Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 6 Special issue [1] 2017: 360-364

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804
NAAS Rating 4.95
FULL LENGTH ARTICLE **OPEN ACCESS**

Long-term effect of organic manures and fertilizers on soil fertility and soil carbon management index after 16 years cycles of pearl millet–wheat cropping system in an Inceptisol of subtropical India

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ABSTRACT
A study was under taken in a long-term experiment on effect of organic manures and nutrient management on soil fertility and soil organic carbon (SOC) after 16 years cycles of pearl millet–wheat cropping system in an Inceptisol of subtropical India. The highest values of TOC (13.2 g kg^{-1}), WBC (11.2 g kg^{-1}) and LBC (1.22 g kg^{-1}) were maintained in 15 Mg FYM + 150 kg N ha^{-1}+30 Kg P_2O_5 ha^{-1} treated plot. The magnitude of change in WBC sub-surface (15–30 and 30-45 cm) soil was low as compared to surface soil (0–15 cm). Significant increase in all the pools of SOC from the FYM treated plots indicates the importance of application of organic manure like FYM in maintaining organic carbon in soil. Highly strong relationships were exhibited between LBC with yield, indicating that these pools are more important for nutrient turn-over and their availability to plants than total SOC. Carbon management index revealed that integrated nutrient management could be followed for enhancement of crop productivity, nutrient availability and soil carbon pools for long-term. 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.
***Key words**: LTFE, SOC, Wheat, Carbon management index*

Received 09.0.2017 Revised 19.08.2017 Accepted 23.08. 2017

INTRODUCTION

In most south Asian countries, degradation of soil organic matter (SOM), soil structure and associated nutrient supply are major factors for yield decline in intensive cereal based cropping system (Ladha et al., 2003; Mulvaney et al., 2009). In general, organic manure combined with inorganic fertilizer exerted greater influence on topsoil C storage and crop yield than chemical fertilizer alone (Ding et al., 2012). The use of inorganic fertilizers in combination with organic manures has been found more advantageous than either of them on their own for sustainable agriculture for long-term basis (Narwal and Antil 2005; Antil et al., 2011). Application of FYM increased the organic C, macro and micronutrient content of soil (Chaudhary and Narwal, 2005); organic C pools (Ranjan laik, 2002) and N balance in soil (Antil et al., 2011). Temperature and rainfall are important factors controlling soil organic matter turnover and understanding how these parameters affect SOC stocks (Haddix et al., 2011). Understanding the temperature sensitivity of SOC decomposition is challenging because soil organic matter is composed of many different compounds with different inherent kinetic properties (Davidson and Janssen, 2006). Continuous application of organic manure alone or in combination with inorganic fertilizer enriched the soil with total OC (Geeta Kumari et al., 2011). The active pools generally contribute about 10-20% towards totals soil organic matters, whereas the stable or passive pools have 50-90% contribution towards total soil organic matters (Brady and Weil, 2002). Application of organic manure, either alone or in combination with mineral fertilizers, is more effective in increasing soil organic matter and its fractions than mineral fertilizers alone (Wu et al., 2004; Blair et al., 2006; Rudrappa et al., 2006; Purakayastha et al., 2008). Therefore, there is need for studying the carbon management index (CMI) at present situation of long-term experiments due to the climatological changes and continuous intensive cropping sequences.

