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Effect of INM on Soil Carbon Pools, Soil Quality and Sustainability in Rice-Brown Sarson Cropping System of Kashmir Valley

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A B S T R A C T

Integrated nutrient management system (INMS) gained importance not only in increased yield of crops but also in maintaining the soil health and fertility. Keeping these in views a field experiment was conducted at Mountain research centre for field crops Khudwani (SKUAST-Kashmir) during 2013 (in progress since march 2008) to study the Effect of INM on soil carbon pools and soil quality in rice-brown sarson cropping system with different treatment combinations. Significant build-up in soil fertility in terms of alkaline $KMnO_4$-N, Olsen-P, NH_4OAc-K and $CaCl_2$-S as well as SOC pools namely, total organic carbon (TOC), Walkley and Black organic carbon (WBC), labile organic carbon (LBC) and microbial biomass carbon (MBC) were maintained under FYM and integrated nutrient management involving FYM and NPK than unfertilized control plot in 0-15 and 15-30 cm soil depths. Results showed that application of NPK+ FYM significantly increased soil organic matter and available water holding capacity but decreased the soil bulk density, creating a good soil condition for enhanced growth. Microbial population (bacteria, fungi and actinomycetes) were very responsive to organic manure application. The long-term application of organic manures in rice-brown sarson cropping system increased the index value because it increased the nutrient index, microbial index and crop index of soils. The use of only chemical fertilizers in the rice–brown sarson cropping system resulted in poor soil microbial index and crop index. The sustainability index values were 1.00 (the highest for this system) and 0.72, respectively. These results conclude that for sustainable crop production and maintaining soil quality, input of organic manure like FYM is of major importance and should be advocated in the nutrient management of intensive cropping system for improving soil fertility and biological properties of soils.

Introduction

India is second largest rice producer accounting for 20% of global rice production. The crop plays a significant role in livelihood of the people of Jammu and Kashmir State. Although area under rice is very small (0.27 m ha), it plays an important role in the state economy (DRR Hyderabad). The total annual rice production of the state is more than 0.59 million metric tonnes, but continuous rice planting has a negative impact on soil properties, such as reduced soil nitrogen supply and organic carbon content (Doberman and Witt, 2000). Furthermore, because of long-term submergence and mineral fertilizer application, these soils experience degradation of soil quality, such as breakdown of stable aggregation and deterioration of soil organic matter (SOM), which negatively affects agricultural sustainability (Mohanty and Painuli, 2004). On the other hand *brown sarson* is a dominant oilseed crop in Jammu and Kashmir, often grown after rice in rotation. It is popular with the farming community of valley as it fits well on rice-oilseed rotation under temperate climatic conditions.

As agriculture is a soil-based industry that extracts nutrients from the soil, effective and efficient approaches to slowing the pace of nutrient mining by returning the nutrients to the soil will be required in order to increase and maintain crop productivity and sustain agriculture. Maintenance and management of soil fertility is the core for development of sustainable food production systems (Doran *et al.,* 1988). The integrated plant nutrient supply system, by which we can apply the nutrients in balanced form, is emerging as the most logical concept for managing and sustaining long term soil fertility and productivity. INM, which entails the maintenance/adjustment of soil fertility to an optimum level for crop productivity to obtain the maximum benefit from all possible sources of plant nutrients both organics as well as inorganics in an integrated manner (Aulakh and Grant, 2008), is an essential step to address the twin concerns of nutrient excess and nutrient depletion. INM is also important for marginal farmers who cannot afford to supply crop nutrients through costly chemical fertilizers only. Agricultural soil is a potential sink for atmospheric C as soil organic C (SOC), which contributes to the productivity and quality of soils (Kundu *et al.,* 2007). Dynamics of organic C storage in agricultural soils strongly affects global climatic change and crop productivity and yield (Li and Zhang, 2007). Routine applications of inorganic fertilizer and manure are an essential component of soil management in arable crop production systems. These amendments are used primarily to increase nutrient availability to plants, but they can also affect soil microorganisms. The benefits of using organic manure and straw in maintaining soil quality have been increasingly recognised (Chander *et al.,* 1997). Soil microorganisms and the processes that they control are essential for the long-term sustainability of agricultural systems (Wardle *et al.,* 1999) and are important factors in soil formation and nutrient cycling. It has been frequently reported that soil microbial biomass and activity is an important aspect of soil quality (Schloter *et al.,* 2003). Research has shown that soil microbial biomass and activity responds to crop and soil management practices such as organic manure and inorganic fertilizers application (Livia *et al.,* 2005). Numerous reports showed that application of both inorganic and organic fertilizers maintains soil fertility and productivity by improving water holding capacity, porosity, and water stable aggregates and decreasing bulk density and surface crusting. As the application of organic manures brings about structural improvement, it increases the air capacity, may cause the roots to extend into and exploit a larger volume of soil in addition to increasing water retention in the soil profile (Pernes-Debuyser and Tessier, 2004).

Thus, the importance of organic matter in relation to the physical fertility of the soil has been widely recognized (Barzegar *et al.,* 2002). Although organic manure addition and the strengthening of soil biological practices can alleviate nutrient constraints, the problem of soil fertility decline is so serious (Smaling *et al.,* 1997) that it may not be possible to cover all of it with these approaches alone. Chemical fertilizers with instant ability to refurbish depleted nutrients in necessary quantities and forms have come to be recognized as a key component of sustainable soil fertility management and sustainable development of agriculture. Organic matter improves soil aggregation and structure formation (Caravaca *et al.,* 2004) and it mediates many chemical and physical soil properties (Dexter, 1988).

