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EFFECT OF FERTILIZER AND MANURE APPLICATION ON SOIL ORGANIC CARBON SEQUESTRATION, SOIL FERTILITY AND YIELD SUSTAINABILITY UNDER MAIZE-WHEAT CROPPING SYSTEM IN SUBTROPICAL MOLLISOLS

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ABSTRACT

A field experiment with nine treatments was initiated in 2014 on a Mollisol to study the effect of fertilizers (NPK) and farmyard manure (FYM) application with or without *Azotobacter* or Zinc on yields, soil organic carbon (SOC) storage and sequestration and soil properties in maize-wheat rotation. After four years it was revealed that continuous application of 100% recommended dose of NPK+ FYM @ 5 t ha⁻¹ recorded significantly higher grain yields of maize and wheat and N, P, and K removal by the system. Crops yield increased by 100% NPK alone or combined with FYM or Zn in the fourth year compared to the first year. Intercropping of cowpea with maize caused a reduction in maize yield but its residual effect enhanced wheat yield. Bulk density of surface soil reduced significantly from 1.4-4.3% over initial except in control and 50% NPK. Available N, P, K, and Zn increased under integrated use of NPK fertilizer and FYM or Zn but decreased more in control. Response to the application of 100% NPK was maximum to the tune of 1.31 t ha⁻¹ for maize and 1.34 t ha⁻¹ for wheat whereas least with cowpea intercropping. SOC content and storage/pool in the surface soil increased from 0.7-7.2% and 0.5-2.9%, respectively, in FYM applied plots over the initial level. Application of FYM @ 10 t ha + *Azotobacter* in cowpea intercropping sequestered maximum SOC (0.14 Mg C ha⁻¹ yr⁻¹) but reduced yields of maize and wheat. Grain yield of maize rather than wheat was more closely correlated with SOC content and storage. Results suggested that continuous application of 100% NPK along with FYM @ 5 t ha⁻¹ led to better soil fertility and yield sustainability.

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1 Introduction

The plain zone of state Uttarakhand known as *Tarai* falls under order Mollisols and covers an area of about 1.6 million hectares which is more fertile. The soils in the *Tarai* region have a wet moisture regime and shallow water table for most time of the year and are poorly drained in the low lying areas. *Tarai* soils have been brought under cultivation on the recently removed forested ecosystem in late 1940 after clearing of dense forest and grasslands (Ram et al., 2016). Rice-wheat is the major cropping system for the past several decades in the *Tarai* region. Both crops are heavy nutrient feeders (Panwar et al., 2019). Moreover adaptation of high yielding and nutrient responsive varieties of these crops, as well as faulty agricultural practices by the farmers, are common in this area. Consequently overexploitation of the natural resources especially fertile land and plenty of available water created an adverse impact on the soil in the form of deterioration of soil health, fragile crop environment and, reduced profitability of crops (Ram et al., 2016). On the other hand, various researches had reported that manure application increases crop yields besides soil organic matter and improves soil quality as well (Blair et al., 2006; Yang et al., 2015). Inorganic fertilizers are the major inputs in the present agriculture system rather excessive and indiscriminate use led to the depletion of soil fertility and productivity (Dubey et al., 2012; Rahman & Zhang, 2018). Naresh (2013) reported that under continuous and intensive farming, of rice-wheat cropping system, the nutrient supplying power of most of the soils has been found declining, therefore becoming less profitable consequently farmers are shifting to other profitable cropping systems. The maize-wheat cropping system occupies fifth place in Indo-Gangetic Plains of India (Yadav & Subba Rao, 2001). Although maize is not a major cereal crop and grown only in 23 thousand hectares land of hill and plain area of Uttarakhand (Annual Progress Report, IIMR, 2016) however, farmers of *tarai* region are showing their interest in this crop due to its multipurpose use and higher profitability. Maize could be a suitable substitute for rice and fits well in the maize-wheat cropping system, yet careful nutrient management is the prerequisite for the successful cultivation of hybrid maize. Continuous application of chemical fertilizer for a long time may give rise to soil fertility related problems. Many long-term soil fertility experiments on various cropping systems draw attention to soil fertility (Manna et al., 2005; Sharma et al., 2019) but little information is available on the consequences of long-term soil fertility management on the productivity of maize-wheat systems in Asia. In hilly areas of Uttarakhand, the average utilization of inorganic fertilizers is 8-10 kg ha⁻¹ as compared to the plain region (200 kg ha⁻¹). Among the organic sources, farmyard manure is the most important as it contains all the nutrients needed for crop growth including trace elements, albeit in small quantities (Achieng et al., 2010). Continual applications of FYM not only supply plant nutrients to the crop but also increase the soil organic