MATERIALS AND METHODS

An ongoing long-term field experiment with pearl millet-wheat cropping sequence which was established in 1995 on a coarse loamy, Typic Ustochrept soil at CCS Haryana Agricultural University, Hisar, India was selected to study the effect of various combinations of organic manures and fertilizers on yield, soil organic carbon pools, organic N fractions in soil. The soil was classified as coarse loamy, Typic Ustochrept. The site is located between 29.16^{o}N latitude and 75.75^{o}E longitude in the northwest part of India. The climate of the experimental area is semi-arid with a mean annual precipitation of 443 mm and mean annual temperature of 24.8 ^{0}C. The average nutrient composition of FYM, poultry manure and pressmud applied in the experiment during 2011 and soil chemical properties of soil at the time of start of experiment are given in Table 1 and 2, respectively. All the organic manure contained about 20% moisture. The experiment was laid out with the following treatments in a randomized block design with three replications; T_1: 75 kg N + 30 Kg P_2O_5 ha^{-1}, T_2: 150 kg N + 60 Kg P_2O_5 ha^{-1}, T_3: 15 Mg FYM ha^{-1}, T_4: 15 Mg FYM + 150 kg N ha^{-1}, T_5: 15 Mg FYM + 150 kg N ha^{-1}+30 Kg P_2O_5 ha^{-1}, T_6: 5 Mg poultry manure ha^{-1}, T_7: 5 Mg poultry manure +75 kg N ha^{-1}, T_8: 7.5 Mg pressmud ha^{-1}, T_9: 7.5 Mg pressmud +75 kg N + 30 Kg P_2O_5 ha^{-1}, T_{10}: 7.5 Mg pressmud +150 kg N + 30 Kg P_2O_5 ha^{-1}. FYM, poultry manure and pressmud were applied once in a year in winter at time of wheat planting. The plots are of 24 m x 5 m in size. Both crops were harvested at about 2-3 cm above ground level and the grain and straw yield of both the crops were recorded.

Carbon management index

The carbon management index (CMI) was obtained according to the mathematical procedures used by Blair et al. (1995), which are described below:

$$\mathbf{CMI=CPI x LI x 100}$$

Where CPI is the carbon pool index and LI is the lability index.
The CPI and the LI are calculated as follows:

$$\text{Carbon pool index (CPI)} = \frac{\text{Total C in treated sample (mg g}^{-1}\text{)}}{\text{Total C in reference soil (mg g}^{-1}\text{)}}$$

$$\text{Lability index (LI)} = \frac{\text{Lability of C in sample soil}}{\text{Lability of C in reference soil}}$$

$$\text{Lability of C (L)} = \frac{\text{C in fraction oxidized by KMnO4 (mg labile C g}^{-1}\text{ soil)}}{\text{C remaining unoxisized by KMnO4 (mg labile C g}^{-1}\text{ soil)}} = \frac{\text{LBC (Labile C)}}{\text{NLC (Non-labile C)}}$$

The native uncultivated soil near the experimental field was used as the reference, with a CMI defined as 100. The labile C was considered as the portion of soil organic C that was oxidized by 333 mM $KMnO_4$ (Blair et al., 1995). The non-labile C (NLC) was estimated from the difference between total organic C pool as determined by wet oxidation method (Snyder and Trofymow, 1984) and the labile C (NLC = TOC − LBC).

Statistical analysis

For statistical analysis, Microsoft Excel (Microsoft Corporation, USA) and SPSS (Statistical Package for the Social Science, SPSS, Inc., Chicago, USA) window version 16.0 were used. Analysis of variance (ANOVA) was done as per the procedure outlined by Gomez and Gomez (1984). The significant differences between treatments were compared with the least significance (LSD) at 5% level of probability.

RESULTS AND DISCUSSION

Carbon management index

The carbon management index (CMI) is derived from the total soil organic C pool and C lability index and is useful to evaluate the capacity of management systems to promote soil quality. This index compares the changes that occur in total and labile carbon as a result of agricultural practices, with an emphasis on the changes in labile carbon, as opposed to non-labile carbon in SOM. Therefore, the integration of both soil organic C pool and C lability into the carbon management index can provide a useful parameter to assess the capacity of management systems to promote soil quality (Blair et al., 1995). A management system is considered sustainable, if the value of CMI is greater than 100. In the present study, the highest CMI value of 973.7 was obtained in treatment receiving integrated use of FYM and NP (15 Mg FYM + 150 kg N ha^{-1}+30 Kg P_2O_5 ha^{-1}) (Table 3). The addition of FYM (15 Mg FYM ha^{-1}) alone resulted in CMI values of 792.3 in surface soil, respectively; while that of NP (150 kg N ha^{-1}+30 Kg P_2O_5 ha^{-1}) fertilizer resulted in CMI values of 144.9 surface soil depth. Improvement in CMI value under integrated use of organic and inorganic fertilizer over their sole application of organic manures (FYM, poultry manures and pressmud) and inorganic fertilizers alone could be attributed to addition of organic carbon and other nutrients through these sources. Similar result in higher CMI under rice–wheat cropping system amended with Lantana spp. was reported earlier by Sharma et al. (2003). Blair et al. (1995) reported that there was no ideal value of CMI. However, this index provides a sensitive measure of the rate of changes in soil carbon dynamics of the system related to the more stable reference soil. The higher values of CMI indicate that the system have greater soil quality than the other management systems. These results indicated that integrated use of organic manures and NP fertilizer in intensive cropping system like pearl millet–wheat system could be considered as the sustainable management option for crop production.