Furthermore, soil organic carbon (SOC) is an important component playing key multifunctional roles in soil quality and determining many soil physical and biological properties (Shen *et al.,* 2004). Sustaining SOC is of primary importance in terms of cycling plant nutrients and improving the soils' physical, chemical and biological properties. SOC is an important index of soil quality because of its relationship with crop productivity (Lal, 1997). A decrease in SOC leads to a decrease in soil's structural stability (Castro Filho *et al.,* 2002). Also restoration of SOC in arable lands represents a potential sink for atmospheric CO_2 (Lal and Kimble, 1997). Agricultural utilization of organic materials, particularly farmyard manure (FYM) has been a rather common traditional practice (Shen *et al.,* 1997), as it enhances the SOC level, which has direct and indirect effect on soil physical properties (Lado *et al.,* 2004). In general, application of organic fertilizers and especially manure, either alone or in combination with inorganic fertilizers, increases SOC concentration (Purakayastha *et al.,* 2008). There is a critical need for the development of best management practices that enhance SOC sequestration. Regular additions of organic materials to soil are required to improve and maintain SOC pools and to help in governing nutrient fluxes, microbial biomass and their activities and improvement in soil physical properties (Marinari *et al.,* 2000). Labile organic carbon is sensitive to soil management practices and thus provides the better management of carbon dynamics in short-term to medium-term effect than total carbon alone. Soil organic carbon refers to the sum total of different heterogeneous organic substances, which may be simply divided into stable and labile organic carbon fractions (Wander, 2004). Stable SOC fractions are relatively resistant to decompose, take longer time to turn-over and do not take part in several nutrient cycling. However, labile SOC fractions are readily accessible source of microorganisms, turn-over rapidly (weeks or months) and have an impact on plant nutrient supply. Labile SOC fractions could indicate changes in soil quality due to management practices more rapidly than measuring changes in the magnitude of total SOC (Ding *et al.,* 2006). Some of the important labile pools of SOC currently used as indicators of soil quality are microbial biomass carbon (MBC), mineralizable organic carbon (Cmin), particulate organic carbon (POC) and $KMnO_4$-oxidizable labile organic carbon (LBC). Highly recalcitrant or passive pool of SOC is very slowly altered by microbial activities and hence hardly serves as a good indicator for judging soil quality. It is now widely recognized that SOC plays an important role in soil biological (provision of substrate and nutrients for microbes), chemical (buffering and pH changes) and physical (stabilization of soil structure) properties. In fact, these properties, along with SOC, N and P, are considered critical indicators of soil health and quality. In particular, the suitability of soil for sustaining plant growth and biological activity is a function of physical (porosity, water holding capacity, structure and tilth) and chemical properties (nutrient supply capability, pH, salt content), many of which are a function of SOM content (Doran and Safley, 1997). Studies have shown that such an increase in SOC levels is directly linked to the amount and quantity of organic residues return to the soils (Rasmussen *et al.,* 1980). Increased sequestration of C in agricultural soils has the potential to mitigate the increase in atmospheric greenhouse gases (Sampson and Scholes, 2006). For studies on soil quality, the evaluation of long term soil fertility experiments provide a good base that cannot be accomplished with the results of typical short-term experiments (Jordan *et al.*, 1995). Long-term experiments provide the best means of studying changes in soil properties and processes over time, and these experiments are important for obtaining information on long term sustainability of agricultural systems to formulate future strategies for maintaining soil health (Swarup *et al.*, 1998).

With this backdrop the proposed study shall be undertaken to evaluate the long term effect of fertilizers along with organics on soil carbon pools in *rice-brown sarson* cropping system under temperate conditions.

Materials and Methods

Experimental site

The experiment was carried out during *rabi* season of 2013 at Mountain Research Centre for Field Crops, Khudwani of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir in a long term experiment initiated in march 2008.It is located at a latitude of 33^o43.260' N and longitude of $75^0$05.803 'E with an altitude of 1650 m above mean sea level.

Experimental design and treatments

The field experiment on rice- brown sarson cropping system consisted of eleven treatments along with a control in a randomized block design with four replications. The treatments selected for this study consisted of:

Soil sampling

Composite soil samples were collected from surface (0-15 cm) and sub-surface (15-30 cm) after harvesting of oilseed and before transplantation of rice (May, 2013). The soil samples were collected by core sampler of diameter 10 cm and all the samples were weighed. The samples were brought to the laboratory, air dried and crushed to pass through 2.0 mm mesh sieve. The processed samples were subjected to appropriate mechanical and chemical analyses to estimate its Physico-chemical status in terms of fertility and effect on carbon pools and sustainability index. The soil is silty clay loam in nature with 11.50% sand, 54.30% silt, 27.80% clay.

Soil organic C fractions

Organic carbon content was determined by wet oxidation method of Walkley and Black (1934).

The Walkley and Black method is based on oxidation of organic matter by $K_2Cr_2O_7$ with H_2SO_4 heat of dilution. Total organic carbon content was computed based on amount of CO_2 evolved.

The amount of oxidizable carbon by $KMnO_4$ (labile carbon) in soil was determined by following the procedure of Blair *et al.*, (1995). Particulate organic matter (POM) was separated from 2-mm soil following the method described by Camberdella and Elliot (1992). The C content in POM was determined following the method of (Snyder and Trofymow, 1984).

Microbial biomass carbon (MBC) was estimated by the chloroform-fumigation incubation method of Jenkinson and Powlson (1976). The amount of CO_2 evolved was determined by back titration with 0.05N HCl. The MBC was computed by subtracting the amount of CO_2 evolved in fumigated soil from that of unfumigated one. A sub-sample of soil was drawn for moisture determination so as to express the data on oven dry weight basis. The amount of the MBC in soil was calculated as follows:

Microbial biomass carbon (MBC) = OCF - OCUF/KEC

Where, OCF and OCUF are the organic carbon extracted from fumigated and unfumigated soil, respectively (expressed on oven dry basis), and KEC is the efficiency of extraction. A value of 0.45 is considered as a general KEC value for microbial extraction efficiency and used for calculation.

Soil physical properties

Soil bulk density of each site was determined by the core method (Blake and Hartge, 1986). Mechanical composition of soil was determined by the international pipette method (Piper, 1966). 1% of sodium hexameta phosphate salt solution was used for chemical dispersion of soil fractions. Each fraction was mechanically stirred for 10 minutes. Sand (0.2-0.02mm) was separated by wet sieving silt (0.02-0.002) and clay (<0.002mm) were separated by decantation and sedimentation. The ISSS textural triangle was used for determining textural class. Soil moisture was determined on an air or oven-dry basis, and therefore must consider the actual soil moisture content (Hesse, 1971).

Soil chemical properties

Soil pH and EC were determined in 1:2.5 soil-water suspensions, using combined electrode for pH and Conductivity Bridge for EC, as per the procedure given by Jackson (1973). Soil was saturated with Na^+ ions by shaking with 1N NaOHAc. After washing the excess salts with alcohol, the adsorbed Na^+ ions were replaced by NH_4^+ using sodium acetate. The CEC was calculated from the amount of Na^+ that had been released from the exchange sites (Jackson, 1973). The alkaline potassium permanganate oxidizable soil N ($KMnO_4$-N) as an index of available N was determined as per the procedure given by Subbiah and Asija (1956). Olsen-P was extracted with 0.5 M sodium bicarbonate (pH 8.5) as outlined by (Olsen *et al.*, 1954) and the P content in the extract was deter-mined using ascorbic acid as reducing agent (Watanabe and Olsen, 1965) by a spectrophotometer. Available K was determined in the neutral normal ammonium acetate extract of soil with the help of flame photometer (Jackson, 1973). While available sulphur ($CaCl_2$-S) was determined by extracting the soil sample with 0.15% $CaCl_2$ (Williams and Steinbergs, 1959). Soil was extracted with DTPA solution for available Zn, Cu, Mn and Fe as outlined by Lindsay and Norvell, in 1978. The DTPA extracting solution consists of 0.005M DTPA + 0.01M$CaCl_2.2H_2O$ + 0.1M triethanolamine (TEA) with pH adjusted 7.3±0.05 and determined by atomic absorption spectrophotometer.