matter and improve soil water holding capacity (Mongare et al., 2020). Many long-term studies reported that the application of FYM considerably increased the maize yield in different maize-legume intercropping systems (Saini & Kumar, 2014; Ndiso et al., 2018). *Azotobacter*, a free-living N₂ fixing bacterium contributes to nitrogen in many non-leguminous crops such as wheat, maize, rice, sugarcane, etc. without causing damage to the environment as well as soil. Besides nitrogen fixation, *Azotobacter* also synthesizes and secretes a considerable amount of biologically active substances which enhances root growth and protects the plant from diseases (Soleimanzadeh & Gooshchi, 2013). The increase in grain yield of crops is higher when inoculation is done without the use of chemical fertilizer (Baral & Adhikari, 2013). The addition of external organic sources in the field is the common practice for the farmers of hilly areas while in plain areas it is rarely applied by the farmers. Considering the declining soil fertility and productivity, reduced profitability, ecological disturbance, etc. prolonged excessive and indiscriminate the uses of chemical fertilizers and intensive farming system, the present investigation was undertaken to investigate the effect of the use of fertilizers and organic manure in integrated mode or alone in the maize-wheat cropping system.

2 Materials and Methods

2.1 Site description

A field experiment was initiated in *kharif* 2014 at the Norman E. Borlaug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand situated at 28°58'–29°1'N latitude and 79°24'–79°31'E longitude. The climate of the area is humid sub-tropical with an annual rainfall of 1,433 mm, of which, more than 85% is received during the wet season (June to September). The mean maximum temperature may go up to the 43°C in May during summer and a minimum below 2 °C in January during winter. The monthly distribution of precipitation, air temperature, and relative humidity prevailed at the study site during 2014–2017 is presented in Figure 1. The soils of the research center are classified as fine mixed hyperthermic *Aquic Hapludoll* (Deshpande et al., 1971b). The experimental soil (sandy loam, sand-52%, silt- 32.0% and clay-16.0%) was neutral in reaction (6.92), low in salt content 0.18 dS m⁻¹, available N (187.9 kg ha⁻¹) and Zn (0.47 mg kg⁻¹), high in organic carbon (0.95 %) and medium in available P (24.5 kg ha⁻¹) and K (152.6 kg ha⁻¹).

2.2 Experimental design and treatments

The experiment was laid out in a randomized block design with three replications. The size of each plot was 9.0 m × 15.0 m and had 15 and 40 rows of maize and wheat, respectively. There were 9 treatments. In the maize crop, the experimental treatments were as

Figure 1 Monthly distribution of precipitation, relative humidity and air temperature during the 2014 to 2017 existing for maize and wheat crops during growing period

follows: 100% recommended dose of fertilizers (RDF) (120, 60, 40 kg N, P_2O_5 , K_2O ha^{-1}); 50% RDF; FYM @ 10 t ha^{-1} + *Azotobacter*; Maize + cowpea with FYM @ 10 t ha^{-1} + *Azotobacter*; 100% RDF + FYM @ 5 t ha^{-1} ; 50% RDF + FYM @ 5 t ha^{-1} ; 100% RDF + Zn @ 5 kg ha^{-1} ; and FYM @ 5 t ha^{-1} (state hill practice) and no fertilizer and farmyard manure (control). In maize crop, treatments FYM @ 10 t ha^{-1} + *Azotobacter*; Maize + cowpea with FYM @ 10 t ha^{-1} + *Azotobacter* and FYM @ 5 t ha^{-1} received nutrients through organic mode while in other treatments through inorganic alone or combination with FYM. However, in case of the wheat crop, 100% RDF (150, 60, 40 kg N, P_2O_5 , K_2O ha^{-1}) was applied only in those treatments where NPK was supplied through inorganic fertilizers in the maize crop but in the other treatments (FYM @ 10 t ha^{-1} + *Azotobacter*; Maize + cowpea with FYM @ 10 t ha^{-1} + *Azotobacter* and FYM @ 5 t ha^{-1}), similar doses of FYM only in the respective treatments were incorporated as given in maize crop. Control did not receive any inorganic fertilizers or FYM in both crops. Cowpea was intercropped as a grain crop in between the rows of maize crops only. *Azotobacter* was inoculated with maize seeds only.