Grain yield of wheat

The lowest grain yield wheat crop was recorded when either 15 Mg FYM or 5 Mg poultry manure or 7.5 pressmud ha^{-1} was applied alone (Fig. 1). With the application of NP in conjunction with organic manures, there was a significant increase in the crop yield which was comparable with recommended dose of applied NP alone or half dose of NP applied alone. There was an increase of about 126, 92 and 109 % in wheat grain yield upon application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha^{-1} along with recommended N and half of P over manures applied alone, respectively. The organically manures plots produced significantly higher crop yield as compared to NP fertilized treated plots, reflecting the positive interaction of integrating organic and inorganic fertilizers on crop yield. Increase in grain yield of wheat with the application of organic manures along with NP fertilizers may be due to additional supply of plant nutrients and nutrients mineralized from the organic manures meeting the need of the crop slowly but continuously along with readily available macro and micronutrients. The addition of FYM and other organic materials had directly added an appreciable amount of major nutrients which contributed to the enhanced yield. In contrast, Edmeades, (2003) stated that relative to the same amounts of nutrients application as chemical fertilizers, applying organic manures had no obvious advantages to soil productivity, measured as crop yields, despite the positive effects of these organic manures on soil physical and biological properties. Linear regressions fitted to pooled data across the locations revealed highly significant ($p < 0:01$) annual increase in yield of rice with integrated supply of nutrients through fertilizers and manures, indicating thereby the advantage of combined use of manures plus fertilizers over fertilizers applied alone in sustaining crop yields reported by Yadav et al. (2006). The increasing C sequestration was observed by increasing C input through crop residues and organic manures. The higher magnitude of residual effect of FYM may be due to the higher quantity of FYM application. The increase in soil organic C pools with application of manures could be attributed to an increase in belowground biomass production compared to fertilizers N or NP applied plots. Continual addition of FYM increases MBC, which could lead to a positive effect on both soil aggregation and macro porosity and it improves the growth and development of crop. Labile C fractions are active C is a small fraction of soil organic manures, it acts as a buffering agent in replenishment of all bioavailability of nutrients to crops. Integration of organic and inorganic sources resulted in higher biological yield in sunflower that is attributed to more availability of nutrients and their uptake, which increased flowering, leaf area index, biomass (Munir et al., 2007).

Increase of nutrients, structural development and changes in soil health might have collectively contributed to improve in crop yields. Large increase the yield with integrated use of FYM and inorganic fertilizers have been reported by Yadvinder-Singh et al., 2004. Increase in yield of crops with FYM application is expected due to its favorable effect on physical, biological and chemical properties of the soil (Edmeades, 2003). Amujoyegbe et al., (2007) found highest grain yield and biomass of maize and sorghum with the combined application of inorganic fertilizer + poultry manure followed by inorganic fertilizer. Tahir et al. (2011) recommended that organic matter alone with synthetic fertilizers could be helpful for enhancing stagnant wheat grain yield.

CONCLUSION

The present study demonstrated that integrated use of FYM and NP fertilizers for increased soil fertility and pools of SOC. Significant and positive correlations of LBC with yield indicate that these pools are more important for nutrient turn-over and their availability to plants than TOC. Carbon management index revealed that integrated nutrient management could be followed for enhancing crop productivity, nutrient availability and soil carbon pools for long-term. These results conclude that for sustainable crop production and maintaining soil quality, input of organic manure like FYM is the major importance and should be advocated in the nutrient management of intensive cropping system for improving chemical and biological properties of soils. Therefore, encourage the farmers to manage nutrients and soil fertility through integrated nutrient management by combining organic with inorganic fertilizer to increase crop productivity, enhancing nutrient availability and sustaining soil carbon pools for long-term.

