weighted. The material that settled during equilibrium period was resuspended and shaken for 16 hours on a reciprocating shaker. Thereafter the material was allowed to equilibrate for 48 hours at room temperature. The suspended material was labeled as the intra- aggregate light fraction organic matter. It was transferred to a filtration unit. Then it was washed and dried as per the method described for LFOM.

The residual heavy fraction that settled after the removal of intra-aggregate organic matter was sieved through 53 µm sieve and the material retained on the sieve was washed with distilled water and labeled as heavy fraction organic matter. After drying at 70°C, heavy fraction was weighed. Both light and heavy fraction carbon content was determined following loss-on-ignition (LOI) using a muffle furnace (Schulte and Hopkins, 1996).

3.4.9 Estimation of humic acid content

Humic acid content was determined by the method as given by Stevenson, 1982. To a 40 g of soil sample 200ml of 0.5 N NaOH was added and shaken for 12 hours following centrifugation at 3000 rpm for 10 minutes. Dark coloured supernatant was filtered and pH was adjusted to 1 with conc. HCl. The same soil was again extracted with additional 200ml of 0.5N NaOH and 200 ml of distilled water and supernatant solution was added to the previous extract and pH was adjusted to 1 using HCl. The humic acid was allowed to settle down. The supernatant liquid in the acidified extract was fulvic acid which was siphoned off and the suspension (humic acid) was transferred to another container. The suspension (HA) was centrifuged at 3000 rpm for 10 minutes. Then the humic acid was redissolved in 0.5 N NaOH and reprecipitated with conc. HCl. The process was repeated to purify humic acid .the supernatant was transferred in each case. The humic acid was dried and ground to fine powder. Humic acid content was calculated in percentage.

3.4.10 Sustainable yield index (SYI)

The sustainable yield index (SYI suggested by Singh *et al.*,1990) is defined as

$$SYI= Y-Sd/ Y_{max}$$

Where, Y is the average yield of rice over the years and Sd is the standard deviation and Y_{max} is the observed maximum yield in the experiment over the year of cultivation.

3.4.11 Statistical analysis

The data were analyzed using randomized block design (RBD). Statistical analysis was performed by Windows based SPSS Programme (vers.14.0, SPSS Inc., 1996).The SPSS procedure was used for analysis of variance (ANOVA) to determine the statistical significance of treatments effect. Duncan's Multiple Range Test (DMRT) was used to compare treatments means. Simple correlation co-efficient and regression equation were also developed to evaluate relationship between the response variables using the same statistical package. The 5% probability level is regarded as statistically significant.

RESULTS

4.1 Effect of long term manuring on crop yield and Sustainable yield index (SYI)

The results of grain yield, sustainable yield index and harvest index of kharif rice are presented in table 4. Perusal of results reveals that there was a significant variation with different treatments. However, the yield of rice and harvest index have been found to be increased due to different fertilization, being recorded highest yield of rice (48.24 q ha⁻¹) and harvest index (0.436) in the 100% NPK+FYM treatment and 100% NPK treatment respectively. Super-optimal dose of NPK i.e. 150% NPK produced higher yield than balanced fertilization i.e. 100% NPK (32.89 q ha⁻¹) but lower straw yield cause lower harvest index. Unfertilized control plot showed significantly lowest yield (19.39 q ha⁻¹).

Table 4: Influence of organic amendments and inorganic fertilizers on yield, harvest index and sustainable yield index after 10 years of rice-rice cropping system under different fertilizer combinations

Treatment	Yield (q ha ⁻¹)	SYI	HI
Control	19.39 ^e	0.25 ^e	0.407 ^b
100% N	26.31 ^d	0.45 ^d	0.407 ^b
100% NP	31.12 ^c	0.50 ^c	0.430 ^a
100% NPK	32.89 ^c	0.55 ^b	0.436 ^a
150% NPK	42.88 ^b	0.58 ^b	0.410 ^b
100% NPK + FYM	48.24 ^a	0.66 ^a	0.432 ^a

LSD (p<0.05): grain yield = 4.35; SYI = 0.039; harvest index = 0.012. In each column the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05) between treatments by DMRT

Among the fertilized treatments, the lowest yield (26.31 q ha⁻¹) as well as harvest index (0.407) was recorded in the treatment receiving 100% N. Application of nitrogen alone @ 80 kg ha⁻¹ increased yield by 34.76% over unfertilized control treatment. Application of phosphorous resulted in 18.28% of more yield over 100% N treatment. Thus the treatments were in the order 100% NPK + FYM > 150% NPK > 100% NPK >

100% NP > 100% N > control. SYI was significantly higher (0.66) in 100% NPK + FYM treatment than other fertilizer treated plot. The unfertilized control plot did not show any sustenance, being the lowest (0.25) among all the treatments. However, the pattern of changes among the fertilizer treatments showed a similar trend to that of the rice yield.

4.2 Effect of long term manuring on gross carbon input

Appraisal of the data present (Table 5) indicated that annual crop mediated C input through left-over stubble at harvest, roots in the plough layer and rhizodeposition ranged between 0.94 to 2.22 Mg ha⁻¹ under different treatments. Application of FYM supplied additional 2.04 Mg C ha⁻¹ in 100% NPK+ FYM treatment.

Table 5: Mean annual organic carbon inputs returned to soil through above ground and belowground biomass as well as FYM-C of the system (rice-rice) during 10 year of cropping

Treatment	Biomass (Mg ha ⁻¹)			Biomass C (Mg ha ⁻¹)				Total C input (Mg ha ⁻¹)
	Stubble	Root	Rhizodeposition	Stubble	Root	Rhizodeposition	FYM	
Control	0.46	0.88	0.92	0.20	0.40	0.34		0.94
100% N	0.74	1.02	1.26	0.30	0.46	0.42		1.18
100% NP	0.80	1.14	1.36	0.34	0.52	0.44		1.30
100% NPK	0.84	1.22	1.38	0.36	0.58	0.46		1.40
150% NPK	1.0	1.58	2.04	0.44	0.74	0.68		1.86
100% NPK + FYM	1.24	2.14	2.04	0.54	1.0	0.68	2.04	4.26

4.3 Effect of long term manuring on soil organic carbon (SOC), SOC stock, C-Sequestration and Sequestration rate, Sequestration potential and Sequestration efficiency

4.3.1 Soil organic carbon

The results presented in the table 6 revealed that cultivation over the years caused a significant decrease in the soil organic carbon content as compared to that in the

uncultivated fallow land, excepting with 100% NPK, 150% NPK and 100% NPK + FYM treatments. The magnitude of such decrease was severe in the control (14%) and only N (2.36%) treatments. The balanced fertilization, super-optimal dose of NPK and integration of balanced fertilization with organic manure (FYM), on the other hand increased the content by 17.88%, 27.20 % and 50.62% over the control respectively. Imbalance fertilization (100% N and 100% NP) did not differ significantly in the SOC content from balanced fertilization. On an average, the amount of SOC in different treatments was in the following order 100% NPK+ FYM > 150% NPK > uncultivated soil= 100% NPK> 100% NP > 100%N and control.

Table 6: Influence of organic amendments and inorganic fertilizers on soil organic carbon, soil organic carbon stock, carbon sequestration, carbon sequestration rate after 10 years of rice-rice cropping system(A,B : Mean of four replications)

Treatments	SOC (g kg ⁻¹)A	SOC Stock (Mg ha ⁻¹)B	C- sequestration (Mg ha ⁻¹)	C-sequestration rate (Mg ha ⁻¹ Yr ⁻¹)
Initial	4.30	9.30		
Uncultivated Soil	4.67	9.52 ^{bc}		
Control	3.97 ^c	8.21 ^c	-1.092	-0.1092
100% N	4.56 ^b	9.56 ^{bc}	0.062	0.0062
100% NP	4.75 ^b	9.84 ^b	0.198	0.0198
100% NPK	4.68 ^b	9.55 ^{bc}	0.251	0.0251
150% NPK	5.05 ^b	9.86 ^b	0.564	0.0564
100% NPK + FYM	5.98 ^a	11.07 ^a	1.776	0.1776

LSD (p<0.05): SOC = 0.49; SOC stock =1.26. In each column the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05) between treatments by DMRT.

4.3.2 SOC Stock

Among different fertilized plot, SOC stocks (Table 6) in the 15 cm plough layer were significantly highest under 100% NPK + FYM (11.07 Mg ha⁻¹) followed by 150 % NPK (9.86 Mg ha⁻¹) and least under unfertilized control (8.21 Mg ha⁻¹). Due to fertilization SOC stocks did not differ significantly. Use of balance fertilization which involved cumulative carbon input of 1.40 Mg ha⁻¹ (Table 5) increased SOC stocks (9.55Mg ha⁻¹) almost equivalent to the uncultivated soil (9.52 Mg ha⁻¹) (Table 6). On the contrary, cultivation without fertilization reduced SOC stocks by 13.76 % compared to uncultivated soil.

4.3.3 Carbon sequestration, Sequestration rate, Sequestration Potential and Sequestration efficiency

After 10 years of rice-rice cropping C- sequestration in the 15 cm plough layer ranged from -1.09 to 1.77 Mg ha⁻¹ over the initial SOC stocks (9.32 Mg ha⁻¹) in 2005 (Table 6). Highest C-sequestration (1.77 Mg ha⁻¹) was observed under 100% NPK+FYM treatment and least under (0.061 Mg ha⁻¹) under 100% N treatment. The unfertilized control treatment did not show any build up of SOC. During the 10 years period 4.6% of the added C was sequestered over the initial stocks of 9.30 Mg ha⁻¹. The critical cumulative carbon input for zero change in SOC stocks as at the start of the experiment was estimated to be 1.2 Mg ha⁻¹ (Fig.1) requiring an annual C input of 0.12 Mg ha⁻¹. Carbon sequestration potential (CSP) which was computed as the increase in SOC stock in a treatment compared to reference treatment is depicted in fig.2. CSP was highest (2.86 Mg ha⁻¹) in 100 % NPK+FYM and lowest in 100% N (1.15 Mg ha⁻¹) treatment. CSP varied in the order of 100% NPK+ FYM > 150% NPK > 100% NPK=100% NP > 100% N. The rate of sequestration was 0.177 Mg ha⁻¹ in the 100% NPK+FYM treatment where as in the 100%NPK treatment the rate was 0.025 Mg ha⁻¹. The rate of C- sequestration was lowest (0.0062 Mg ha⁻¹) in the imbalanced fertilization (100%N). C- sequestration efficiency i.e. C-sequestration rate of the treatment over the C input through that treatment varied from 0.52 to 4.10 % (Fig.2). Soil carbon sequestration efficiency in 100% NPK+FYM was maximum (4.10%) and minimum (0.52%) in 100% N treatment.