2.3 Agronomic practices

The sources of N, P, K, and Zn were urea, single super phosphate, muriate of potash, and zinc sulfate, respectively.

Applied FYM varied in their nutrients content from 0.45-0.9% N, 0.3-0.42% P, and 0.45-0.55% K and 0.002-0.004% Zn on dry weight basis. Before sowing both of the crops, one-third dose of N and a full dose of P, K, Zn, and fully decomposed FYM were mixed properly in soil and remaining N was given in two equal splits by top dressing at the knee-high stage and tassel emergence in maize and first irrigation and at the time of panicle initiation in wheat. Pioneer P 3396, UP 2565, and Pant Lobia-1 were the varieties of maize, wheat, and cowpea, respectively. Maize seeds were sown at a row spacing of 60 cm with the plant to plant spacing at 25 cm while in wheat row spacing was maintained at 22.5 cm. Two rows of cowpea were sown at the spacing of 15 cm plant to plant between two rows of maize in an additive manner. Maize and cowpea were sown in the second fortnight of June and harvested in mid-October followed by the sowing of wheat during the second fortnight of November and harvested in mid-April. Irrigation was given at the critical stages of the crops. The crops following standard agronomic practices did not face any damage due to insects and pests during their growing cycle. In both crops, weeds in the NPK fertilizers received plots were controlled manually and chemically however, FYM received plots were weeded manually. After the harvest of crops, the data for grain and stover/straw was recorded for the respective plots and presented accordingly.

2.4 Soil sampling and analysis

The single composite soil sample was collected from the experimental site initially from topsoil (0-15 cm depth) and thereafter each year after the harvesting of wheat crop. Random samples (10 numbers) from the surface (0-15 cm depth) were collected from each plot and mixed well to obtain the composite sample for further soil analysis. The collected air-dried soil samples were grounded with a wooden roller and passed through 0.2 mm sieve for organic carbon and 2 mm sieve for other soil quality parameters. The samples were analyzed for soil pH and electrical conductivity (EC) in 1:2 soil: water suspension using pH and conductivity meter, respectively. Organic carbon by potassium dichromate oxidizing method (Jackson, 1973), oxidizable N by alkaline potassium permanganate method (Subbiah & Asija, 1956), available P by extraction with 0.5 M sodium bicarbonate (pH 8.5) and determined using an ascorbic acid method (Olsen et al., 1954), available potassium with neutral ammonium acetate (Hanway & Heidel, 1952) followed by emission spectrometry and available Zn with DTPA-extraction using spectrophotometer (Lindsay & Norvell, 1978). The bulk density of soil was measured by the core method (Blake & Hartze, 1986). The soil organic carbon pool for the surface soil was estimated using the following formula (Chaudhary et al., 2017):

$$\text{SOC pool (Mg ha}^{-1}\text{)} = \text{SOC (\%)} \times \text{soil depth (m)} \times \text{Db (Mg m}^{-3}\text{)} \times 10^4 \text{ (m}^2 \text{ ha}^{-1}\text{)} \times 10^{-2}$$

Soil carbon sequestration rate was calculated as per the equation given by Brar et al. (2015):

$$\text{Soil carbon sequestration rates (Mg C ha}^{-1} \text{ year}^{-1}\text{)} = (\text{SOC}_{\text{Pi}} - \text{SOC}_{\text{Po}})/T$$

Where Db is bulk density, SOC_{Pi} is soil organic carbon pool at the

time of last wheat crop harvest, SOC_{Po} is the initial soil organic carbon pool at the time of the start of the experiment and T is total years of experiment.

2.5 Plant sampling and analysis

Grain and straw samples of crops were collected from each plot over the years after harvesting then processed and digested in the tri-acid mixture and total content of N, P, K, and Zn were estimated using standard procedures (Jackson, 1973). The nutrient uptake by crops was computed by multiplying the content of the specific element with their air-dried grain and straw yields. The total nutrient uptake for the maize-wheat system was calculated as the sum of nutrients harvested in both crops.

2.6 Data analysis

Analysis of data was carried through analysis of variance prescribed for RBD and significant differences between the treatments were evaluated at $P < 0.05$. The regression line of crop yields to soil organic carbon and regression equations for different fertilizer and FYM treatments were computed using Microsoft Excel 2010.