Soil biological properties

Microbial count was determined by serial dilution method (Pikovskaya, 1948). In a viable count technique, the test soil sample was serially diluted and aliquots of selected dilutions were inoculated in a suitable culture media, taken in a sterilized petri plates. Each colony, developed in the culture media, is assumed to have grown from one viable unit which may be one cell or a group of cells of organism. The colony forming units were counted and expressed as cfu/g of soil on a moisture free basis. The isolation was carried out using agar media for bacteria, Rose bengal for fungi and Jensen's media for actinomycetes. This parameter was observed in soil lab at Regional Research Station, Wadura, SKUAST-Kashmir.

Yield parameters

The net area of plot was harvested. The grain yield of each net plot was recorded after thoroughly cleaned and sun dried. The yield from each plot was recorded separately as kg $plot^{-1}$.

Sustainability index

Sustainability index was calculated to assess soil quality under the influence of different fertilizer management practices.

It is based on the area of the triangle in which nutrient index, microbial index and crop index of soil represented the three vertices of a triangle., are represented in radar graph as a, b and c, respectively, which are the three lines of different lengths originating from common point O common point O.

$$\text{Nutrient index} = \frac{1}{n}\sum_{j=1}^{n} I_{ij}$$

$$\text{Microbial index} = \frac{1}{n}\sum_{j=1}^{n} I_{ij}$$

$$\text{Crop index} = \frac{1}{n}\sum_{j=1}^{n} I_{ij}$$

Where, NIi, MIi, CIi is the nutrient index, microbial index and crop index for *ith* treatment and j is the number of parameters considered in deriving nutrient index, microbial index and crop index.

Statistical analysis

For statistical analysis of data, Microsoft Excel (Microsoft Corporation, USA) and CPCS1 window version 32.0 were used. Analysis of variance (ANOVA) The ANOVA is based on three replicate plots per treatment (1984). The significant differences between treatments were compared with the least significance (LSD) at 5% level of probability.

Results and Discussion

Soil carbon fractions

Soil organic C

Walkley and Black method mostly determines both labile and small part of non-labile organic carbon which is the readily accessible source of carbon to micro-organisms and have direct impact on plant nutrient supply. Soil organic C contents changed significantly across the fertilizer treatments (Table 1). The plots that received 50% NPK + 50% FYM (1.76g kg^{-1}) and 50% NPK +50% rice straw (1.62 g kg^{-1}) had significantly higher build-up in WBC over 100% NPK treated (1.54 g kg^{-1}), farmers practice (1.55 g kg^{-1}) and unfertilized control plots (1.21 g kg^{-1}) in the surface soil. The increase in build-up in WBC was 31.2% over control. In case of sub-surface soil, the build-up in WBC under plots receiving 50% NPK+50% FYM fertilizer (1.16 g kg^{-1}) and 50% NPK+50% rice straw (0.99 g kg^{-1} was higher than in the plots receiving only 100% NPK fertilizer (0.87 g kg^{-1}), farmers practice (0.88g kg^{-1}) and in the control (0.58 g kg^{-1}). In general, the values of WBC in sub-surface soils were low compared to surface soil. The organic carbon of soil was significantly affected by nutrient management practices. Under organic and integrated nutrient management practices, there was significant buildup of organic carbon as compared to initial values. This might be because of continuous use of organic manures.

Manure applications sustain a significantly increasing trend in SOC, not only in the humid and semi-humid warm temperate areas with the double cropping system, but also in arid and semi-arid areas with the mono-cropping systems, which is widely documented all over the world (Galantini and Rosell, 2006; Shen *et al.*, 2007). Apparently, manure application is one way to offset the depletion of SOC due to soil organic matter decomposition especially for the dry areas The significantly greater SOC in the fertilized plots over the control may be explained by the greater yield and associated greater amount of root residues and stubbles of all the crops added to the soil (Ghosh *et al.*, 2003). Greater SOC under complete doses of NPK fertilizer as compared to unfertilized soil has also been reported in long-term studies (Swarup and Wanjari, 2000). Kundu *et al.,* (2002) reported that SOC content improved in fertilized plots as compared to the unfertilized plots due to C addition through the roots and crop residues, higher humification rate constant, and lower decay rate. Similarly, in a long-term experiment, Masto *et al.,* (2006) observed that the SOC was considerably greater in soils receiving FYM or straw along with NPK fertilizer than in plots receiving merely NPK fertilizer. In this study, the combination of organic and inorganic fertilization enhanced the accumulation of SOC which is consistent with many other studies (Hao *et al.,* 2008; Banger *et al.,* 2009). Significant increase in SOC in FYM and straw treated plots over control was also reported by Zhang *et al.,* (2010) and Moharana *et al.,* (2012).

Total organic carbon

Application of FYM in combination with NPK resulted in considerable accumulation of total soil organic carbon in 0-15 cm soil layer than unfertilized control plots (Table 1). Soils under the FYM + NPK treated plots resulted in higher total soil organic carbon in the 0-15 cm and 15-30 cm soil layer over those under the NPK treated plots. The TOC in surface soil were in the order of 75% NPK + 25% FYM (4.63 g kg^{-1}) > farmers practice (4.59 g kg^{-1}) > 50% NPK+50% RS (8.50 g kg^{-1}) > 100% NPK (4.33 g kg^{-1}) > unfertilized control (2.75 g kg^{-1}). However, increase in TOC was more in surface as compared to sub-surface soil, which indicate that higher accumulation of organic carbon due to application of FYM was confined to surface soil. The increase in total organic carbon in 75% NPK + 25% FYM treatments in surface layer was 40% greater over unfertilized control. Continuous application of FYM in combination with NPK resulted in considerable accumulation of total SOC in surface as well as sub surface soil layer than unfertilized control plots However, increase in TOC was more in surface as compared to sub-surface soil, which indicate that higher accumulation of organic carbon due to application of FYM was confined to surface soil. This might be due to more turn-over of root biomass in FYM + NPK treatment because of better growth and higher average yields obtained during the study period of both the crops in FYM + NPK treatment. Increase in TOC in optimal and balanced application of NPK is because of greater input of root biomass due to better crop growth. It was supported by the data published by Moharana *et al.,* (2012) who noted. Similar effects of manure and inorganic fertilizer applications on soil organic C has also been reported by Rudrappa *et al.,* (2006).