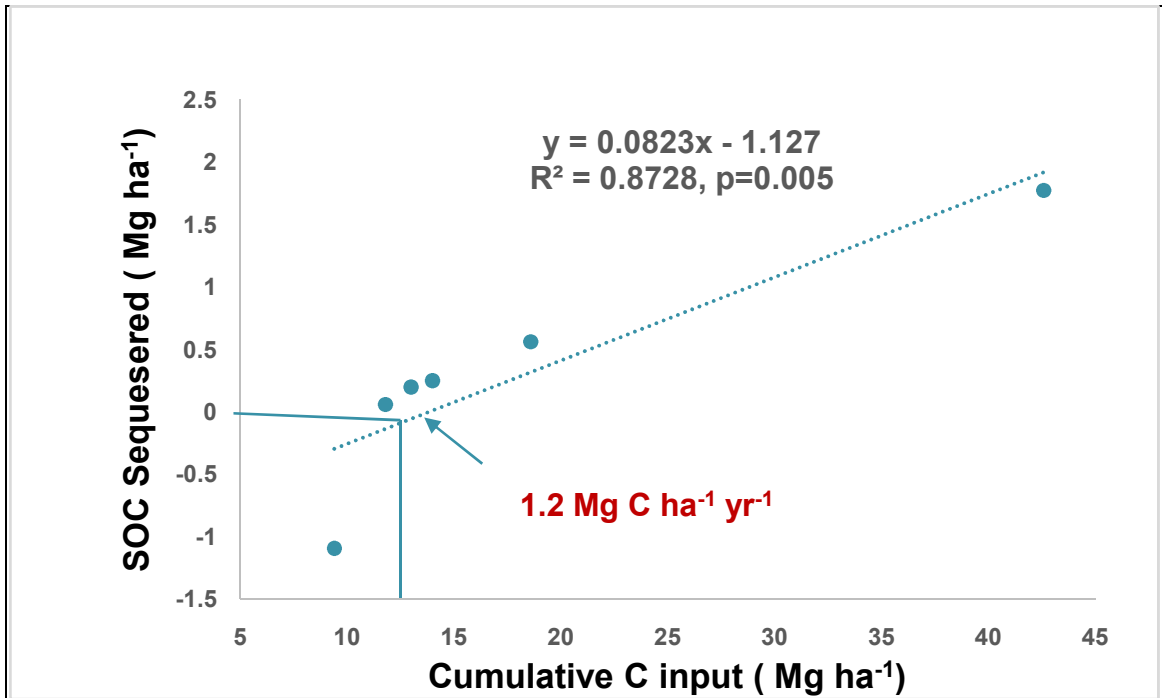


Fig 1: Relationship between cumulative carbon input and carbon sequestered and critical carbon input value for zero change in SOC stock

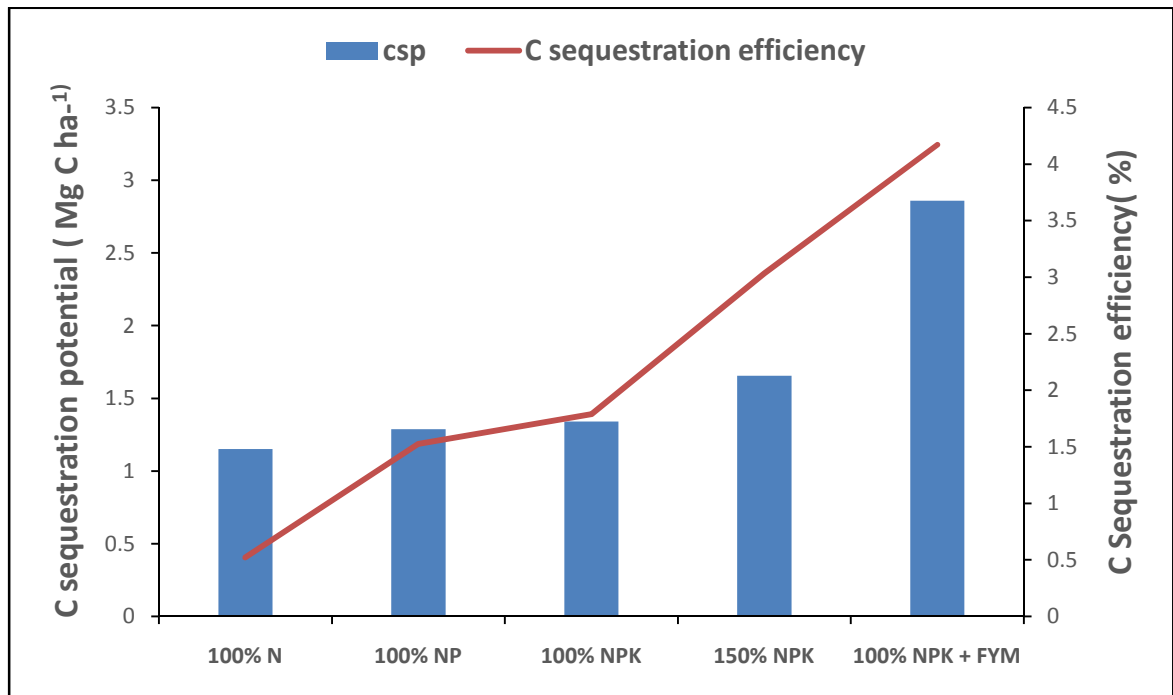


Fig 2: Influence of organic amendments and inorganic fertilizers on carbon-sequestration potential and carbon-sequestration efficiency under rice-rice cropping system

4.4 Effect of long term manuring on Microbial Biomass Carbon (C_{mic}), Carbon Mineralisation (C_{min}), Microbial Quotient (MQ), and Metabolic Quotient (qCO₂)

4.4.1 Mineralisable Carbon

The results of mineralisable Carbon (C_{min}) presented in table 7 revealed that the cumulative C mineralized (CO₂-cum) in 36 days of incubation of the surface soil ranged between 1.08 to 2.18 g kg⁻¹ with a mean value of 1.47 g CO₂-C kg⁻¹ soil constituting about 30% of the total SOC. The highest C_{min} (2.18 g kg⁻¹) was observed in 100 % NPK+FYM treatment where lowest (1.08 g kg⁻¹) amount of carbon was mineralized in the unfertilized control. However, balanced fertilization and super-optimal dose of NPK did not differ significantly in respect to carbon mineralization. But there was a significant variation among imbalanced fertilization i.e. 100% N and 100% NP. The amount of cumulative C mineralized under different treatments were in the following order 100% NPK+FYM > 150% NPK > 100% NPK > 100% NP > 100% N > control.

Table 7: Influence of organic amendments and inorganic fertilizers on Microbial Biomass Carbon (C_{mic}), Carbon Mineralisation (C_{min}), Microbial Quotient (MQ) and Metabolic Quotient (qCO₂) under rice-rice cropping system

Treatment	C_{min} (g kg ⁻¹)	C_{mic} (μ g g ⁻¹)	Metabolic Quotient (g CO ₂ -C g ⁻¹ C_{mic} day ⁻¹)	Microbial Quotient (g C_{mic} g ⁻¹ C SOC)x100
Control	1.08 ^d	100.22 ^e	0.30 ^a	2.53 ^d
100% N	1.14 ^d	122.35 ^d	0.26 ^b	2.68 ^d
100% NP	1.26 ^c	146.57 ^c	0.24 ^c	3.10 ^c
100% NPK	1.55 ^b	145.22 ^c	0.30 ^a	3.13 ^c
150% NPK	1.62 ^b	210.21 ^b	0.21 ^d	4.17 ^b
100% NPK + FYM	2.18 ^a	282.18 ^a	0.22 ^d	4.74 ^a

LSD (p<0.05): C_{min} = 0.95; C_{mic} = 8.62; Metabolic Quotient = 0.016; Microbial quotient = 0.315. In each column the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05) between treatments by DMRT

4.4.2 Microbial biomass carbon, Microbial quotient and Metabolic quotient

The results of soil microbial biomass carbon (C_{mic}) and microbial indices are presented in table 7. Perusal of results revealed that C_{mic} content under different treatments varied from $100.22 \mu\text{g g}^{-1}$ to $282.18 \mu\text{g ha}^{-1}$ with a mean value of $167.79 \mu\text{g ha}^{-1}$ constituting 3.4% of soil total organic carbon (Fig.3a) The C_{mic} content was greater in 100% NPK+ FYM over the other treatments. Both 100% and 150% NPK showed significant higher C_{mic} over the 100% N treatment. But there was no significant difference between 100% NPK and 100% NP treatment. The unfertilized control showed lowest content ($100.22 \mu\text{g g}^{-1}$) of C_{mic} . The MBC content in 100% NPK was increased by 18% over 100% N treatment. The soil C_{mic} content under different treatments were in the following order 100% NPK+FYM > 150% NPK> 100%NP > 100% NPK > 100% N > control. The microbial quotient (MQ, C_{mic} as a proportion of total soil organic carbon) also varied widely from 2.53 to 4.74 % under different treatments in the present study (Table 7). Its value was highest (4.74%) in balanced fertilizer treatment along with FYM and lowest value being recorded (2.53%) in unfertilized control. The 100% NPK+FYM showed significantly higher microbial quotient than all other treatments. The metabolic quotient or respiratory quotient (the ratio of C_{min} and C_{mic}) was, however, significantly higher under control and only 100% N vis-à-vis other fertilized treatments (Table 7), the least value being recorded in the 100% NP, 150% NPK and 100%NPK+FYM treatments.

4.5 Effect of long term manuring on labile pool of soil organic carbon

4.5.1 Readily mineralizable carbon (RMC)

The results on different labile carbon fractions presented in table 8 and depicted in fig 3b revealed that the readily mineralizable carbon (RMC) i.e. K_2SO_4 –extractable carbon ranged from 27.20 to $147.12 \mu\text{g g}^{-1}$ and accounted for 0.69 to 2.46 % of the total SOC in the soils under study. The amount of RMC was significantly higher in 100% NPK+FYM than other treatments. There was a significant variation in every treatment. The lowest RMC ($27.20 \mu\text{g g}^{-1}$) content was recorded in the unfertilized control plot. The balanced fertilization with 100% NPK recorded 63 % and 23% more RMC content over the imbalanced fertilization i.e. 100% N and 100% NP respectively. Addition of extra

50% NPK over the 100% NPK showed 26.24% more RMC content compared to 100% NPK treatment. However, treatments under the study were in the following order of : 100% NPK + FYM > 150% NPK > 100% NPK > 100% NP > 100% N > control.

Table 8: Influence of fertilizers and manures on readily mineralisable carbon (RMC), water extractable carbon (WEOC), KMnO₄- extractable carbon (KMnO₄-C) and Carbon Management Index (CMI) during 10 years of rice-rice cropping system

Treatment	RMC($\mu\text{g g}^{-1}$)	WEOC(g kg^{-1})	KMnO ₄ -C(g kg^{-1})	CMI
Control	27.202 ^f	0.107 ^d	0.519 ^d	100.000 ^d
100% N	55.957 ^e	0.217 ^c	0.566 ^{cd}	109.362 ^{bcd}
100% NP	74.350 ^d	0.254 ^c	0.570 ^{cd}	107.845 ^{cd}
100% NPK	91.685 ^c	0.305 ^b	0.608 ^{bc}	117.507 ^{bc}
150% NPK	115.745 ^b	0.307 ^b	0.630 ^b	120.955 ^b
100% NPK + FYM	147.125 ^a	0.369 ^a	0.783 ^a	151.295 ^a

LSD ($p < 0.05$): RMC = 6.60; WEOC = 0.03; KMnO₄-C = 0.051; CMI = 11.63. In each column the values (mean of four replicates observations) followed by common letters are not significantly different ($p < 0.05$) between treatments by DMRT

4.5.2. Water- Extractable Carbon (WEOC)

The appraisal of results are presented in the table 8 and depicted in fig.3c. It is revealed that water extractable carbon (WEOC) comprised of 2.77 to 6.19 % of total soil organic carbon (Fig. 3c). The water extractable carbon content varied from 0.11 to 0.37 g kg^{-1} under the present study (Table 8). The 100% NPK+FYM recorded significantly highest (0.37 g kg^{-1}) water extractable carbon content than all other treatment. There was significant difference between balanced fertilization and super-optimal dose of NPK with imbalance fertilization (0.22 and 0.25 g kg^{-1}). But extra 50% NPK over balanced fertilization with NPK did not show any significant increase in water-extractable carbon

content. There was 19.35% more WEOC content in integration of balanced fertilization along with FYM compared to balanced fertilization only with NPK. The lowest WEOC content was recorded (0.11 g kg^{-1}) in unfertilized control.

4.5.3 KMnO_4 - Extractable Carbon

The data in respect of KMnO_4 -extractable C are presented in table 8 and depicted in fig 3d. Perusal of the results (Fig 3d) indicated that KMnO_4 Extractable C was relatively larger in size and comprised 13.04 to 13.10% of the soil organic carbon content. Application of FYM along with NPK (100% NPK+FYM) showed highest accumulation of KMnO_4 -C (0.78 g kg^{-1}) while the unfertilized control plot observed lowest value (0.52 g kg^{-1}) (Table 8). There was a significant difference in KMnO_4 -C content in 100% NPK (0.608 g kg^{-1}) and 150% NPK (0.63 g kg^{-1}) compared to unfertilized control (0.52 g kg^{-1}) which also indicated lowest value among all the treatments. Under different fertilizer combination both imbalanced and balanced, there was no significant difference among them. However, the treatments under study were in the following order of : 100% NPK+FYM > 150%NPK > 100% NPK > 100% NP > 100% N > control.

4.6 Effect of long term manuring on Carbon Management Index (CMI)

The data presented in the table 8 revealed that CMI value were significantly affected by fertilization. In our study, the CMI values were in a increasing order of control < 100% NP < 100% N < 100% NPK < 150% NPK < 100% NPK+FYM and CMI values were significantly enhanced by FYM application compared with balanced or super optimal dose of NPK or imbalanced fertilization.