3 Results and Discussion

3.1 Effect of chemical fertilizers and FYM on soil properties

The experimental results revealed that soil reaction and salts content did not get influence significantly the treatments (Table 1). However, soil reaction was found slightly alkaline ranging from 7.04-7.10 pH and rose by 0.12-0.25 units in the NPK fertilizer applied treatments and control but lowered in FYM applied plots in both the crops. The

Table 1 Soil characteristics in the surface soil (0-15 cm) after 4 years application of fertilizer and manure in a maize-wheat cropping system

Treatment	pH (1:2)	Electrical conductivity (dS m ⁻¹)	Bulk density (Mg m ⁻³)	Available nutrients (kg ha ⁻¹)			
				N	P	K	Zn
NPK*	7.06 ^{abc}	0.19 ^{ab}	1.38 ^{bc}	184.1 ^{abc}	25.5 ^b	153.4 ^b	0.452 ^{bc}
NPK**	7.09 ^a	0.20 ^a	1.40 ^{ab}	180.1 ^c	23.3 ^{cd}	148.3 ^d	0.444 ^{cd}
FYM*+ <i>Azotobacter</i>	6.95 ^{abc}	0.17 ^{ab}	1.35 ^{de}	178.3 ^{cd}	22.5 ^{de}	146.1 ^c	0.429 ^{de}
Cowpea with FYM* + <i>Azotobacter</i>	6.91 ^c	0.16 ^b	1.34 ^e	181.3 ^c	22.9 ^d	147.2 ^{de}	0.434 ^d
NPK*+FYM**	7.04 ^{abc}	0.17 ^{ab}	1.36 ^{cde}	187.2 ^a	27.1 ^a	156.9 ^a	0.463 ^b
NPK**+FYM**	7.05 ^{abc}	0.18 ^{ab}	1.37 ^{cd}	182.6 ^{bcd}	24.7 ^{bc}	151.0 ^c	0.450 ^{bc}
NPK*+ 5 kg Zn	7.07 ^{ab}	0.19 ^{ab}	1.38 ^c	185.4 ^{ab}	25.2 ^b	152.8 ^b	0.479 ^a
FYM**	6.94 ^{bc}	0.17 ^{ab}	1.37 ^c	176.4 ^d	21.9 ^{de}	144.4 ^e	0.425 ^e
Control	7.10 ^a	0.20 ^a	1.42 ^a	175.7 ^d	21.2 ^c	142.4 ^f	0.415 ^e
Initial	6.92	0.18	1.40	187.9	24.5	152.6	0.472
SEm±	0.04	0.01	0.01	1.00	0.5	0.6	0.005
LSD _{0.05}	NS	NS	0.02	2.99	1.4	1.8	0.015

NPK*- 100% NPK, NPK**- 50% NPK, FYM*- FYM 10 t ha⁻¹, FYM**- FYM 5 t ha⁻¹

decline in pH under FYM alone plots could have resulted from the build-up of organic matter which releases hydrogen ions during decomposition (Pareek & Yadav, 2011). A similar trend for electrical conductivity as found for soil reaction was noted among the treatments. Soil bulk density was found to be significantly affected under different treatments over the years (Zhang et al., 2006) and reduced from 0.4–0.06 Mg m⁻³ under sole FYM received plots over initial but increased non-significantly in others. A decrease in soil bulk density is mainly attributed to higher organic matter content due to FYM and more root and plant biomass addition into the soil which results in better aggregation of soil separates and a consequent increase in the volume of micropores (Tripathi et al., 2014). Raising the NPK fertilizers from sub-optimal to optimal levels with or without FYM and cowpea intercropping did not significantly influence this property. Availability of N, P, and K found to be highest with conjoint use of 100% NPK and FYM (Kang et al., 2005; Meena et al., 2017), while lowest under control. Compared to the initial status of N, P, and K, only balance use of chemical fertilizers and FYM could maintain the higher availability of P and K which found to remain at par with 100% NPK + FYM @ 5 t ha⁻¹ however reduced significantly in other practices. The greater availability of N with combined application of 100% NPK and FYM @ 5 t ha⁻¹ may be due to higher addition of organic matter through FYM and root as well as plant biomass, which might have helped in the multiplication of soil microbes, ultimately enhancing the conversion of organically bound N to mineral form (Tolanur & Badanur, 2003). Regular addition of an optimum dose of phosphates fertilizer in both crops as well as FYM may help in solubilizing the native P at a greater rate in the soil through the release of various organic acids (Tiwari, 2003) and organic ions compete with the phosphate ions for binding sites on soil particles, thereby reducing the P fixation (Panneerselvam et al., 2000) and reduction in K fixation and