Labile organic carbon

High fertility significantly increased labile carbon fraction in both surface and sub-surface soils (Table 1). The plots that received 50% NPK +50% FYM treatments showed significant increase in LBC over 100% NPK and unfertilized control treatments in both surface and sub-surface soil depth. However, the highest value of 10.42 mg g^{-1} was observed in 75% NPK +25% FYM treatment in surface soil. The labile carbon in surface soils were in order of 75% NPK+ 25% FYM (10.42mg g^{-1}) > 50% NPK+50% RS (9.28 mg g^{-1}) > farmers practice (8.47mg g^{-1}) > 100% NPK (8.45 mg g^{-1}) > unfertilized control (7.28 mg g^{-1}). Similar trend occurs in sub surface soil depth. The increase in LBC in 75% NPK +25% FYM was 30.7% greater over unfertilized control. Labile soil organic carbon pool is considered as the readily accessible source of microorganisms which turns over rapidly and has direct impact on nutrient supply. Labile soil organic carbon pool generally includes light faction of organic matter, microbial biomass and mineralizable organic matter. The labile organic carbon (LBC) pool or $KMnO_4$ oxidizable carbon is considered as a useful approach for the characterization of SOC resulting from different soil management practices including cropping systems and application of organic and inorganic sources of nutrients. The plots that received with FYM + NPK treatments showed significant increase in LBC over NPK and unfertilized control treatments in both surface and sub-surface soil depth. This may be due to the application of FYM as well as higher turn-over of root biomass because of better growth and yield of rice and rapeseed crops under combined application of FYM + NPK. Greater increase in LBC in combined application of 75% NPK + 25% FYM fertilizer indicate that this pool of soil organic C is more sensitive to change due to manuring and fertilization. Higher turn-over of root biomass under integrated nutrient management (FYM + NPK) also might have attributed to higher increase in this pool as compared to other treatments. Our results are in agreement with the values reported by Rudrappa *et al.,* (2006), Purakayastha *et al.,* (2008), Moharana *et al.,* (2012).

Particulate organic carbon

The INM treatment significantly influenced the POC contents in 0-15 cm soil depth (Table 1). The highest value of 5.39 mg kg^{-1} was observed in 75% NPK + 25% FYM treatment in surface soil. The particulate organic carbon in surface soils were in order of 75% NPK + 25% FYM (5.39 mg kg^{-1}) > farmers practice (4.40mg kg^{-1}) > 50% NPK + 50% RS (4.20 mg kg^{-1}) > 100% NPK (4.17 mg kg^{-1}) > unfertilized control (3.58 mg kg^{-1}). Similar trend was recorded in sub surface soil depth. There was 33.5% increase in particulate organic carbon over control due to integrated nutrient management. Particulate organic C makes up a large portion of the light fractions of SOC (Camberdella and Elliott, 1992). The POM is often separated densimetrically and is comprised of plant residues as well as microbial and micro faunal debris including fungal hyphae and spores (Janzen *et al.,* 1992). Therefore, POC is composed of a large proportion of relatively labile organic materials, often of recent origin. Application of FYM along with N-P-K (NPK + FYM) resulted in a significant positive built up of POC over NPK at different locations at all soil depths. Similarly, substitution of 50% N through CR or GM to rice also recorded significantly higher POC concentration over NPK at all locations in 0-15 and 15-30 cm soil depths only. The increase in POC in fertilized plot was mainly being due to increased yield trend in this treatment over past years. The additional amounts of organic C input from organics in the treatments received NPK along with organics further enhanced the POC contents in these treatments. The main source of POC in this study was mainly the left over root biomass and increased microbial biomass debris. Our results corroborate the findings reported by (Purakayastha *et al.,* 2008; Nayak *et al.,* 2012).

Microbial biomass carbon

It is evident that the MBC contents in both surface and sub-surface soil were significantly higher in plots receiving 75%NPK + 25%FYM compared to 100% NPK fertilizer and unfertilized control plots (Table 1). The values of MBC in surface soil varied from 208.1 mg kg^{-1} in unfertilized control plot to 230 mg kg^{-1} in integrated nutrient use of 75% NPK+ 25% FYM plots, respectively; while it varied from 206 mg kg^{-1} (control) to 225 mg kg^{-1} (75%NPK + 25%FYM) in sub-surface soil. There was 10.4% increase in MBC in 75%NPK + 25%FYM treatment over unfertilized control. The microbial biomass carbon (MBC) is an important component of the SOM that regulates the transformation and storage of nutrients.

The soil MBC regulates all SOM transformations and is considered to be the chief component of the active SOM pool. It is evident that the MBC contents in both surface and sub-surface soil were significantly higher in plots receiving 75% NPK+ 25% FYM and FYM treated plots compared to NPK fertilizer and unfertilized control plots Continuous application of FYM along with N-P-K (NPK + FYM) resulted in a significantly higher soil MBC over control. In our study, MBC was highest in the FYM plus inorganic fertilizer treatment. The increase of MBC under FYM amended soils could be attributed to several factors, such as higher moisture content, greater soil aggregation and higher SOC content. The FYM amended plots provided a steady source of organic C to support the microbial community compared to NPK treated plots. Generally, FYM applied to soil has long been employed to enhance favourable soil conditions. Decomposition of manure in soil releases essential nutrients such as N, P and S that are required by microorganisms. The highest value of MBC due to integrated use of FYM and NPK fertilizer might be due to higher turn-over of root biomass produced under FYM + NPK treatment. Similar increases in integrated nutrient management with manure + fertilizer have been reported by others (Moharana *et al.*, 2012; Nayak *et al.*, 2012). In a long-term field experiments in Denmark, Powlson *et al.*, (1987) showed that straw manure could increase MBC up to 45%.