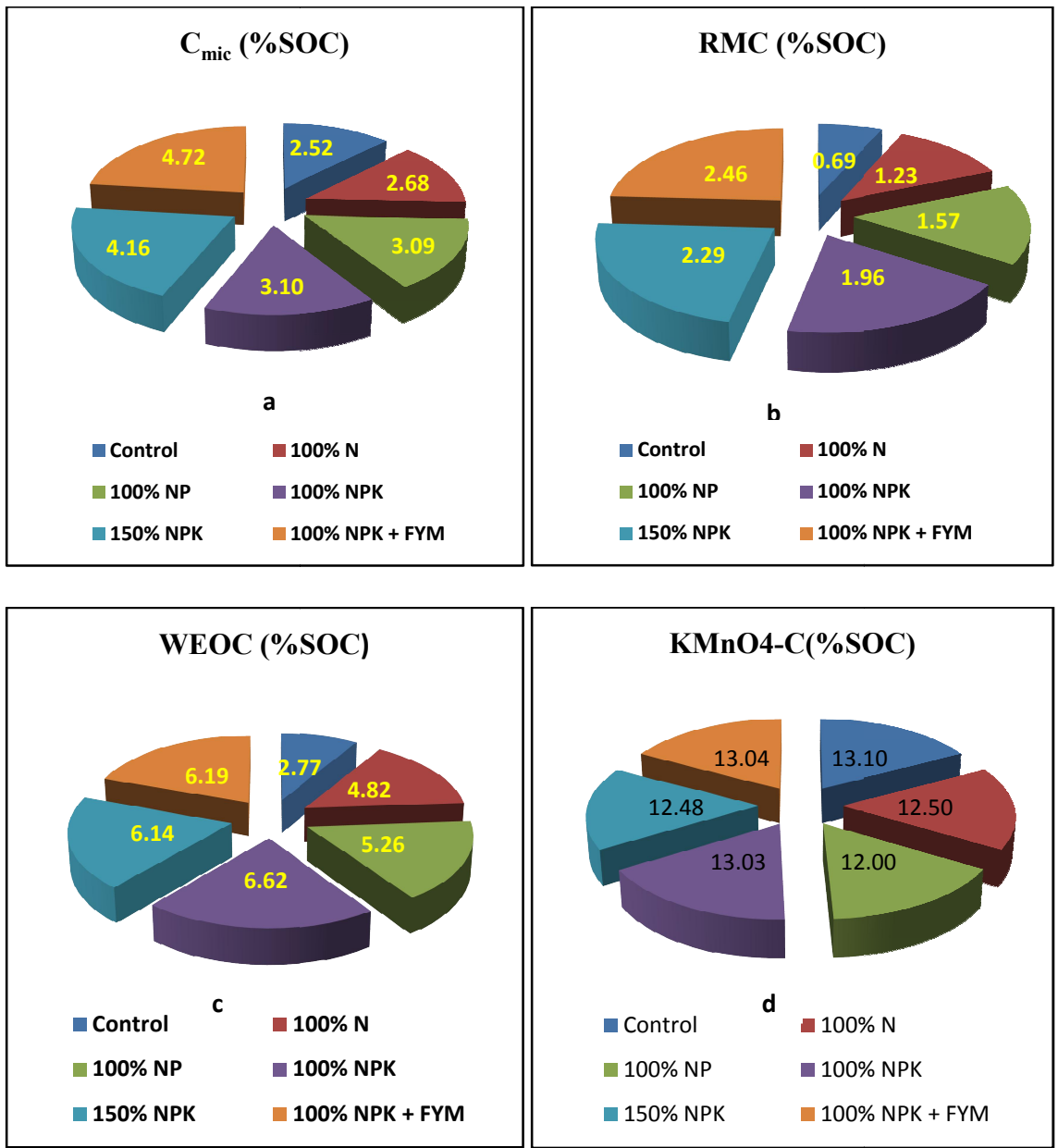


Fig 3. Influence of fertilizers and manures on C_{mic}, RMC, WEOC, KMnO₄-C as proportion of soil organic carbon during 10 years of rice-rice cropping system

4.7 Effect of long term manuring on active pool of Soil organic Carbon

4.7.1 Particulate organic carbon and mineral associated carbon

Experimental results presented in table 9 and depicted in fig 4 revealed that fine particulate organic carbon (FPOC) constituted 24.69 to 34.62 % of SOC (Fig 4b) compared to 17.88 to 30.60 % (Fig 4a) for coarse particulate organic carbon (CPOC). The proportion of both POC fractions was significantly higher in 100 % NPK+FYM treatment compared to other treatments (Table 9). A greater amount of C in this pool (POC) was found with the NPK + FYM (3.90 g kg^{-1}) and NPK (3.07 g kg^{-1}) vis- a-vis the others. The CPOC and FPOC pools were lower (0.71 and 0.98 g kg^{-1}) in the unfertilized control than all other treatments. Application of FYM along with 100% NPK increased CPOC pools by 39.69% and FPOC by 16.94% over the 100% NPK only. Conjoint use of FYM and 100% NPK resulted in significantly high FPOC pool (2.07 g kg^{-1}) and CPOC pool (1.83 g kg^{-1}) than all other treatments. However, FPOC pool was on an average 1.4 times larger than CPOC pool under various treatments. There was no significant difference between 100% NPK and 150% NPK in both the pools. But in case of FPOC pools 100% NP constituted significantly higher (1.46 g kg^{-1}) C content than 100% N (1.26 g kg^{-1}). However, the treatments were found in the following order in both the pools $100\% \text{ NPK+FYM} > 150\% \text{ NPK} > 100\% \text{ NPK} > 100\% \text{ NP} > 100\% \text{ N} > \text{control}$.

In respect to mineral associated carbon (MAC) only 100% NPK+FYM showed the significantly higher (2.61 g kg^{-1}) content compared to all other treatments. It comprised of 35.90 to 51.64 % of SOC content (Fig 4c). There was no significant variation among the fertilized treatments.

Table 9: Influence of fertilizers and manures on Coarse Particulate Organic Carbon (CPOC), Fine Particulate Organic Carbon (FPOC) and Mineral Associated Carbon (MAC)

Treatment	CPOC(g kg ⁻¹)	FPOC(g kg ⁻¹)	MAC(g kg ⁻¹)
Control	0.71 ^d	0.98 ^e	2.05 ^{bc}
100% N	0.97 ^c	1.26 ^d	2.16 ^b
100% NP	1.02 ^c	1.46 ^c	2.18 ^b
100% NPK	1.31 ^b	1.77 ^b	1.68 ^c
150% NPK	1.33 ^b	1.66 ^b	2.07 ^{bc}
100% NPK + FYM	1.83 ^a	2.07 ^a	2.61 ^a

LSD (p<0.05): CPOC = 0.151; FPOC =0.173; MAC =0.373. In each column the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05) between treatments by DMRT

4.7.2 Density fractions

The experimental findings of density fractions were presented in table 10 and depicted in fig.5. Perusal of results revealed that pool of heavy fraction organic C (HFOC) dominated soil organic carbon content ranging from 32.49 to 50% (Fig 5a) whereas light fraction organic carbon (LFOC) was computed only 0.50 to 5.35 % (Fig 5b) of the soil organic carbon. The pool of light fraction carbon was also significantly differentiated by treatments. Application of FYM significantly improved both the light fraction (59.37%) and heavy fraction (31.71%) (Table 10) as compared to only balanced fertilization with NPK. The effect of fertilization was relatively small in heavy fractions pool as compared to light fraction pool. In heavy fraction pool the super-optimal dose of NPK (2.35 g kg⁻¹) did not show any significant difference with balanced dose of NPK (2.27 g kg⁻¹) but in light fraction pool, former increased up to 76% more as compared to later. But in both pool unfertilized control resulted very low carbon content. However in both the pool the treatments under present study were in the following order 100% NPK+FYM > 150% NPK > 100% NPK > 100% NP > 100% N > control.

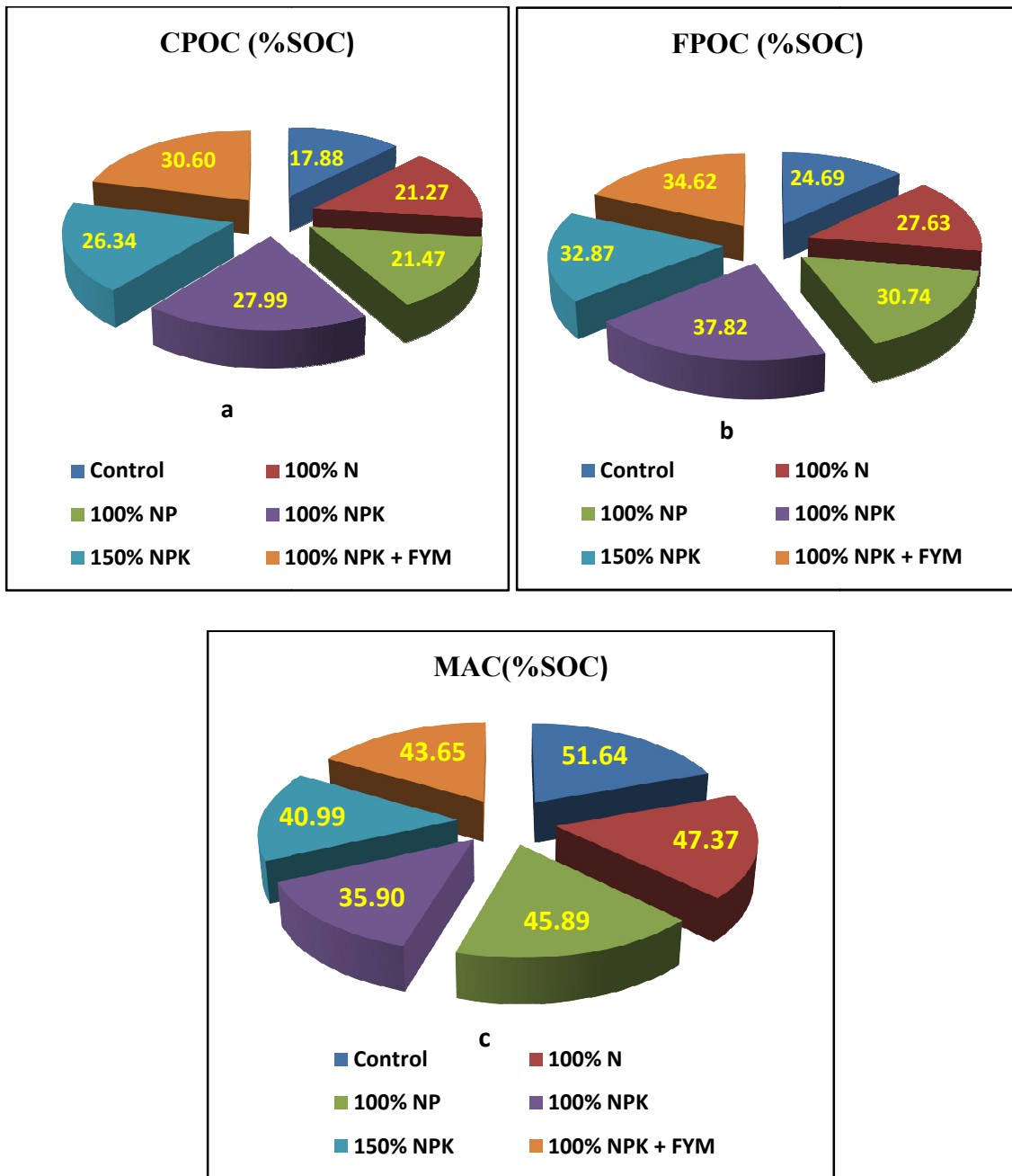


Fig.4: Influence of fertilizers and manures on CPOC,FPOC and MAC as proportion of soil organic carbon during 10 years of rice-rice cropping system

4.8 Effect of long term manuring on Passive pool of Soil organic Carbon

4.8.1 Humic acid content

Results obtained from humic fraction are presented in Table 10 and depicted in fig 5. The estimation of humic substances showed that humic acid content significantly differ among the treatments under present study. Humic acid content was ranged from 0.079% to 0.167 %. The content of humic acid increased with increased levels of fertilizer application and ranged from 20 to 72% over control (0.079%) and higher content of humic acid was recorded under 100% NPK+FYM (0.167%) followed by 150% NPK (0.136%) and 100% NPK (0.117%). The humic acid comprised of 1.99 to 2.79 % of the soil organic carbon content (fig 5c).