release of K ions due to the interaction of organic matter with clay (Urkurkar et al., 2010). Increasing the NPK dose from 50 to 100% with or without FYM significantly enhanced N, P, and K availability from 4.6, 2.4 and 5.9 and 4.1, 2.2 and 5.1 kg ha⁻¹, respectively, however intercropping of cowpea with maize along with FYM+ *Azotobacter* over FYM+ *Azotobacter* and Zn addition over 100% NPK gave at par availability. Addition of Zn @ 5 kg ha⁻¹ along with 100% NPK recorded the greatest availability of Zn followed by 100% NPK+FYM @ 5 t ha⁻¹ whereas control arrested the greatest reduction. Availability of DTPA extractable Zn enhanced by 1.5% in 100% NPK + Zn @ 5 kg ha⁻¹ but remained at par with 100% NPK + FYM @ 5 t ha⁻¹ however depleted from 4.2–12.1% in other treatments over the initial level of 0.472 kg ha⁻¹. The increase in Zn availability could be attributed to direct and continuous application of Zn in the soil as well as mineralization of organically bound forms of Zn in the FYM (Kher, 1993) whereas reduction could be attributed to more removal of Zn under intensive crop production system. Comparing the increase in nutrients availability between treatments 100% NPK and 50% NPK, FYM@10 t ha⁻¹ + *Azotobacter* and cowpea with FYM @ 10 t ha⁻¹ + *Azotobacter*, 100% NPK + FYM @ 5 t ha⁻¹ and 50% NPK + FYM @ 5 t ha⁻¹, 100% NPK and 100% NPK + 5 kg Zn and FYM @ 5 t ha⁻¹ and Control, maximum increase of N, P and K was recorded for 100% NPK + FYM @ 5 t ha⁻¹ and 50% NPK + FYM @ 5 t ha⁻¹ and Zn for 100% NPK and 100% NPK + 5 kg Zn.

3.2 Effect of chemical fertilizers and FYM on SOC storage and sequestration

Over four years of continuous application of NPK fertilizer and FYM alone or in combinations significantly affected the content, pool/stock, and sequestration rate of SOC in the surface soil (Table 2). SOC

Table 2 Soil organic carbon (SOC) dynamics at the surface soil (0–15 cm) after 4 years application of fertilizer and manure in maize-wheat cropping system

Treatment	SOC (g/kg)	SOC pool (Mg C ha ⁻¹)	SOC sequestration over initial (Mg C ha ⁻¹)	SOC sequestration rate (Mg C ha ⁻¹ yr ⁻¹)
NPK*	9.57 ^g	19.85 ^{cde}	-0.097 ^{def}	-0.025 ^{def}
NPK**	9.42 ^h	19.83 ^{de}	-0.123 ^f	-0.031 ^{ef}
FYM*+ <i>Azotobacter</i>	10.04 ^b	20.29 ^{ab}	0.337 ^{ab}	0.084 ^{ab}
Cowpea with FYM* + <i>Azotobacter</i>	10.18 ^a	20.52 ^a	0.567 ^a	0.142 ^a
NPK*+FYM**	9.88 ^c	20.21 ^b	0.260 ^b	0.065 ^b
NPK**+FYM**	9.80 ^{de}	20.09 ^{bc}	0.143 ^{bcd}	0.035 ^{bc}
NPK*+ 5 kg Zn	9.61 ^{fg}	19.90 ^{cd}	-0.053 ^{cc}	-0.013 ^{cde}
FYM**	9.75 ^c	20.04 ^{bcd}	0.090 ^{bcd}	0.023 ^{bcd}
Control	9.23 ⁱ	19.62 ^e	-0.332 ^f	-0.083 ^f
Initial	9.50	19.95	-	-
SEm±	0.03	0.08	0.078	0.019
LSD _{0.05}	0.096	0.23	0.233	0.059