Soil physical properties

Soil bulk density

On the perusal of data from table 2 it is evident that soil bulk density differed significantly due to INM. The maximum bulk density was recorded in inorganic treatment and the minimum was recorded 50%NPK + 50%FYM treatment. The bulk density of the experimental soil varied from 1.08 to 1.19g cm^{-3} in the 0 to 15 cm soil layer. The decrease in bulk density was greater in the soil depth of 0 to 15 cm. The bulk density of soil increased with depth (15 to 30 cm).There was 5.04% decrease in bulk density. The decrease in bulk density in the treatments which were treated with different organic manures might be due to improvement of structural status of soil by judicious application of bulky organic manures and fertilizers. The addition of FYM promotes the total porosity of the soils as the microbial decomposition products of organic manures such as polysaccharides and bacterial gums are known to act as soil particle binding agents. These binding agents increase the porosity and decrease the bulk density of the soil (Bhatia and Shukla, 1982) by improving the aggregation. This increase in bulk density has been attributed to the deterioration of the structure with N fertilizers when applied alone or in combination with other inorganic fertilizers. The decrease in bulk density was greater in the soil depth of 0 to 15 cm. The bulk density of soil increased with depth 15 to 30 cm, varying from 1.18 to 1.30 g cm^{-3} in all the treatments. These results are similar to those reported by Walia *et al.,* (2010), Nayak *et al.,* (2012), Datt *et al.,* (2013), Tadesse *et al.,* (2013).

Available moisture content

On the perusal of data from table 2, it is evident from the table that the available water content did not differed significantly. It was numerically lowest in the control and was numerically higher in the integrated nutrient management treatments than rest of the treatments. Increased in organic matter content which resulted in the improvement in stable soil aggregates and macro and micro pore spaces resulted in an increase in free movement of water within the soil that might have increased the available water content of the soil. Similar results were also reported by

Walia *et al.,* (2010) and Tedesse *et al.,* (2013). A similar experiment on sorghum crop in the north-eastern part of the country demonstrated that the soil water content was significantly improved with FYM application than the control (Bayu *et al.,* 2006). Organic matter not only increases the available water of the soil but also increases the available water for plant growth

Soil chemical properties

Soil pH and EC

The nutrient management practices did not differ with respect to soil pH and EC (dS/m) (Table 3). The soil pH ranged from 6.05 to 6.52 in different treatments in the 0-15 cm soil depth and from 6.70 to 6.90 in the 15-30 cm depth. The soil EC ranged from 0.05 to 0.13 dS/m. The results were in conformity with the study conducted by Sridevi *et al.,* (2000), Tolanur and Badanur (2003) who found that neither residue nor fertilizer treatments had significant influence on soil pH and EC values. Our results are also in conformity with the results reported by Ayoola and Titilola (2006), Katkar *et al.,* (2011), Kannan *et al.,* (2013).

Cation exchange capacity

CEC differed significantly among various treatments (Table 3). It varied from 8.43 in control to 9.42 cmol (p+) kg^{-1} in 75% NPK + 25% FYM treatments. The values were significantly higher in INM than inorganic treatments.

The organic treatments contained significantly higher values than control. This might be due to release of cations with the decomposition of organic matter which would have increased the CEC and due to more exchange sites on humus. Similar results were obtained by Ayoola and Titilola (2006) and Datt *et al.,* (2013).

Available N

The available nitrogen content of soil differed significantly between different treatments (Table 4). The available N was significantly high in integrated nutrient management practice. Significant increase in available N in surface soil (0-15 cm) was maintained in plots receiving 50%NPK + 50%N (rice straw) (330.62 kg N ha^{-1}) and integrated use of 75%NPK + 25%FYM fertilizer (294.66 kg N ha^{-1}) over NPK treated (250.93 kg N ha^{-1}) and unfertilized control plots (242.40 kg ha^{-1}). However, increases in N in sub-surface soil (15-30 cm) was observed only in the plots receiving 50%NPK+ 50% rice straw and 75%NPK+ 25%FYM fertilizer over unfertilized control. Increase in N in surface soil was 26.6 and 17.7 per cent in 50%NPK + 50% rice straw and NPK +FYM fertilizer treated plots over control, respectively. There was 26.6% increase in available N over control. However, application of fertilizers and manures resulted in significant improvement in the buildup of the available N content of subsurface soil. So, it is clear that application of organic manures in conjunction with chemical fertilizers increased the available N in soil is attributed to the increase in total SOC that might have been partially due to a slow release of N from straw and manure as suggested by Yadav *et al.,* (2000), Gami *et al.,* (2001) and Bhandari *et al.,* (2002). Farmyard manure and straw is known to stimulate biological N_2 fixation in the soil, which may also have been responsible for the increase in soil N (Ladha *et al.,* 1989) over NPK treatment, apart from FYM's own N contribution. In addition, soils under NPK + FYM and Rice straw treated plots produced more biomass and, therefore, possibly had more extensive root systems that may have contributed to increased N levels It might be due to fact that integration of organic and chemical fertilizer has increased the mineralization owing to narrow C/N ratio as compared to organic treatments. It is evident from this study that higher values of N were observed in surface soil as compared to subsurface soil irrespective of the treatments. This might be due to higher organic carbon content observed in surface as com-pared to sub-surface soil. The results are corroborated with the findings of Walia *et al.*, (2010), Moharana *et al.*, (2012), Datt *et al.*, (2013).

Experimental design and treatments

Treatment	Rice (SR-1)	Brown sarson (KS-101)
T_1	Control	Control
T_2	50% NPK	50% NPK
T_3	50% NPK	100% NPK
T_4	75% NPK	75% NPK
T_5	100% NPK	100% NPK
T_6	50% NPK + 50% FYM	100% NPK
T_7	50% NPK + 50% FYM	50% NPK
T_8	75% NPK + 25% FYM	75% NPK
T_9	50% NPK + 50% N (Rice straw)	100% NPK
T_{10}	50% NPK + 25% N (Rice straw)	75% NPK
T_{11}	Farmers practice (60-80 kg N+30-40 kg P_2O_5+5-10 t FYM)	Farmers practice (30-40 kg N+40 P_2O_5+5t FYM)

The NPK dose was applied through urea, DAP and MOP. FYM and rice straw applied were 36.6 and 46% total carbon. On an average farmyard manure contained 0.60% N, 0.15% P and 0.54% K.