Table 10: Influence of Inorganic fertilizers and organic amendments on light fraction carbon, heavy fraction carbon and humic acid content after 10 years under rice-rice cropping system

Treatment	HFOC(g kg ⁻¹)	LFOC(g kg ⁻¹)	Humic acid(%)
Control	1.29 ^d	0.02 ^e	0.079 ^e
100% N	1.58 ^c	0.05 ^e	0.095 ^d
100% NP	1.61 ^c	0.08 ^d	0.104 ^{cd}
100% NPK	2.27 ^b	0.13 ^c	0.117 ^c
150% NPK	2.35 ^b	0.23 ^b	0.136 ^b
100% NPK + FYM	2.99 ^a	0.32 ^a	0.167 ^a

LSD (p<0.05): HFOC = 0.218;LFOC= 0.027; Humic Acid = 0.015.In each column the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05) between treatments by DMRT

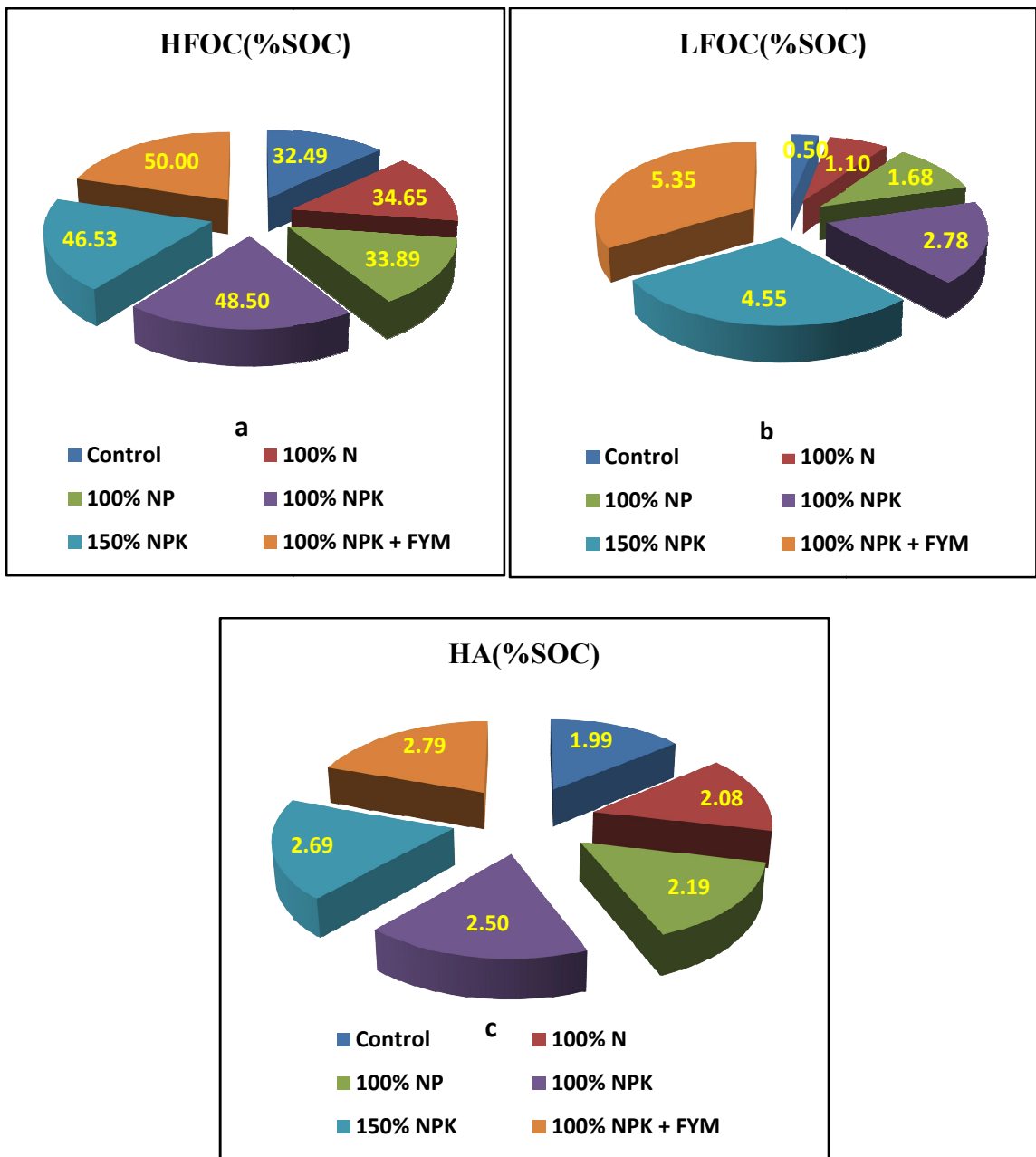


Fig 5 : Influence of fertilizers and manures on humic acid content(HA), LFOC and HFOC as proportion of soil organic carbon during 10 years of rice-rice cropping system

4.9 Relationship among different organic carbon pools and with crop productivity

The co-efficient of correlations amongst various pools of C showed that all pools were significantly correlated with each other except MAC (Table11) The MAC was only highly related to SOC ($r = 0.47$). The labile pools namely WEOC, $\text{KMnO}_4\text{-C}$, C_{mic} , RMC were significantly and positively related with SOC and other pools but C_{mic} , RMC and $\text{KMnO}_4\text{-C}$ showed the highest correlation. The relationship of SOC with labile pools followed the order $C_{\text{mic}} > \text{RMC} > \text{KMnO}_4\text{-C} > \text{WEOC}$. The relationship with LFOC with other active pools followed the order $\text{HFOC} > \text{CPOC} > \text{FPOC}$ but HFOC followed the order $\text{LFOC} > \text{CPOC} > \text{FPOC}$. Both POC fractions viz. CPOC and FPOC were significantly correlated. All the labile pools were also significantly correlated with all active pools but again C_{mic} , RMC and $\text{KMnO}_4\text{-C}$ exhibited better correlation compared to others. Linear regression best described the relationship of C_{min} with all the fractions. Except MAC all the fractions are strongly and significantly ($p < 0.01$) related with C_{min} . The relationship of C_{min} with POC fractions though significant was lower than with density fractions. The C_{min} was better correlated with CPOC ($r = 0.95^{**}$) than FPOC ($r = 0.90^{**}$). Significant relationships between the SYI and rice yield and all the SOC pools were observed (Table12), the relationship being stronger particularly with LFOC, CPOC, $\text{KMNO}_4\text{-C}$, C_{mic} , RMC, and WEOC. There was a significant correlation between CMI and each of the C fraction being strongest with $\text{KMnO}_4\text{-C}$ ($r = 0.98^{**}$) and CPOC ($r = 0.90^{**}$). Carbon stock calculated at 6 different treatments was considered as dependent variable to fit a stepwise multiple regression model where predictors set was different carbon fractions for the same set of treatments(Table 13, Eq.1). The best fitted model is included in the table 13. The multiple regression results revealed that $\text{KMnO}_4\text{-C}$, LFOC and C_{mic} were important predictors (Eq.1) out of those predictors considered which can explain 99% of the total variance. When predictors variables are used to predict the yield (Eq 2), the stepwise technique of multiple regression revealed that $\text{KMnO}_4\text{-C}$, CPOC, FPOC, LFOC, C_{mic} and HA are only important predictors which can explain 97% of the total variance. Likewise, LFOC and HA together explain 93% of SOC (Eq. 3) and in case of CMI the $\text{KMnO}_4\text{-C}$, LFOC and C_{mic} are the important predictors which can explain 97% of the total variance(Eq .4)

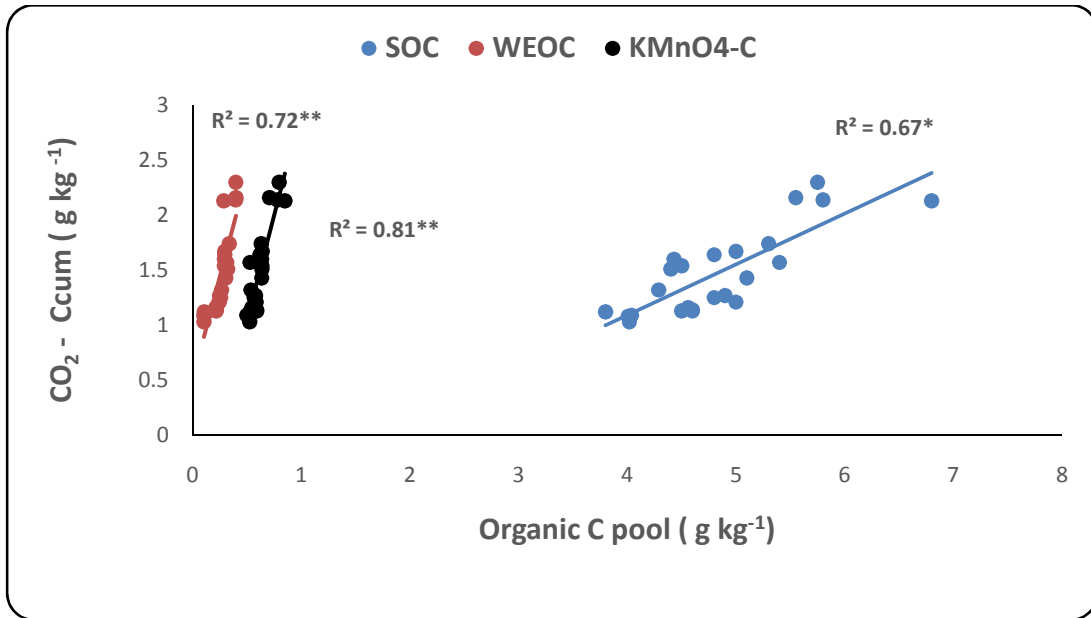


Fig6: Relationship of mineralizable C ($\text{CO}_2 - \text{C}_{\text{cum}}$) with SOC, WEOC and $\text{KMnO}_4\text{-C}$
**** and * next to R^2 values indicate significant a $p < 0.01$ and $p < 0.05$ respectively.**

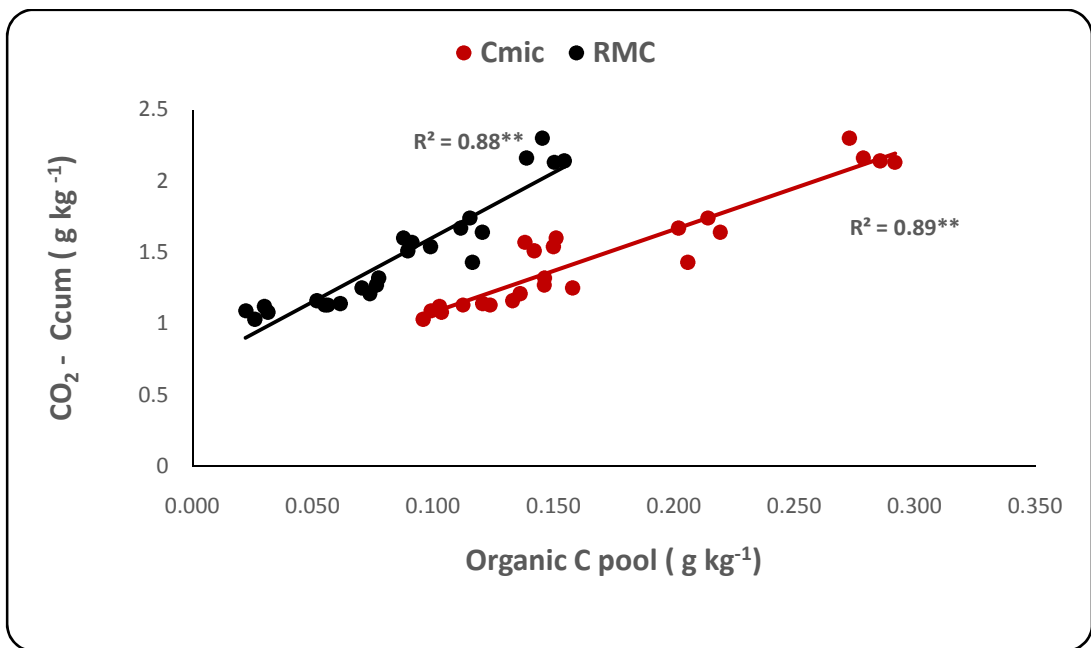


Fig 7: Relationship of mineralizable C ($\text{CO}_2 - \text{C}_{\text{cum}}$) with C_{mic} and RMC