NPK*- 100% NPK, NPK**- 50% NPK, FYM*- FYM 10 t ha⁻¹, FYM**- FYM 5 t ha⁻¹, SOC- soil organic carbon

content was recorded maximum under 100% NPK+ FYM @ 5t ha⁻¹ which was recorded 1.4-8.1% significantly higher over other treatments (Rasool et al., 2008). Compared with initial SOC content, 50% NPK, FYM @ 5t ha⁻¹ and control reduced SOC from 0.8-2.8% while in other treatments it enhanced from 0.7-7.2%. Moreover, FYM incorporated plots led to significant changes in SOC over the initial SOC content. More increase in SOC under FYM applied treatments for four years was due to the addition of carbon through FYM, root biomass, and crop residue (Brar et al., 2015). Inclusion of NPK without FYM from 50 to 100% significantly enhanced SOC however on the other side increasing NPK with FYM @ 5t ha⁻¹ had no significant effect on SOC accumulation during four years of maize-wheat rotation. The effect of different combinations of NPK fertilizer and FYM on the SOC pool showed a similar trend to that of SOC content. After four years, the SOC pool ranged from 19.62 Mg C ha⁻¹ for control to 20.52 Mg C ha⁻¹ for cowpea intercropped maize with FYM @ 10t ha⁻¹ + *Azotobacter*. Continuous application of FYM either alone or along with NPK fertilizer increased the SOC pool from 20.04 – 20.52 Mg C ha⁻¹ over the initial level of 19.95 Mg C ha⁻¹ however it decreased from 0.05-0.12 Mg C ha⁻¹ in other treatments. An increase in 50% NPK with or without FYM, intercropping of cowpea, and inclusion of zinc did not enhance a significant amount of SOC storage. FYM received plots increased the SOC sequestration from 0.023-0.142 Mg C ha⁻¹ yr⁻¹, on the other hand, the loss was obtained in other treatments. Application of FYM @ 10 t ha⁻¹ + *Azotobacter* with cowpea intercropping sequestered the highest SOC (0.142 Mg C ha⁻¹ yr⁻¹) followed by FYM @10t ha⁻¹ + *Azotobacter* while the maximum was obtained under controlled condition (-0.083 Mg C ha⁻¹ yr⁻¹). Organic manures contain most carbon in recalcitrant forms resulting in more carbon sequestration as it had already gone under some decomposition before application in agricultural fields (Benbi & Senapati, 2009).

3.3 Effect of chemical fertilizers and FYM on maize grain yield

The data on the maize grain yield in the initial year (2014), fourth-year (2017), and the average yield over the years (2014-17) are presented in Table 3. In the initial year of experiment grain yield of maize under different organic, inorganic, and integrated mode varied from 4.59-5.33 t ha⁻¹. Among the treatments, the lowest grain yield was recorded with control (4.23 t ha⁻¹) whereas significantly superior yield was noticed under 100% NPK + FYM @ 5t ha⁻¹ treatment which produced 0.13-1.1 t ha⁻¹ higher yield over others except 100% NPK + 5 kg Zn. Changing the dose of NPK fertilizer from 50 to 100% either alone or conjoint with FYM significantly enhanced maize grain yield from 5.3-8.0%. However, an increase in yield was found less when NPK fertilizers dose increased alone as compared to FYM. Less difference in yields between 100% NPK + FYM @ 5 t ha⁻¹ and 50% NPK + FYM @ 5 t ha⁻¹ might be attributed to the balanced nutrient supply by FYM