Table.1 Long term effect of INM on soil carbon pools

Treatments	0-15 cm					15-30 cm				
	OC	**TOC**	**LBC**	**POC**	**MBC**	**OC**	**TOC**	**LBC**	**POC**	**MBC**
T_1	1.21	2.75	7.28	3.58	208.1	0.58	2.22	7.02	3.16	206.3
T_2	1.31	3.17	8.20	3.81	214.9	0.63	3.03	7.85	3.21	208.0
T_3	1.33	3.56	8.22	3.84	218.6	0.69	3.32	7.83	3.42	210.6
T_4	1.38	3.72	8.31	4.00	221.3	0.75	3.60	8.09	3.83	216.0
T_5	1.54	4.33	8.45	4.17	226.5	0.87	3.90	8.19	3.89	217.3
T_6	1.76	4.59	10.07	5.27	228.0	1.16	4.19	9.13	4.59	225.3
T_7	1.73	4.34	9.82	5.27	228.0	1.02	4.09	9.11	4.56	224.0
T_8	1.75	4.63	10.42	5.39	230.3	1.14	4.36	9.46	4.77	225.3
T_9	1.62	4.22	9.28	4.18	219.7	0.99	4.04	8.62	3.97	219.3
T_{10}	1.57	4.09	8.45	4.20	219.3	0.89	3.83	8.29	3.86	217.6
T_{11}	1.55	4.59	8.47	4.40	224.0	0.88	4.32	8.29	4.04	217.3
$CD_{(P<0.05)}$	**0.22**	**0.272**	**0.408**	**0.095**	**8.93**	**0.19**	**0.094**	**0.183**	**0.275**	**11.29**

(OC: organic carbon (g/kg), TOC: total organic carbon (g/kg), LBC: labile carbon (mg/g soil), POC: particulate organic carbon (mg/kg soil), MBC: microbial biomass carbon (mg/g soil)

Table.2 Long term effect of INM on soil physical properties

Treatments	0-15 cm		15-30 cm	
	Bulk density	**Moisture content**	**Bulk density**	**Moisture content**
T_1	1.19	24.53	1.30	21.53
T_2	1.17	27.63	1.27	22.23
T_3	1.17	28.33	1.28	23.10
T_4	1.15	28.36	1.27	22.53
T_5	1.19	27.73	1.32	24.20
T_6	1.13	29.90	1.19	26.33
T_7	1.16	29.56	1.18	26.86
T_8	1.08	30.20	1.18	25.63
T_9	1.12	28.90	1.27	24.20
T_{10}	1.10	28.73	1.24	23.10
T_{11}	1.14	29.70	1.30	24.53
$CD_{(P<0.05)}$	**0.312**	**NS**	**0.864**	**NS**

Table.3 Long term effect of INM on soil chemical properties

Treatments	0-15 cm			15-30 cm		
	pH	**EC**	**CEC**	**pH**	**EC**	**CEC**
T_1	6.15	0.05	8.43	6.70	0.02	8.73
T_2	6.48	0.08	8.80	6.72	0.05	8.87
T_3	6.29	0.05	8.99	6.74	0.10	8.86
T_4	6.13	0.06	9.01	6.81	0.01	8.60
T_5	6.34	0.07	9.04	6.90	0.02	8.78
T_6	6.33	0.13	9.16	6.88	0.10	9.17
T_7	6.22	0.05	9.32	6.97	0.03	9.05
T_8	6.40	0.06	9.42	6.80	0.02	8.97
T_9	6.05	0.09	9.16	6.75	0.01	9.01
T_{10}	6.40	0.07	9.05	6.73	0.12	8.92
T_{11}	6.52	0.08	9.12	6.71	0.05	8.94
$CD_{(P<0.05)}$	**NS**	**NS**	**0.216**	**NS**	**NS**	**0.236**

Table.4 Long term effect of INM on soil nutrient status

0-15cm

Treatments	**N**	**P**	**K**	**S**	**Zn**	**Cu**	**Fe**	**Mn**
T_1	242.40	22.41	134.40	14.56	1.62	5.94	83.50	77.99
T_2	244.37	32.10	136.26	16.60	1.69	6.43	83.73	78.78
T_3	248.70	34.30	147.46	17.53	1.69	6.62	84.30	79.50
T_4	250.90	35.82	154.93	18.20	1.71	6.54	85.54	80.35
T_5	250.93	38.14	164.56	19.33	1.80	6.57	85.50	80.42
T_6	271.80	46.96	220.26	22.30	2.03	6.82	90.04	82.11
T_7	282.20	44.96	196.00	22.56	1.99	6.78	88.06	81.42
T_8	294.66	50.70	261.33	21.43	2.00	6.91	90.33	82.55
T_9	330.62	41.50	173.56	20.73	1.89	6.79	86.26	81.82
T_{10}	313.56	43.33	173.30	21.96	1.85	6.68	88.25	80.64
T_{11}	271.82	45.54	158.66	19.76	1.81	6.68	86.25	79.56
$CD_{(P<0.05)}$	**15.31**	**4.59**	**15.53**	**3.11**	**0.30**	**0.31**	**4.42**	**3.25**

15-30cm

Treatments	N	P	K	S	Zn	Cu	Fe	Mn
T_1	181.65	18.37	85.86	10.40	0.97	2.88	64.66	45.87
T_2	198.61	27.62	95.20	11.83	1.06	2.94	65.41	48.34
T_3	207.30	27.64	97.06	14.56	1.13	3.24	74.53	49.69
T_4	209.73	34.77	110.13	16.00	1.18	3.42	73.03	55.80
T_5	221.49	35.44	112.80	16.00	1.24	3.06	75.01	58.99
T_6	233.97	42.37	121.33	18.60	1.52	3.45	81.86	70.98
T_7	250.88	40.80	130.66	19.76	1.56	3.83	75.48	62.49
T_8	231.94	47.16	134.40	18.46	1.70	4.02	85.73	75.54
T_9	303.14	39.59	113.86	16.70	1.45	3.45	76.40	62.62
T_{10}	271.98	36.33	102.66	16.56	1.48	3.28	77.52	60.73
T_{11}	229.97	43.06	105.53	16.56	1.30	3.13	75.01	60.29
$CD_{(P<0.05)}$	**19.39**	**4.99**	**10.27**	**2.83**	**0.16**	**0.32**	**6.55**	**5.12**

Table.5 Long term effect of INM on total bacterial, fungi and actinomycetes (*10^5cfu g^{-1}soil)

Treatments	Bacteria	Fungi	Actinomycetes
T_1	51.33	51.66	43.00
T_2	54.33	53.33	45.66
T_3	57.00	56.00	48.00
T_4	61.00	57.00	51.00
T_5	61.00	59.66	49.33
T_6	66.00	69.66	54.00
T_7	67.00	67.66	54.00
T_8	68.66	71.33	57.33
T_9	59.66	66.00	51.00
T_{10}	60.66	64.33	53.00
T_{11}	65.66	70.66	56.33
$CD_{(P<0.05)}$	**3.00**	**2.11**	**3.57**

Table.6 Yield of crop

Treatments	yield
T_1	47.56
T_2	60.96
T_3	64.04
T_4	69.45
T_5	74.12
T_6	78.69
T_7	76.73
T_8	72.81
T_9	67.3
T_{10}	65.81
T_{11}	70.01
$CD_{(P<0.05)}$	**7.35**