****next to R^2 values indicate significant a $p < 0.01$**

Table 11: Correlation coefficient among different soil organic carbon pools

	SOC	C _{min}	C _{mic}	RMC	KMnO ₄ -C	WEOC	CPOC	FPOC	HFOC	LFOC	HA	MAC	CMI
SOC		0.82**	0.87**	0.85**	0.84**	0.72*	0.84**	0.84*	0.92**	0.87**	0.92**	0.47	0.80**
C _{min}	0.82**		0.94**	0.93**	0.90**	0.85**	0.95**	0.90**	0.91**	0.95**	0.92**	0.27	0.89**
C _{mic}	0.86**	0.94**		0.94**	0.91**	0.80**	0.91**	0.84*	0.91**	0.97**	0.94**	0.23	0.87**
RMC	0.85**	0.93**	0.94**		0.88**	0.92**	0.94**	0.92**	0.95**	0.96**	0.95**	0.24	0.85**
KMnO ₄ -C	0.83**	0.90**	0.91**	0.88**		0.73*	0.91**	0.82**	0.88**	0.85**	0.89**	0.33	0.98**
WEOC	0.72*	0.85**	0.80**	0.92**	0.73*		0.87**	0.88**	0.88**	0.85**	0.82**	0.28	0.71*
CPOC	0.84**	0.95**	0.91**	0.94**	0.91**	0.87**		0.97**	0.91**	0.91**	0.92**	0.26	0.90**
FPOC	0.84**	0.90**	0.84**	0.92**	0.82**	0.88**	0.97**		0.89**	0.88**	0.91**	0.30	0.80**
HF	0.82**	0.91**	0.90**	0.95**	0.88**	0.87**	0.91**	0.89**		0.94**	0.93**	0.38	0.85**
LF	0.87**	0.95**	0.97**	0.96**	0.84**	0.85**	0.91**	0.88**	0.94**		0.96**	0.31	0.83**
HA	0.92**	0.92**	0.94**	0.95**	0.89**	0.82**	0.92**	0.91**	0.93**	0.96**		0.34	0.86**
MAC	0.47	0.27	0.23	0.24	0.33	0.28	0.26	0.30	0.38	0.31	0.34		0.19
CMI	0.80**	0.89**	0.87**	0.85**	0.98**	0.71*	0.90**	0.80**	0.85**	0.83**	0.86**	0.19	

** significant at 1% level

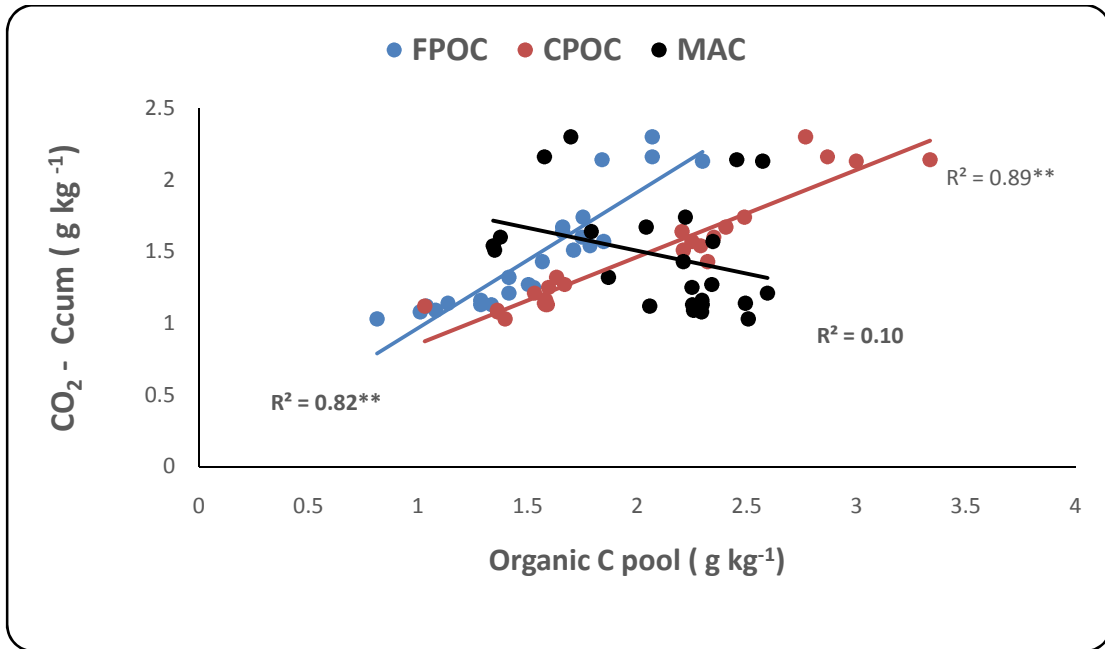


Fig8: Relationship of mineralizable C ($\text{CO}_2\text{-C}_{\text{cum}}$) with coarse fraction organic carbon (CPOC), fine fraction organic carbon (FPOC) and mineral associated (MAC) organic carbon. **next to R^2 values indicate significant a $p < 0.01$

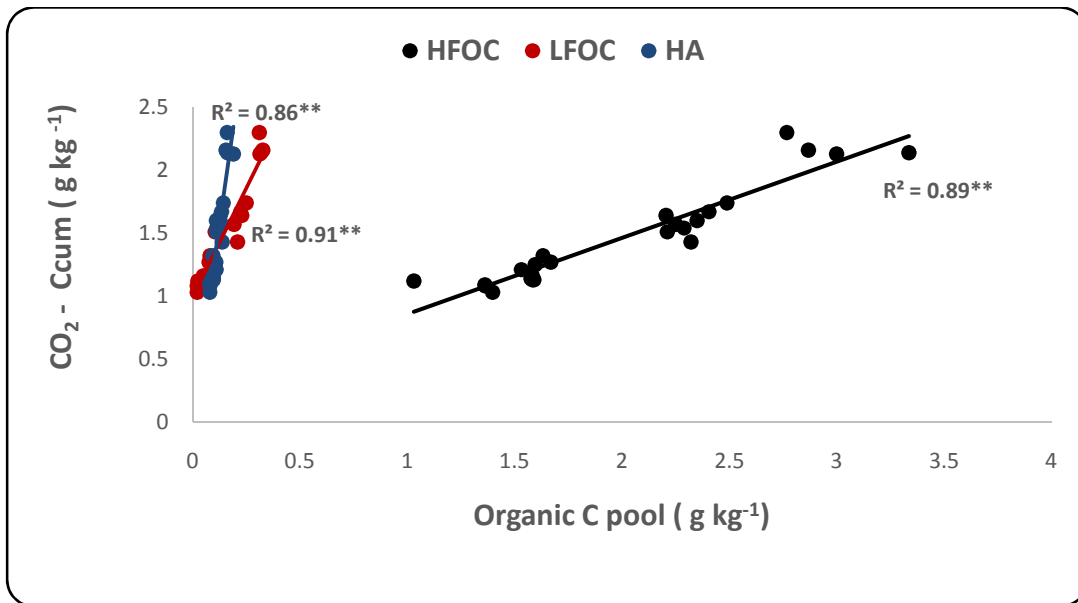


Fig9: Relationship of mineralizable C ($\text{CO}_2\text{-C}_{\text{cum}}$) with soil organic, light (LFOC), heavy (HFOC) and humic acid content.

**** next to R^2 values indicate significant a $p < 0.01$**

Table12 : Relationship of different soil organic carbon (SOC) pools with rice yield and sustainable yield index under different treatments after 10years of rice-rice cropping

	Yield			SYI	
SOC Pools	Equation	R ²	SOC Pools	Equation	R ²
SOC	Y=12.71X-27.95	0.71*	SOC	Y=0.35+1.52X	0.70**
C _{mic}	Y=0.15X+7.84	0.85**	C _{mic}	Y=0.20+0.0017X	0.70*
C _{min}	Y=22.97X-0.37	0.73*	C _{min}	Y=0.18+1.12X	0.68
KMnO ₄ -C	Y=94.22X-24.29	0.69*	KMnO ₄ -C	Y=-0.03+1.31X	0.65*
WEOC	Y=8.04+97.72X	0.68*	WEOC	Y=0.095+1.54X	0.48**
RMC	Y=0.24X+12.47	0.90**	RMC	Y=0.23+0.003X	0.70**
CPOC	Y=24.48X+4.23	0.77**	CPOC	Y=0.09+0.33X	0.54**
FPOC	Y=23.46X-2.52	0.70*	FPOC	Y=-0.035+0.348X	0.60**
MAC	Y=16.99X-2.63	0.22	MAC	Y=1.74+0.152X	0.104
HFOC	Y=15.78X+2.65	0.79**	HFOC	Y=0.098+0.198X	0.71*
LFOC	Y=89.77X+21.05	0.84**	LFOC	Y=0.35+1.04X	0.73*
HA	Y=-229.03X-0.03	0.85**	HA	Y=-0.026+4.05X	0.82*

** and * next to R² values indicate significant a p<0.01 and p< 0.05 respectively.

Table 13: Regression results following stepwise method of analysis where both criterion measure and predictors are mean results are with allowed tolerance = 0.0001

Predictors	Eq.No	Equations	R ²
WEC, KMNO4-C, MBC, RMC, ROC, LFOC, HFOC, MAC,HA	1	Carbon stock =-0.904 + 7.15 KMno4-C**+25.81 LFOC** -0.024 MBC*	0.99**
WEC, KMNO4-C, MBC, RMC, ROC, LFOC, HFOC, MAC,HA	2	Yield=29.07-9.14 KMNO4**-24.69FPOC*+21.61CPOC**-13.0LF**+2.62MBC*+50.9HA**	0.97**
WEC, KMNO4-C, MBC, RMC, ROC, LFOC, HFOC, MAC,HA	3	SOC= 0.404 – 4.6 LFOC*+ 40.60HA*	0.93**
WEC, KMNO4-C, MBC, RMC, ROC, LFOC, HFOC, MAC,HA	4	CMI=-6.24+26.1 KMNO4**+11.92LFOC*-0.159MBC*	0.97**

** significant at 1% level, *significant at 5 % level

DISCUSSION

5.1 Effect of long term manuring on crop yield and Sustainable yield index (SYI)

Soil organic matter (SOM) plays an important role in maintaining the productivity of tropical soils because it provides energy and substrates, and promotes the biological diversity that helps to maintain soil quality and ecosystem functionality (Wendling *et al.*, 2010). There are some possible scenarios relating crop yield or agronomic productivity to organic C content of the soil: (i) increase in crop yield as a consequence of organic carbon pool enhancement (ii) no or little decrease in crop yield with reduction in the organic carbon pool and (iii) increase in crop yield with decrease in the organic carbon pool, (Lal, 2006). There apparently conflicting responses depend on several factors such as the previous organic carbon pool, soil management and use of chemical fertilizers and organic amendments. Application of FYM along with balanced fertilization significantly increased the yields compared to that in unfertilized control or balanced or imbalanced fertilization (Table 4). Long-term application of FYM improves soil fertility including concentration of SOC and of macro and micro nutrients and physical properties. In contrast, application of balanced fertilization increase crop yields by directly supplying plant nutrients required for crop growth. If no organic manure is applied, SOC concentration, especially for stable organic carbon will decline significantly (Ren *et al.*, 2014). The results of the present investigation also find support from the results of the Long term experiments reported by Zhang *et al.*, 2009 and Fan *et al.*, 2008. The higher and/ or lower amounts of crop residues C inputs into soil was associated with higher and/or lower amount of rice yield under different treatments. Among various treatments analyzed, NPK+ FYM, NPK sustained the rice yield more than other treatments under present study.