which provides the essential nutrients as well as induced the availability of nutrients to crops during the growth period (Meena et al., 2017). Maize grown with either organic or inorganic mode of nutrients inclusion produced significantly lower yield compared with the integrated application of nutrients. However, sole maize crop yielded higher than maize + cowpea intercropping under FYM with *Azotobacter* application (Takim, 2012; Hamd Alla et al., 2014). Application of FYM @5t ha⁻¹ and Zn @ 5kg ha⁻¹ increased maize yield marginally by 4.3 and 1.8%, respectively, over 100% NPK. In the fourth year yield trend among the different fertilizer and FYM management practices in general found similar to the initial year. Comparing with respective treatments of the initial year, a slight reduction in yield from 0.12-0.56 t ha⁻¹ could be observed in the treatments 50% NPK, FYM @ 10 t ha⁻¹ + *Azotobacter*, Cowpea with FYM @ 10 t ha⁻¹ + *Azotobacter*, FYM @ 5 t ha⁻¹ and Control where the highest and the least reduction in yield was recorded with control and FYM @ 10t ha⁻¹ + *Azotobacter* with cowpea intercropping, respectively, but in the treatments 100% NPK, 100% NPK + FYM 5 t ha⁻¹, 50% NPK + FYM @ 5 t ha⁻¹ and 100% NPK + 5 kg Zn maize yield enhanced from 0.10-0.22 t ha⁻¹ with maximum under 100% NPK + FYM @10t ha⁻¹. The superiority of this treatment might be due to an adequate supply of macro and micronutrients through FYM. Inclusion of FYM and zinc led to enhance yield while organic mode (FYM @ 10 t ha⁻¹, Cowpea with FYM @ 10 t ha⁻¹ + *Azotobacter* and FYM @ 5 t ha⁻¹) reduced yield over 100% NPK. Although seed inoculation of *Azotobacter* and FYM application-supplied adequate N to crop (Peng et al., 2013) but medium N availability soil of tarai region without the addition of NPK fertilizer could not fulfill the nutrient requirement of maize crop. Four years (2014-17) mean yields revealed that incorporation of FYM @ 10t ha⁻¹ or Zn @ 5kg ha⁻¹ along with 100% NPK could maintain significantly higher yield from 3.7-5.5% over the recommended dose of fertilizer (100% NPK) (Pillai et al., 2006; Kumari et al., 2013). Treatments FYM @ 10 t ha⁻¹ + *Azotobacter* and Cowpea with FYM 10 t ha⁻¹ + *Azotobacter* received a similar dose of FYM and *Azotobacter*, maize when intercropped with cowpea with FYM 10 t ha⁻¹ + *Azotobacter* produced less but statistically at par yield showing the competition for nutrients and light interception by cowpea which resulted in a lower yield of maize (Egbe et al., 2010). Addition of FYM @ 5t ha⁻¹ with 50% NPK and 100% NPK enhanced yields by 6.0 and 5.6%, respectively. This shows the more response of maize crop for the FYM at a lower dose of NPK fertilizers. Compared with control, applied NPK fertilizer and FYM either alone or in combinations produced 17.3-42.2% significantly higher grain yield of maize. Moreover, the use of FYM alone or in combination with *Azotobacter* or a suboptimal dose of NPK could not sustain the productivity of maize compared with 100% NPK alone or with FYM or zinc after four years of experiment.

3.4 Effect of chemical fertilizers and FYM on wheat grain yield

Trends of wheat grain yield among the different treatments were noticed similar to the maize crop in the initial, fourth year, and over the years (Table 3). Wheat grain yields in the first year varied significantly from 3.54-4.82 t ha⁻¹ in the different treatments and highest in 100% NPK+ FYM @ 5t ha⁻¹ applied in maize crop while the lowest in control. Wheat crop received NPK (100% NPK, 50% NPK, 100% NPK + FYM @ 5 t ha⁻¹, 50% NPK + FYM @ 5 t ha⁻¹ and 100% NPK + 5 kg Zn) resulted significantly higher grain yield as compared to sole FYM applied plots (FYM @ 10 t ha⁻¹+ *Azotobacter*, Cowpea with FYM @ 10 t ha⁻¹+ *Azotobacter* and FYM @ 5 t ha⁻¹). Similarly, significant differences in wheat grain yield were recorded in between 50% and 100% NPK alone or with FYM applied plots and sole maize (FYM @ 10 t ha⁻¹+ *Azotobacter*) and cowpea intercropped maize. The significantly higher yield of wheat under cowpea intercropped maize might be due to the inclusion of cowpea residue in the soil that helps to maintain and improve soil fertility as well as N fixation (Alla et al., 2014). In the fourth year, plots received 100% NPK in wheat except for 50% NPK increased wheat grain yield from 0.12-0.34 t ha⁻¹ while in the rest treatments yield declined from 0.12-0.030t ha⁻¹ where a maximum increase was with the treatment receiving 100% NPK + FYM @ 5t ha⁻¹ in maize and maximum reduction in control. Despite receiving an optimal dose of NPK fertilizer in wheat (100% NPK, 50% NPK, 100% NPK+FYM @ 5 t ha⁻¹ and 50% NPK+FYM @ 5 t ha⁻¹), wheat yields were found to be deferred significantly where NPK fertilizer increased from sub-