Table.7 Sustainability index

Treatments	NUTRIENT INDEX	MICROBIAL INDEX	CROP INDEX	SUSTAINABILITY INDEX
T_1	72.85	88.52	47.56	0.72
T_2	74.95	92.05	60.96	0.80
T_3	77.51	94.9	64.04	0.83
T_4	79.24	97.57	69.45	0.86
T_5	80.9	99.12	74.12	0.89
T_6	92.79	106.33	78.69	0.96
T_7	90.49	104.16	76.73	0.95
T_8	101.23	104.99	72.81	1.00
T_9	92.89	99.09	67.3	0.87
T_{10}	91.19	99.32	65.81	0.86
T_{11}	83.6	104.16	70.01	0.96
$CD_{(P<0.05)}$	**0.16**	**0.32**	**6.55**	**5.12**

Available phosphorus

Significantly greater amount of Olsen-P in surface soil was maintained in all the treatments receiving manure and fertilizer applied either alone or in combination over unfertilized control plot (Table 4). The build-up of Olsen-P in surface soil (0-15 cm depth) was 36.58, 35.17, 34.62 and 28.08 kg P ha^{-1} in plots receiving 75%NPK + 25%FYM, 50% NPK + 50% FYM, Farmers practice and 100% NPK respectively as against 20.41 kg P ha^{-1} in unfertilized control plot. The Olsen-P increased by 44.2% over unfertilized plot. Significant differences were found in sub-surface soil. The addition of FYM and Rice straw to the soil helped in increasing the available P in the soil by mineralization or solubilising of the native P during decomposition of organic matter. Continuous application of FYM also reduced the activity of polyvalent cations such as Ca, Fe, and Al due to chelation which, in turn can be considered responsible for reduction in P-fixation (Gupta *et al.,* 1988). The application of FYM increased Olsen-P because of its P content, and possibly by increasing retention of P in soil. These results were similar to the results reported by Ayoola and Titilola (2006), Walia *et al.,* (2010), Moharana *et al.,* (2012), Datt *et al.,* (2013), Tadesse *et al.,* (2013).

Available potassium

The nutrient management practices had a significant effect on available K in soil. Available K levels increased in the plots receiving manure or straw. The NH_4OAc-extractable-K (NH_4OAc-K) showed significant changes at both the depths in different treatments. The NH_4OAc- K content of soil under different treatments varied from 134.40 to 261.33 kg ha^{-1} in surface soil and from 85.86 to 134.40 kg ha^{-1} in subsurface soil (Table 4). Plots that received with 75% NPK + 25%FYM maintained significantly highest amount of NH_4OAc-K (261.33 kg ha^{-1}) followed by 50%NPK + 50% rice straw (173.56 kg ha^{-1}), 100%NPK (164 kg ha^{-1}) and control (134.40 kg ha^{-1}) in surface soil (0-15 cm). Similar trend in NH_4OAc-K due to different treatments was found in sub-surface soil. However, the levels of NH_4OAc-K content were lower in sub-surface than surface soil. There was 48.5% increase in available K over unfertilized control. The increase in available K content of soil may be ascribed to mineralization of organic sources and solubilization from native sources during their decomposition. The buildup of available potassium in soil might have been beneficial effect of organic manures in releasing potassium due to the interaction of organic matter with clay and direct addition of potassium to the available pool of soil. Application of FYM and rice straw resulted in an increase in K due to more release of non-exchangeable K from the soil as FYM increased soil cation exchange capacity, which might have resulted in increased K and its utilization by crops (Blake *et al.,* 1999), besides FYM's own K supply. Considerable build-up of K under FYM + NPK and rice straw treatment in a long-term fertilizer experiment was reported by others (Liu *et al.*, 2010). The significant buildup of available K with the application of organic manures was also reported by others (Ayoola and Titilola, 2006; Walia *et al.*, 2010; Katkar *et al.*, 2011; Moharana *et al.*, 2012; Datt *et al.*, 2013).

Available sulphur

The available S content in surface soil (0-15 cm) was significantly higher in 50%NPK + 50%FYM treatment (22.56 kg ha^{-1}) followed by 50%NPK + 50%rice straw (21.96 kg ha^{-1}) and least in unfertilized control plot (14.56 kg ha^{-1}) (Table 4). The increase in Available S in 0-15 cm soil depth was 35.4 and 33.6% in 50%NPK + 50%FYM and 50%NPK + 50% rice straw treated plots over control. Similar trend was found in sub surface soil.). There was reduction in available sulphur content of soil in treatment with inorganic fertilizers alone. It might be due to lower organic carbon content of soil and continuous removal of sulphur by crops. Increase in available sulphur might be due to addition of manures which after mineralization add to the soil sulphur pool. This increase is attributed to the accretion of sulphur through FYM application. Sarkar *et al.,* (1998) reported that application of various organic sources like compost, FYM, green manure and crop residues can supply adequate quantities of sulphur to crops. Sharma *et al.,* (2001) revealed that integrated use of organic and inorganics improved sulphur status of soil over control. These results are in agreement with the observations reported by Katkar *et al.,* (2011), Moharana *et al.,* (2012).

DTPA extractable micronutrients

The perusal of data indicate that DTPA extractable micronutrient contents increased significantly over control in all the treatments in both surface and sub-surface (Table 4). In integrated nutrient management practice, the DTPA extractable Zn and Fe was found significantly higher in treatment with 50%NPK + 50%FYM (2.03 and 90.04 mg kg^{-1}, respectively) than inorganic nutrient management 100% NPK (1.80 and 85.54 mg kg^{-1}) and control (1.62 and 83.50 mg kg^{-1}). Similarly DTPA extractable Mn and Cu was significantly higher in 75% NPK + 25% FYM (82.55 and 6.91 mg kg^{-1}, respectively) and was found superior over inorganic 100% NPK (80.42 and 6.57 mg kg^{-1}, respectively) and control (77.59 and5.94 mg kg^{-1}, respectively). Similar results were found for sub surface soil.

The data showed that DTPA extractable Zn in treatments with only fertilizer, including the control, tended to decrease. This may be attributed to the higher uptake of Zn associated with the additional dose of N. However, among different organic sources, FYM resulted in significantly higher Zn content of the soil (2.03 mg kg^{-1}) followed by Rice straw (1.89 mg kg^{-1}). This may be ascribed to the better supply of Zn from these sources The DTPA increase in the Fe status of soil over its initial status may be due to the induced submerged conditions and lowering of pH of the soil during the rice growing season, thereby resulting in an increase in the soluble Fe^{2+} ions in the soil (Alexander, 1961). The maximum DTPA-extractable Fe (90.3 mg kg^{-1}) resulted from application of 25% of recommended N through FYM as an additional dose. Further, among the different organic sources, application of FYM in treatments registered higher DTPA-extractable Mn compared to the application of 100% of the recommended NPK dose (T_5).