5.2 Effect of long term manuring on gross carbon input, SOC stock and Carbon sequestration

Cultivation of crop as such without using any organic or inorganic or combination of both inputs (control) caused a net depletion of SOC in soils compared with the fallows

where no cultivation was done since the initiation of the experiments. Cultivation over the years caused a decrease of 14.98% of the SOC content over the fallow uncultivated soil (Table 6). Such cultivation was done with an expense of energy for tilling land that affects the distribution and stability of soil aggregates and reduces soil organic C stocks in soil (Mandal *et al.*, 2007). Many researchers (Swarup *et al.*, 2000; Lal, 2004), however, reported a much higher magnitude (30-60%) of such depletion due to cropping from this subtropical part of India. The lower magnitude of depletion as observed by us was firstly due to the soils being under a unique aquic (flooded) moisture regime for 3 to 4 months under rice crop (Mandal *et al.*, 2007) and secondly due to the soils being inherently low in organic carbon content (SOC- 4.3 g kg⁻¹) (Mandal *et al.*, 2007). Their conditions possibly retarded the rate of C oxidation in the soil.

Cultivation with balanced fertilization, however, caused a net enrichment of SOC content of the soil (Table 6). This was obviously associated with a large amount of crop residues and root biomass C left over in the soil (1.86 and 4.26 vs 0.94 Mg C ha⁻¹ yr⁻¹ : : fertilized : unfertilized control, Table 5) owing to the significantly higher yield of the crops grown under those treatments compared to the control (32.89 and 48.24 q ha⁻¹ vs. 19.39 q ha⁻¹ , Table 4), besides C supplementation through FYM in the NPK+FYM. Our findings suggest that rice-rice cropping system has improved SOC content when cultivated with balanced fertilization while budgeting carbon stock in soil for rice-rice cropping systems in different eco-regions of Asia, Bronson *et al.*, 1998, a possible conservation or even increase in C stocks in soil in lowland tropics, despite high temperature prevalent throughout the years, which favours rapid mineralization of C. According to their opinion, it was due to the relatively slow rate of soil C mineralization under anaerobic condition and also the large C inputs from non- vascular plants (photosynthetic algal communities) in the soil- flood water ecosystem. Results from a few long term experiments also showed similar build up of SOC due to application of manure with balanced fertilization (Tripathy *et al.*, 2014; Rudrappa *et al.*, 2006). Organic sources of nutrients decompose slowly resulting in more SOC accumulation in soil (Mandal *et al.*, 2007).

A significant positive linear relationship between SOC sequestered (Y) and the total cumulative crop residues C inputs (X) to the soils over the years ($R^2 = 0.87$, $p = 0.005$; Fig.1). This is in conformity with findings of other researchers (Majumdar *et al.*, 2008 and Mandal *et al.*, 2007). Six *et al.*, 2002, proposed a conceptual SOM model for a maximum C storage potential. Existence of such strong linear relationship suggested that even after 10 years of C addition at a reasonably high rate through FYM ($2.04 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) and crop residues (0.94 to $2.22 \text{ Mg ha}^{-1} \text{ yr}^{-1}$), the soils of the present experiment still have a capacity for storing carbon and, therefore, have great potential for further C sequestration. Results also revealed that to maintain SOC level (Zero change), the critical amount of C inputs to the soil is $1.2 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ (Fig. 1), which is smaller to that reported by Kong *et al.*, 2005 ($3.1 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ in Davis, USA under Mediterranean like climate and Standley *et al.*, 1990 ($4.0 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) in *vertisols* of the summer rainfall zone of Australia. Considering the quantity of residue C input as obtained for N treatment ($1.18 \text{ kg ha}^{-1} \text{ yr}^{-1}$) that caused little change (2.41% decrease over the uncultivated soil) in SOC, the observed critical amount of $1.2 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ is a reasonable value. The slope of the curve (Fig.1) represents the rate of conversion of input C to SOC, which is about 8.2% each additional Mg C input per hectare under the tested cropping system. However, more studies need to be undertaken using long-term experiments under hot, sub-humid tropical climate to substantiate the observed value and look for suitable alternate cropping systems that provide it with better economics for maintenance of soil health.

Carbon sequestration potential under different scenario denoted that even without any organic matter application, soil could sequester organic carbon through balanced application of NPK. But application of FYM along with inorganic fertilizer led to an additional build up of SOC in soil. Lal, 2004 summarized the results of a number of studies and concluded that improved fertility management can enhance the SOC content at the rate of 0.05 - $0.15 \text{ Mg ha}^{-1} \text{ yr}^{-1}$. Manna *et al.*, 2007 observed that application of fertilizer NPK, either alone or in combination with FYM maintained active or slow release pools of C, sequestered C and improved soil qualities and productivity. The lower efficiency of C sequestration from crop residues (Fig. 2) into soils as observed in our experiments was mainly due to very hot and humid climate prevailing at our experimental sites which facilitated rapid oxidation of soil as well as residue organic

carbon. At a given C input, the C sequestration efficiency was greater in paddy soil than in upland soil, which may be attributed to lower microbial activity but greater chemical (i.e., oxalate-soluble Fe) and physical stabilizations (i.e., soil structure) in paddy field. Paddy soil may sequester more SOC, with higher efficiency, than upland soil does (Yan *et al.*, 2013).

Studies in the past have shown that SOC and its distribution among different physical pools can be altered by soil, crop and fertilizer management practices. The relative increase in SOC storage depends on crop mediated carbon input, exogenous supply of organic matter and the initial organic carbon content of soil (Malhi *et al.*, 2011; Yang *et al.*, 2005) showed that the total C in paddy soil was higher by 40-60% with combined application of organic amendment and chemical fertilizers than the sole application of chemical fertilizers. But our results exhibited that SOC content has increased only 20 -30 % in 100%NPK + FYM as compared to only fertilizer treatments.

5.3 Effect of long term manuring on Mineralizable carbon, Microbial Biomass Carbon and Microbial indices

The amount of C mineralized (25.36% of SOC) that we observed (Table 7) within a short span of 36 days is typical in soils of tropical and subtropical regions (Rudrappa *et al.*, 2006). The amount varied under different treatments, being lowest in the control. This is due to the variable amounts of labile organic carbon fraction in the soils under the treatments which will be discussed later. Variation in the amount of C mineralized under different treatments was possibly associated with the amount and quality (lignin, cellulose and polyphenol content) of crop residues left over in the field by the crops. The higher value of C_{min} in the NPK fertilizer with organic amendments may be attributed to the good supply of labile C substrate in these treatments which stimulated microbial activity with a consequent higher respiration rate (Sayre *et al.*, 2005). The lowest value in the unfertilized control plot seems to be related to the unfavourable environment in the control arising out of the depletion of nutrients due to continuous cropping without any fertilization. Balanced fertilization with C- supplementation, however, provide a congenial environment for microbial growth and thus caused an increased in soil C_{min} over that in the control.

The soil C_{mic} , which normally constitutes about 1-5% of the SOC, can provide an early warning for a possible degradation and/ or aggrading effect of different management practices on soil quality (Powlson, 1994). The lower value of C_{mic} in the control treatment (Table 7) seemed to be related to its unfavourable environment arising out of depletion of nutrients due to continuous cropping without any fertilization while a higher value in the NPK+FYM treatments was due to its congenial environment for microbial growth for C enrichment through plant residues incorporation as well as FYM application (Grego *et al.*, 1998). This observation is consistent with that of Yan *et al.*, 2007, who reported that the C_{mic} content in soils receiving annually FYM for nearly 100 years along with inorganic NPK was higher than that in NPK only, while it was lowest in soils receiving only N or no fertilization of all (control). Reports in literature in this regard are contradictory in nature. Some (Hart and Stark, 1997) reported a positive effect of nitrogenous fertilizer on C_{mic} , while others (Ghani *et al.*, 2003 and Okano *et al.*, 1991) observed a negative effect. Still a few (Fauci and Dick, 1994) found no such effect in the short-term but a negative effect in the long term. Variations in experimental conditions and agro-ecosystems used for those studies may be responsible for the difference in the results. However, increased N availability with N-fertilization has been known to shift the microbial community composition (from fungal to bacterial dominance) (Bardgett and McAlister, 1999). These shifts have been invoked to explain the lower C_{mic} in N-fertilized soils (Omay, 1997). Lower C_{mic} with use of N-fertilizer alone had also been attributed to the slow rate of microbial cell synthesis due to lack of adequate availability of P and K which are essential for microbial proliferation (Rudrappa *et al.*, 2006).

The microbial quotient (MQ) signifies microbial activity. The values of MQ for present experiment were within the range of 1 to 5% (Table 7) as advocated by a number of researchers (Powlson, 1994 and Carter, 2002). Its higher values in NPK+ FYM compared with the control or other imbalanced fertilization may be attributed to a better nutritional environment in the former treatments. The results also suggest that the organic C under the former treatments is more stable than in the control (Sparling *et al.*, 1992). The lowest value of MQ in the control soils indicates that the capacity of the soil for C retention has been impaired, signifying a degradation of its quality (Carter, 2002).

The respiratory or metabolic quotient (the ratio of C_{\min} and C_{mic} , $q\text{CO}_2$) is an indicator of the efficiency of soil microorganism in processing residue or available soil C. The higher $q\text{CO}_2$ in the control, only N or even NP treatments suggested a less efficient use of available C by the microbes there. Higher $q\text{CO}_2$ associated with long-term N application only has also been reported by Fauci and Dick, 1994. Although, $q\text{CO}_2$ undoubtedly indicates microbial efficiency, several other factors such as soil moisture, nature of residue C incorporated into the soil, qualitative changes within microbial population (e.g. increase in the proportion of fungi) etc. may also explain the differences in $q\text{CO}_2$ within the treatments. The higher metabolic efficiency (i.e. lower $q\text{CO}_2$) of microbial population in the fertilized treatments such as NP, NPK and NPK+FYM as observed in the present study suggests that these treatments are most efficient in preserving C in soil. The lower value of $q\text{CO}_2$ in soil with NPK+FYM has been reported by Rudrappa *et al.*, 2006. High values of $q\text{CO}_2$ are indicative of the presence of readily mineralizable C that has not yet led to the growth of the microflora (Franzluebbers *et al.*, 1999). The increase of $q\text{CO}_2$ was also reflected in an increase in the ratio of active : dormant component of microbial population.

5.4 Effect of long term manuring on labile pool of soil organic carbon

After 10 years of rice-rice cropping, all labile SOC pools studied responded significantly to management of changes at the same C inputs. Earlier studies have also shown that some biologically active or labile pools respond to changes in management to a greater extent than TOC (Yang *et al.*, 2005; Gong *et al.*, 2009). Increasing in labile C pools with the application of organic amendments suggest that the management practices help to maintain or improve soil functions as labile C, with a rapid turnover rate, is an important energy sources for the soil food web and thus influences nutrient cycling for maintaining soil quality and productivity (Chan *et al.*, 2001).

Our studies reveal that the RMC content was significantly ($p < 0.01$) correlated with total C and soil C fractions as well as MBC which constitutes as an important part of the soil labile C pool. Water – extractable organic carbon representing only a small proportion (2.77 to 6.19%, Fig.3c) of SOC, showed the greatest increase (13.6 to 68%) with (Table 8) C inputs ranging between 0.22 to 0.37 g kg⁻¹ during the 10 year period. Its

greater responses to management indicate that the root exudates, above ground residues and added organic matter contained much soluble organic C (Chantigny *et al.*, 2002; Lu *et al.*, 2004). Our results are similar to those reported by Liang *et al.*, 2011 and Xu *et al.*, 2011, who reported increase in WEOC as a result of manure or crop residue application. Water soluble organic C is a C source for microorganisms and it is also believed to be microbially mediated (Christ and David, 1996); the flow of carbon through water – production soluble components supplies substrate for microbial biomass turnover (McGill *et al.*, 1986). In our study, significant relationship of WEOC with SOC, C_{min} and MBC (Table 11) corroborated the hypothesis that water-soluble/ extractable C is composed of a range of molecules that reflects the composition of SOC as the soluble phase tends to be in equilibrium with solid phase of SOC (Chantigny, 2003).