Table 1. Average composition of FYM, Poultry Manure and Pressmud

Nutrient (Total)	FYM	Poultry Manure	Pressmud
C (%)	38.1	22.8	38.0
N (%)	1.18	2.55	3.10
P (%)	0.60	1.80	0.90
K (%)	1.92	1.15	0.80
Zn (mg kg^{-1})	53.0	100.3	115.0
Mn (mg kg^{-1})	26.3	56.7	61.5
Cu (mg kg^{-1})	224.5	15.0	14.5
Fe (mg kg^{-1})	2211.0	550.0	460.7

Table 2. Physicochemical properties of the soil at the start of the experiment.

Property	Experiment-II
pH (1:2)	8.1
Organic C (%)	0.39
$CaCO_3$ (%)	1.00
Available N (mg kg^{-1})	98.0
Available P (mg kg^{-1})	12.6
Available K (mg kg^{-1})	217.0

Table 3: Carbon management index (CMI) as affected by application of various organic manures and fertilizers after 16 cycles of pearl millet–wheat cropping system

Type of manure	Dose (Mg ha^{-1})	Fertilizer (kg ha^{-1})		TOC (g kg^{-1})	LBC (g kg^{-1})	NBC (g kg^{-1})	CPI	LI	CMI
		N	P_2O_5						
No manures	0	75	30	4.6	0.39	3.27	1.00	0.11	100.0
	0	150	60	5.3	0.46	3.90	1.20	0.11	144.9
FYM	15	0	0	10.8	1.00	9.12	2.81	0.12	792.3
	15	150	0	11.2	0.94	8.85	2.73	0.13	746.1
	15	150	30	13.2	1.22	10.11	3.12	0.14	973.7
Poultry Manure	5	0	0	7.4	0.50	4.89	1.51	0.12	227.8
	5	150	30	8.8	0.60	5.25	1.62	0.13	262.6
Pressmud	7.5	0	0	9.3	0.70	6.60	2.04	0.11	415.0
	7.5	75	30	9.6	0.76	6.87	2.12	0.12	449.6
	7.5	150	30	9.5	0.79	6.78	2.09	0.13	437.9
SEm±				**0.04**	**0.03**	**0.01**			
LSD (0.05)				**0.1**	**0.1**	**0.04**			

TOC, total organic carbon; LBC, labile organic carbon; NLC, non-labile C; CPI, carbon pool index; LC, lability of C; LI, lability index; CMI, carbon management index.

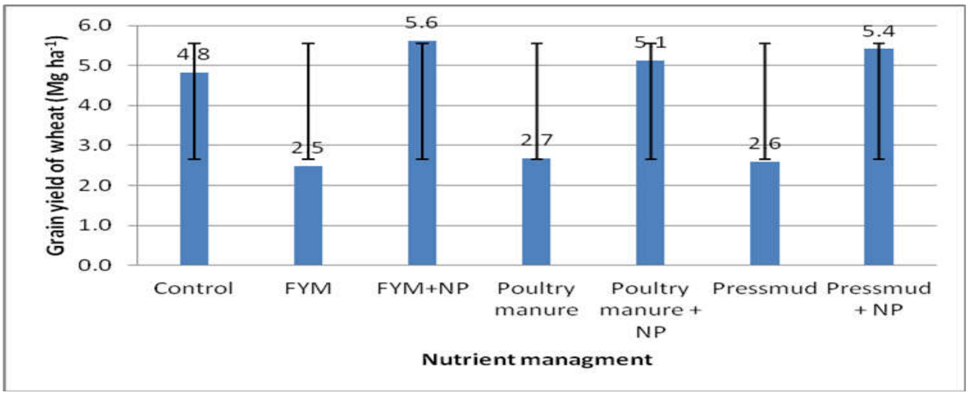

Fig. 1 Effect of organic manures and fertilizers on yield of wheat grown in a 16 cycles of old pearl millet–wheat cropping system. Error bars represent standard deviation of the mean.

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CITATION OF THIS ARTICLE

Kumara BH, Antil R.S, Ch. Srinivasa Rao, Devraj. Long-term effect of organic manures and fertilizers on soil fertility and soil carbon management index after 16 years cycles of pearl millet–wheat cropping system in an Inceptisol of subtropical India.Bull. Env. Pharmacol. Life Sci., Vol 6 Special issue 1, 2017: 360-364