An increase in DTPA-extractable Mn may be attributed to the reduction of Mn^{4+} to Mn^{2+} accompanied by an increase in its solubility under submerged conditions and the chelating action of organic manures. Among different treatments that showed the slight increase in the Cu content (5.64 to 6.91mg kg^{-1}) it was most observed in the organic manured plots as compared with the control plot This increase in available Cu contents may be ascribed to reduction in the redox-potential of the soil with the addition of FYM and rice straw which led to more release of micronutrients in an available form in the soil as compared with the application of chemical fertilizers alone.

The increase in DTPA-extractable Cu may be attributed to the chelating action of organic compounds released during decomposition of FYM and Rice straw which increased availability of micronutrients by preventing fixation, oxidation, precipitation and leaching.

In general the increase in available micronutirents status of soil in organically treated plots might be due to direct addition of micronutrients to soils and release of chelating agents from organic matter decomposition which might have prevented micronutrients from precipitation, oxidation and leaching (Sharma *et al.*, 2001). Similar results were reported by Hau and Chang (2002), Harish Kumar (2003), Patil (2006), Walia *et al.,* (2010).

Soil biological properties

Total viable bacteria, fungi and actinomycetes

Population of bacteria in soil after the harvest of crop was increased significantly due to application of different levels of organic and inorganic sources of nutrients either alone or in combination (Table 5). The highest population of bacteria was recorded with 75% NPK + 25% FYM (68.6×10^5 cfu/g) followed by farmers practice (65.6×10^5 cfu/g). Application of inorganic and organic source of nutrients in combination influenced the population of fungi. In general, treatments with NPK + FYM recorded highest population. The maximum population of fungi was noticed with 75% NPK + 25% FYM (71.3×10^5 cfu/g).

The lowest population of fungi was observed in the treatment unfertilized control (51.6×10^5 cfu/g). Population of actinomycetes in soil after the harvest of crop was increased significantly due to application of different levels of organic and inorganic source of nutrients either alone or in combination. The treatments with combination of organic and inorganic source of nutrients recorded more population of actinomycetes than 100% NPK and control. The maximum population was noticed with 75% NPK + 25% FYM (57.3×10^5 cfu/g) The treatments with 50%NPK + 50%rice straw and farmers practice recorded 53×10^5 and 56×10^5 cfu per g, respectively.

The lowest population of actinomycetes was observed in the unfertilized control (43×10^5 cfu/g). The increase in microbial population (bacteria, fungi and actinomycetes) with the incorporation of organics (FYM and Rice straw) have been due to the improvement of hydrothermal regime and supply of large amount of carbon during the decomposition (Badiyala *et al.,* 1990). In a long-term application of inorganic fertilizer in combination with organic manures, increased microbial population was observed over the control (Sharma *et al.,* 1983). Higher levels of microflora may be ascribed to microbial decomposition of organic manures. The increase in the microbial populations of the soil under organic amended treatments may be ascribed to the decomposition of FYM and Rice straw as well as improvement in physical conditions of the soil, resulting in the better growth of micro-organisms. Among the microbes, bacterial population was highest as compared to fungal and actinomycetes it may be due to their high multiplication rate This finding is in accordance with the findings of Walia *et al.,* (2010), Ndubuisi-Nnaji *et al.,* (2011), Zak *et al.,* (2011), Meena *et al.,* (2013).

Yield parameters

The highest productivity of rice (78.69 kg ha^{-1}) was recorded with the application of farmyard manure at 50% NPK + 50% FYM. This was significantly higher than 100% NPK (Table 6). The highest grain and straw yields were obtained in integrated treatment (FYM + NPK) and lowest in control. This showed the superiority of integrated nutrient management over either fertilizers or FYM. The highest grain yield recorded under the application of inorganic sources of nutrient may have been due to the immediate release and availability of nutrients as compared to organic sources of nutrient, which release the nutrient slowly. Combined use of organic and inorganic sources of nutrient could be attributed to better synchrony of nutrient availability to the wheat crop, which was reflected in higher grain yield and biomass production and also the higher nutrient use efficiency. The higher wheat yield obtained on FYM + NPK fertilizer-treated plots was possibly caused by other benefits of organic matter such as improvements in microbial activities, better supply of secondary and micronutrients which are not supplied by inorganic fertilizers, and lower losses of nutrients from the soil besides supply of N, P and K (Yadvinder-Singh *et al.,* 2004). The improved soil physical properties in the FYM-treated plots as observed in the present study might have also contributed to the improvement in crop yields. The present results corroborate the findings of other workers – Liu *et al.,* (2010), Moharana *et al.,* (2012), Datt *et al.,* (2013), Kannan *et al.,* (2013).

Sustainability index

In this experiment, the treatment with farmyard manure (75% NPK + 25% FYM) added to soil was the most sustainable for the rice- oilseed system. On the contrary, the 100% NPK treatment was unsustainable for the same cropping system (Table 7). The nutrient indices, microbial indices and crop indices were highest in the treatment in which 75% NPK + 25% FYM was used with a sustainability index of 1.0. In the 100% NPK treatment, nutrient, microbial and crop indices were low making soils unsustainable. The control soil was characterized by the lowest indices. The lack of sustainability of the inorganic fertilizer treated plots was due to the low microbial and crop indices. On the contrary, the application of farmyard manure that increased the soil organic matter content gave higher nutrient, microbial and crop indices than the application of inorganic fertilizers, thus making the system more sustainable (sustainability index of 1.00) The results indicated that soil organic matter content and soil microbial activities, vital for the nutrient turnover and long-term productivity of the soil, are enhanced by balanced application of nutrients and manure The data support the conclusion that, wherever feasible and practical, application of FYM is important to soil C sequestration and improving soil quality. Our results were in collaboration with the results reported by Maria *et al.,* (2002), Kang *et al.,* (2005), Liang *et al.*, (2011).

Thus, it could be concluded that long-term application of farmyard manure in combination with NPK to Rice and brown sarson cropping system significantly improved the soil physico- chemical and biological properties as well as productivity of sorghum and wheat. Higher addition rates of organic manure benefited more prominent increase in the total SOC and its various C fractions. Manure and straw application had beneficial effects on SOC, LBC, POC, MBC concentration, total SOC stocks. Neither organic sources alone nor mineral fertilizers can achieve sustainability in crop productivity under intensive cropping sequence, where nutrient turnover in soil plant system is much higher. Conjoint and judicious use of organics and mineral fertilizers found promising in long run.

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