Soil $KMnO_4$ -C is composed of amino acids, simple carbohydrates, a portion of microbial biomass and other simple organic compounds (Zou *et al.*, 2005) and is a fraction of SOC with a turnover time of less than a few years (Parton *et al.*, 1987). $KMnO_4$ -C can be used effectively to monitor the rate of change in SOC and thus has been suggested as an early indicator of the effects of soil managements on SOC quality (Naklang *et al.*, 1999). $KMnO_4$ -oxidizable organic C represented a relatively larger pool of SOC and constituted 12-13% of SOC with the greatest amount being under NPK+FYM treatment (Fig. 3d). Our values are similar to those shown by Lou *et al.*, 2011 and Rudrappa *et al.*, 2006. $KMnO_4$ -C was significantly enhanced under the single N management compared to the unfertilized control in our study. Rudrappa *et al.*, 2006, Purakayastha *et al.*, 2008 and Gong *et al.*, 2009, also reported similar results in long term fertilizer experiments. This may be explained by the increase in rhizodeposition. Crop root biomass has been widely suggested as an important source of $KMnO_4$ -C (Gong *et al.*, 2009; Purakayastha *et al.*, 2008). In this study, $KMnO_4$ -C was more increased by the organic amendments than the inorganic N management alone. The result is consistent with Rudrappa *et al.*, 2006 and Lou *et al.* 2011. This indicates that the added organic manure may also make a considerable consideration to the $KMnO_4$ -C could be well considered as a labile C fraction as proposed by Blair *et al.*, 1995.

5.5 Effect of long term manuring on Carbon Management Index (CMI)

Compared to a single measure such as SOC, CMI can be used as a more sensitive indicator of the rate of change of SOC in response to soil management changes and was suggested by Whitbred *et al.*, 1998 to be a useful technique for describing soil fertility. CMI values were calculated to obtain indicator of the C-dynamics of the system. The values as such are not important, but difference among them reflects effects of different management strategies on studied system (Blair *et al.*, 1995). Soils with higher CMI values are considered better managed. In our study, CMI was more significantly enhanced by the balanced fertilization with organic manure than the imbalanced fertilization. This is due to the increase in annual C input and the variation in organic matter quality, thus modifying the lability of C to KMnO_4 -oxidation (Tirol-Padre and Ladha, 2004). The result is similar to that by Blair *et al.*, 2006 and Lou *et al.*, 2011 who reported that manure with inorganic fertilizer significantly increased CMI compared to any other chemical fertilizer treatments in a long-term experiment. Our research findings are also corroborative with the findings of Verma and Sharma (2007) and Gong *et al.*, (2009). The significant correlation between CMI and each of the C fractions (Table 11) strengthen the suitability of using KMnO_4 -C for calculating CMI and the reliability of CMI as an indicator for evaluating SOC storage.

5.6 Effect of long term manuring on active pool of soil organic carbon

5.6.1 Particulate Organic carbon and Mineral associated organic carbon

Particulate organic matter, an active pool of soil organic matter, mainly consists of partially decomposed plant and animal residues, root fragments, fungal hyphae, spores, faecal pellets, faunal skeleton and seeds (Christensen, 2001; Gregorich and Janzen, 1996). The main source of POC in soil is the difficultly decomposable organic residues having high lignocellulose index as is found in root biomass, often of recent origin. Several studies have reported the positive effect of FYM and fertilizer application on POC in soil (Yan *et al.*, 2007 and Chan, 2001); the effect being greater with manure than fertilizer application (Mandal *et al.*, 2005). We observed that in organic amendment plot, the POC (sum of CPOC and FPOC) represented 65% of the total SOC in the plough layer

(Fig. 4a &b). Cropping without organic amendments reduced the POC pool to 42% of SOC. This reduction was limited to CPOC pool only, which decreased from 26% (150% NPK) to 17.88% (control). The diminutive effect of cropping without organic amendments or with relatively low C input (control) was small on FPOC pool (19-52%) than the CPOC pool (27-65%), compared to the unfertilized control, but both CPOC and FPOC was significantly increased by the N treatment (Table 9). The result is in agreement with Manna *et al.*, 2007. This indicates the increased rhizodeposition might enter the particulate fraction of SOC. Both the fraction was significantly elevated by the organic amendments compared to imbalanced fertilization in this study. Similar observations were also made by Su *et al.*, 2006 and Lou *et al.*, 2011. This elucidates the organic manure may also contribute to the POC fraction in soil (Whalen *et al.*, 2003) suggested that significant quantities of C from farm yard manure were retained in soil particulate fractions.

5.6.2 Density fraction of soil organic carbon

The LFOC pool was smaller in size than the HFOC and MAC pools and represented 0.5 to 5% of the SOC in the surface soil layers (Fig 5b). This values are similar to those (3-5%) reported by Haile-Mariam *et al.*, 2008, under long-term continuous cropping. The proportion of SOC recovered as LFOC varies widely depending on land use, vegetation type and other factors that influence the balance between litter input and decomposition (e.g. climate, soil type, faunal activity). The management practices, which accumulate greater amount of SOC, such as organic amendments addition and nutrient application, are considered to increase the proportion of LFOC in soil (Nyborg *et al.*, 1999). We observed that changes in LFOC pool were commensurate with C input under different treatments. Cropping without organic amendments increased LFOC pool in the surface layer by 62.5% (Table 10) as compared to imbalanced fertilization whereas addition of organic amendments increased up to 146% as compared to balanced fertilization. The higher LFOC values for NPK+FYM treated soils also support findings of Graham *et al.*, 2002 and Yang *et al.*, 2012, who concluded that a high input of organic matter could increase soil LFOC and its significant relationship with short-term C mineralization suggests that LFOC is a useful indicator of

labile C. Sand sized heavy fraction (HFOC) was second in abundance and represented 32-50% of SOC (Fig 5a) in the plough layer. Heavy fraction composed of organic matter adsorbed or deposited by microorganisms on aggregate surfaces and sequestered within organo-mineral aggregates (Strickland and Sollins, 1987). Increment in the HFOC as compared to LFOC could be due to yearly biomass production, residue input and less decomposition activities. Majority of SOC was associated with the silt and clay sized mineral fraction (MAC), which comprised 35-51% of SOC (Fig. 4c). These values are similar to those (46-50%) reported by Haung *et al.*, 2009 for paddy soils. VonLutzow *et al.*, 2007 showed that in the temperate top soils about 50-75% of SOC was associated with clay sized particles (<2 μ m) and about 20-40% with silt sized particles (2-63 μ m). Our values are lower than that reported for the temperate conditions probably because of hot and humid tropical condition at our experimental site and relatively low silt and clay content in the soil (Table 1). Depending on the C input, MAC was lower by 21-36% in the plough layer. These results showed that addition of organic amendments could lessen the decline in MAC pool.

5.7 Effect of long term manuring on passive pool of soil organic carbon

5.7.1 Humic Acid content

Highest content of humic acid (0.167%)(Table 10) concentration were recorded under 100% NPK+FYM which could be due to improvement of soil properties and favourable environment for the formation of humic substances in this treatment. The lowest humic acid concentration was recorded in control (0.079%). The organic carbon content increased with NPK dose so was the case with HA due to possible association between HA and total organic matter. The decomposition of added residues to contribute parts such as lignin derived phenolic units, carbohydrates or amino compounds yields the building blocks or substrate for humus formation. The addition of organic amendments over a decade resulted in the higher organic carbon content, improved crop growth when compared to unfertilized control. The plots which received 100% NPK+FYM recorded the highest organic carbon content. This might be due to consistent higher yields obtained in this treatment since inception. The relative increase in organic carbon due to FYM addition could be attributed largely to increased return of organic materials and direct

addition of organic matter through FYM along with recommended dose of NPK (Bharadwaj and Omanwar, 1994).

5.8 Relationship among different organic carbon pools and with crop productivity

The observed significant correlations among the pools of C in the soil indicate the existence of a dynamic equilibrium among them. This means that depletion or enrichment in one would change the equilibrium and affect the size of the others. Such relationships, particularly for $\text{KMnO}_4\text{-C}$, WEOC, C_{mic} , LFOC, and CPOC with others were stronger. This emphasizes the importance of monitoring these pools for a better understanding of C preservation in the soil. Considering the prevailing information on the relative strength and weakness (Bronson *et al.*, 1998 and Regmi *et al.* 2002) the linear relationships were drawn between SYI and rice yield and all the pools of SOC (Table 12).

Such relationships for both yield and SYI were strong particularly with RMC, LFOC, HA, C_{mic} , CPOC and $\text{KMnO}_4\text{-C}$. They accounted for as much as 90, 84, 85, 85, 77 and 69 % variability in rice yield and 70, 73, 82, 70, 54 and 65 % variability in SYI. This suggests the importance of these pools of SOC in influencing crop yield, possibly through improving better soil health. Because of low cost and ease of estimation, $\text{KMnO}_4\text{-C}$ can reasonably be used as a good indicator for assessing soil health and its crop productivity.

The mineralization amount of SOC had a significant correlation at $p < 0.05$ level with rice yield ($R^2=0.67$) which can confirm the result of crop yield related to SOC. (Yang *et al.*, 2015). Short term carbon mineralization was better related to $\text{KMnO}_4\text{-C}$, C_{mic} and RMC (fig. 6 & 7) among the labile pool suggesting their role in improving the soil fertility. Again $\text{CO}_2\text{-cum}$ was better related to CPOC ($R^2=89^{**}$) than FPOC ($R^2=0.82^{**}$) (Fig. 8) suggesting that CPOC is more readily decomposable than FPOC and active pool of SOC. Our results contradict with the findings of Duval *et al.*, 2013. Hassink, 1995, also showed the positive relationship between C_{min} with POC. The LFOC content of the soils was strongly correlated to C_{min} ($R^2=0.91$) (Fig. 9) suggesting that LFOC may be an important C and energy source for soil microorganisms. Because the LFOC is not protected by clay minerals (Young and Spycher, 1979) or other

mechanisms, it is readily accessible to microbial and enzyme activity. Furthermore, the LFOC is believed to be comprised of relatively labile constituents, such as carbohydrates (Skjenstad *et al*, 1986) which would further enhance its susceptibility to microbial attack. The influence of LFOC on microbial activity is supported by a positive correlation between LFOC and C_{mic} ($r=0.97^{**}$) (Table 11). However, LFOC exhibited a strong relationship ($R^2=0.91^{**}$) with C_{min} compared to CPOC ($R^2=0.89^{**}$) (Fig 8) and C_{mic} ($R^2=0.89^{**}$) (Fig 7). This implies that LFOC could be a better indicator of labile C than CPOC. Relatively weak relationship ($R^2=0.10$) (Fig 9) of MAC with C_{min} shows that MAC is more stable and thus supports the hypothesis that it may be considered a passive pool of SOC. The significant correlation between CMI and each of the carbon fractions strengthen the suitability of using $KMnO_4$ -C for calculating CMI and reliability of CMI as an indicator for evaluating SOC change.

SUMMARY AND CONCLUSION

Soil organic carbon management has been put forward as one of the mitigating options for global climate change because of the potentiality of agro-ecosystems to absorb a large amount of atmospheric carbon dioxide through soil carbon sequestration. The potential of soil to sequester C, its dynamics and turnover can vary with soil type and climate. Therefore, it is important to determine C dynamics under different climatic regions, in order to draw meaningful conclusions about their contribution (either source or sink) towards global C stock. Therefore it is proposed to study the carbon dynamics, carbon sequestration and its relation with crop productivity. A long term fertilizer experiment (LTFE) with rice-rice cropping system conducted since 2005-06 under the ICAR at Bhubaneswar on a moderately well drained acidic sandy loam soil was used for studying the relative effect of six different manurial treatments (T_1 =control, T_2 =100%N, T_3 =100%NP, T_4 =100%NPK, T_5 =150%N and T_6 =100% NPK + FYM) on carbon sequestering capacity of the soil and carbon dynamics in relation to crop productivity. The present investigation was made on the kharif rice grown during 2014. Soil samples (0–15 cm) were taken after the harvests of kharif rice were analyzed for various physical, chemical and biological soil attributes using standard analytical methods. The data were analysed using randomized block design (RBD). Statistical analysis was performed by Windows based SPSS Programme (vers.14.0, SPSS Inc., 1996). The SPSS procedure was used for analysis of variance (ANOVA) to determine the statistical significance of treatments effect. Duncan's Multiple Range Test (DMRT) was used to compare treatments means. Simple correlation co-efficient and regression equation were also developed to evaluate relationship between the response variables using the same statistical package. The 5% probability level is regarded as statistically significant.

Results revealed that the yield of rice and harvest index have been found to be increased due to different fertilization, being recorded highest yield of rice (48.24 q ha^{-1}) and harvest index (0.436) in the 100% NPK+FYM treatment and 100% NPK treatment respectively. Among the fertilized treatments lowest yield (26.31 q ha^{-1}) as well as

harvest index (0.407) was recorded in 100% N treatment. Application of nitrogen alone @ 80 kg ha⁻¹ increased yield by 34.76% over unfertilized control treatment. Application of phosphorous resulted in 18.28% of more yield over 100% N treatment. Thus the treatments were in the order 100% NPK + FYM > 150% NPK > 100% NPK > 100% NP > 100% N > control. SYI was significantly higher (0.66) in 100% NPK + FYM treatment than other fertilizer treated plot. The unfertilized control plot did not show any sustenance, being the lowest (0.25) among all the treatments. The treatments were in the same manner as observed in the rice yield. The higher and/ or lower amounts of crop residues C inputs into soil was associated with higher and/or lower amount of rice yield under different treatments.

Annual crop mediated C input through left-over stubble at harvest, roots in the plough layer and rhizodeposition ranged between 0.94 to 2.22 Mg ha⁻¹ under different treatments. Application of FYM supplied additional 2.04 Mg C ha⁻¹ in 100% NPK+ FYM treatments.

Cultivation over the years caused a significant decrease in the soil organic carbon content as compared to that in the uncultivated fallow land, excepting with 100% NPK, 150% NPK and 100% NPK + FYM treatments. The magnitude of such decrease was severe in the control (14%) and only N (2.36%) treatments. The balanced fertilization, super-optimal dose of NPK and integration of balanced fertilization with organic manure (FYM), on the other hand increased the content by 17.88%, 27.20 % and 50.62% over the control respectively. On an average, the amount of SOC in different treatments was in the following order 100% NPK+ FYM > 150% NPK > uncultivated soil= 100% NPK > 100% NP > 100%N and control. Organic sources of nutrients decompose slowly resulting in more SOC accumulation in soil.

Due to fertilization SOC stocks did not differ significantly. Use of balance fertilization which involved cumulative carbon input of 1.40 Mg ha⁻¹ increased SOC stocks (9.55Mg ha⁻¹) almost equivalent to the uncultivated soil (9.52 Mg ha⁻¹). Contrarily, cultivation without fertilization reduced SOC stocks by 13. 76 % compared to uncultivated soil. Highest C-sequestration (1.77 Mg ha⁻¹) was observed under 100% NPK+FYM treatment and least under (0.061 Mg ha⁻¹) under 100% N treatment. The

unfertilized control treatment did not show any build up of SOC. The critical cumulative carbon input for zero change in SOC stocks as at the start of the experiment was estimated to be 1.2 Mg ha^{-1} requiring an annual C input of 0.12 Mg ha^{-1} . cultivation was done with an expense of energy for tilling land that affects the distribution and stability of soil aggregates and reduces soil organic C stocks in soil.

The highest C_{\min} (2.18 g kg^{-1}) was observed in 100 % NPK+FYM treatment where lowest (1.08 g kg^{-1}) amount of carbon was mineralized in the unfertilized control. However, balanced fertilization and super-optimal dose of NPK did not differ significantly in respect to carbon mineralization. But there was a significant variation among imbalanced fertilization i.e. 100% N and 100% NP. The amount of cumulative C mineralized under different treatments were in the following order $100\% \text{ NPK+FYM} > 150\% \text{ NPK} > 100\% \text{ NPK} > 100\% \text{ NP} > 100\% \text{ N} > \text{control}$.

Results revealed that C_{mic} content under different treatments varied from $100.22 \text{ } \mu\text{g g}^{-1}$ to $282.18 \text{ } \mu\text{g ha}^{-1}$ with a mean value of $167.79 \text{ } \mu\text{g ha}^{-1}$ constituting 3.4% of soil total organic carbon. The C_{mic} content was greater in 100% NPK+ FYM over the other treatments. The microbial quotient (MQ, C_{mic} as a proportion of total soil organic carbon) also varied widely from 2.53 to 4.74 % under different treatments. Its value was highest (4.74%) in balanced fertilizer treatment along with FYM and lowest value being recorded (2.53%) in unfertilized control. The metabolic quotient or respiratory quotient (the ratio of C_{\min} and C_{mic}) was, however, significantly higher under control and only 100% N vis-à-vis other fertilized treatments, the least value being recorded in the 100% Np, 150% NPK and 100%NPK+FYM treatments. Balanced fertilization with C- supplementation, however, provide a congenial environment for microbial growth and thus caused an increased in soil C_{\min} over that in the control.

Readily mineralizable carbon i.e. K_2SO_4 -extractable carbon ranged from 27.20 to $147.12 \text{ } \mu\text{g g}^{-1}$ and accounted for 0.69 to 2.46 % of the total SOC in the soils under study. The amount of RMC was significantly higher in 100% NPK+FYM than other treatments. WEOC comprised of 2.77 to 6.19 % of total soil organic carbon. The water extractable carbon content varied from 0.11 to 0.37 g kg^{-1} under the present study, being recorded highest (0.37 g kg^{-1}) in the 100% NPK+FYM treatment. KMnO_4 Extractable C was

relatively larger in size and comprised 13.04 to 13.10% of the soil organic carbon content. Application of FYM along with NPK (100% NPK+FYM) showed highest accumulation of $\text{KMnO}_4\text{ C}$ (0.78 g kg^{-1}) while the unfertilized control plot observed lowest value (0.52 g kg^{-1}). CMI value were significantly affected by fertilization. $\text{KMnO}_4\text{-C}$ can be used effectively to monitor the rate of change in SOC and thus has been suggested as an early indicator of the effects of soil managements on SOC quality

FPOC constituted 24.69 to 34.62 % of SOC compared to 17.88 to 30.60 % for CPOC. The proportion of both POC fractions was significantly higher in 100 % NPK+FYM treatment compared to other treatments. A greater amount of C in this pool (POC) was found with the NPK + FYM (3.90 g kg^{-1}) and NPK (3.07 g kg^{-1}) and NPK (3.07 g kg^{-1}) vis- a-vis the others. In respect to mineral associated carbon only 100% NPK+FYM showed the significantly higher (2.61 g kg^{-1}) content compared to all other treatments. Heavy fraction C dominated soil organic carbon content ranging from 32.49 to 50% whereas light fraction was computed only 0.50 to 5.35 % of the soil organic carbon. Humic acid content was ranged from 0.079% to 0.167 %. The content of humic acid increased with increased levels of fertilizer application and ranged from 20 to 72% over control (0.079%). High input of organic matter could increase soil LFOC and its significant relationship with short-term C mineralization suggests that LFOC is a useful indicator of labile C.

Correlation analyses amongst the pool of C showed that all pools were significantly correlated with each other except MAC. The labile pools namely WEOC, $\text{KMnO}_4\text{-C}$, C_{mic} , RMC were significantly and positively related with SOC and other pools but C_{mic} , RMC and $\text{KMnO}_4\text{-C}$ showed the highest correlation. Linear regression best described the relationship of C_{min} with all the fractions. Except MAC all the fractions are strongly and significantly ($p < 0.01$) related with C_{min} . The relationship of C_{min} with POC fractions though significant was lower than with density fractions. The C_{min} was better correlated with CPOC ($r = 0.95^{**}$) than FPOC ($r = 0.90^{**}$). Significant relationships between the SYI and rice yield and all the SOC pools were observed, the relationship being stronger particularly with LFOC, CPOC $\text{KMnO}_4\text{-C}$, C_{mic} , RMC, and WEOC. There was a significant correlation between CMI and each of the C fraction

being strongest with $\text{KMnO}_4\text{-C}$ ($r= 0.98^{**}$) and CPOC ($r=0.90$). The observed significant correlations among the pools of C in the soil indicate the existence of a dynamic equilibrium among them. RMC , LFOC , HA , Cmic , CPOC and $\text{KMnO}_4\text{-C}$ were strongly related with both yield and SYI. They accounted for as much as 90,84, 85, 85, 77 and 69 % variability in rice yield and 70, 73, 82,70, 54 and 65 % variability in SYI. This suggest the importance of these pools of SOC in influencing crop yield , possibly through improving better soil health.

From the entire study following conclusions can be drawn:

- Cultivation with balanced fertilization did not cause any significant depletion of SOC under rice-rice cropping system.
- Differences in C storing capacity and in C partitioning within the plants resulting in difference in root biomass, shoot biomass and amount of root exudates can influence organic matter mineralization and accumulation in soils.
- Under the present cropping system, integrated application of manure and 100% NPK was most effective for improving all the SOC pools along with C sequestering capacity and has to be promoted to maintain long term rice - rice productivity.
- Among the labile pools, microbial biomass carbon, $\text{KMnO}_4\text{-C}$ and Readily mineralisable carbon respond strongly to soil management practices.
- Metabolic quotient was significantly lowest in 100% NPK +FYM to make it the most efficient manuring practice to preserve more organic carbon in soil.
- Various physical fractions of SOC respond differentially to management. The CPOC though represents a small proportion of SOC responds to management to a greater extent than FPOC and may thus be considered a more labile pool of SOC.
- The LFOC is most sensitive to management followed by sand sized HFOC and silt and clay sized MAC pool suggesting that these may be considered to represent active, slow and passive pools of SOC respectively.
- Compared to single measure such as total SOC, CMI can be used as a more sensitive indicator of the rate of change of SOC in response to soil management changes and it can be a useful technique for describing soil fertility. The significant correlation between CMI and each of the C fraction strengthen the reliability of using CMI as an indicator for evaluating SOC change.

- Among the SOC pools, all fractions except MAC explained higher variability in crop yield and SYI, but $\text{KMnO}_4\text{-C}$, CPOC, LFOC and MBC may be used as a good indicator for routine monitoring of soil health in relation to crop productivity and sustainability of the system.
- Over all consideration of the results indicate that of all the treatments tested, balanced fertilization along with adequate amount FYM is most suitable for the continuous rice-rice cropping system in the tropical parts of India for improving the SOC stock and sustaining crop productivity.

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Appendix I: Weather data from June 2014 to December 2014

Week No	Temperature		Sunshine (hr)	Rainfall (mm)	Evaporation	Humidity (%)	
	Max (°C)	Min (°C)				Morning	Afternoon
June							
23	36.9	26.6	7.1	19.1	6.3	89	62
24	39.6	28	7.3	0	6.4	82	46
25	34.4	26	2.5	17.3	5.6	89	67
26	34.8	24.7	2.6	106.1	4.7	92	72
July							
27	31.9	24.4	3.5	51.6	3.4	95	79
28	33.7	25.2	3.8	100.1	2.8	92	79
29	28.8	24.5	0	128	2.6	95	90
30	31.8	24.9	3	12.2	3.2	91	77
31	30.8	24.7	2	151.8	2.2	95	86
August							
32	32.4	24.8	4.6	25.7	3.4	92	77
33	33.5	24.4	3.9	25.2	3.3	93	77
34	34.8	25	5.8	61.6	3.3	94	70
35	31.1	24.4	4.5	164.4	2.4	97	89
September							
36	29.2	23.6	2.4	115.6	2.3	96	81
37	33.6	24.6	5.7	45.2	3.3	94	79
38	30.7	24.4	2.9	116.1	2.7	95	81
39	34.1	24.6	6.8	0	3.4	93	60
October							
40	33.8	23.1	7.1	26.1	3.3	93	63
41	31.2	23.7	5	84.4	3.1	92	74
42	32.5	22.2	7.3	51.6	3	96	62
43	30.6	20.5	5.9	1	3.4	94	62
44	30.4	19.4	6.3	0	3.5	90	51
November							
45	31.1	20.4	6.2	0	3.6	84	52
46	31.8	20.3	6.6	0	3.6	90	47
47	30.1	14.9	8	0	3.6	90	36
48	30.6	14.7	8.6	0	3.5	95	36
December							
49	29.7	14.3	7.5	0	3.6	95	48
50	28.2	16.4	3.2	0	3.5	88	49
51	26.4	11.9	7.2	0	3.6	87	40
52	25.8	12.9	5.9	0	3.7	79	46