optimal to an optimal level in maize. Similarly, the addition of FYM @ 5t ha⁻¹ over 50 or 100% NPK in maize produced a significantly higher yield of wheat. This might be attributed to the residual organic manure made through FYM applied in maize not only improved the physical properties of soil but also helped to make proper availability of nutrients to the succeeding wheat crop (Bi et al., 2009). Plots receiving nutrients only through inorganic way produced 0.71- 0.82 t ha⁻¹ higher grain yield of wheat than plots received FYM only. The residual impact of FYM @ 5t ha⁻¹ along with 100% NPK used in maize responded 0.41 t ha⁻¹ more wheat grain yield as compared to the residual effect of FYM @ 5t ha⁻¹ with 50% NPK which attracted towards the significance of FYM application with the optimal dose of NPK. Inclusion of Zinc @ 5kg ha⁻¹ with 100% NPK in maize did not respond significantly to the wheat grain yield over 100% NPK, suggesting that applied Zn was used by maize crop to a greater extent. Although treatment 100% NPK, 50% NPK, 100% NPK+FYM@ 5 t ha⁻¹ and 50% NPK+ FYM @ 5 t ha⁻¹ received the same dose of NPK in wheat crop however increased NPK level from 50 to 100% NPK alone or with FYM in previous maize crop led to the significant increase in wheat grain yield.

3.5 Effect of chemical fertilizers and FYM on nutrient uptake by maize-wheat system

Total N, P, K and Zn uptake by the maize-wheat system under different NPK chemical fertilizer and FYM application either alone or jointly (Table 3) influenced significantly and varied from

Table 3: Grain yield of maize and wheat and nutrient uptake by system after 4 years of maize-wheat cropping system

Treatment	Grain yield (t ha ⁻¹)						Nutrient uptake (kg ha ⁻¹) by maize-wheat system			
	Initial year	4 th year	Over the years(2014-2017)	Initial year	4 th year	Over the years (2014-2017)	N	P	K	Zn
NPK*	5.11 ^{bc}	5.21 ^b	5.19 ^b	4.60 ^b	4.75 ^c	4.67 ^b	288.0 ^c	56.0 ^b	166.0 ^b	0.66 ^c
NPK**	4.73 ^{dc}	4.55 ^c	4.87 ^c	4.38 ^c	4.26 ^d	4.22 ^c	241.0 ^d	45.0 ^d	141.0 ^d	0.52 ^g
FYM*+ <i>Azotobacter</i>	4.85 ^d	4.64 ^c	4.73 ^{cd}	3.96 ^c	3.76 ^f	3.84 ^d	217.0 ^e	39.0 ^e	128.0 ^e	0.60 ^d
Cowpea with FYM* + <i>Azotobacter</i>	4.68 ^{de}	4.56 ^c	4.59 ^{de}	4.12 ^d	3.94 ^e	3.98 ^d	235.0 ^d	44.0 ^d	133.0 ^e	0.58 ^d
NPK**+FYM**	5.33 ^a	5.54 ^a	5.48 ^a	4.82 ^a	5.16 ^a	5.06 ^a	340.0 ^a	60.0 ^a	179.0 ^a	0.70 ^b
NPK**+FYM**	5.06 ^c	5.28 ^b	5.16 ^b	4.61 ^b	4.73 ^c	4.65 ^b	281.0 ^c	48.0 ^c	153.0 ^c	0.60 ^{de}
NPK*+ 5 kg Zn	5.20 ^{abc}	5.34 ^b	5.38 ^a	4.77 ^a	4.92 ^b	4.80 ^b	303.0 ^b	55.0 ^b	161.0 ^b	0.78 ^a
FYM**	4.59 ^e	4.27 ^d	4.55 ^c	3.80 ^f	3.59 ^g	3.51 ^e	189.0 ^f	37.0 ^e	115.0 ^f	0.48 ^h
Control	4.23 ^f	3.67 ^e	3.88 ^f	3.54 ^g	3.24 ^h	3.33 ^f	170.0 ^g	30.0 ^f	102.0 ^g	0.37 ⁱ
Initial	0.06	0.05	0.05	0.04	0.05	0.05	3.5	0.9	2.3	0.01
SEm±	0.18	0.16	0.15	0.12	0.15	0.16	10.6	2.6	6.8	0.02

NPK*- 100% NPK, NPK**- 50% NPK, FYM*- FYM 10 t ha⁻¹, FYM**- FYM 5 t ha⁻¹

Figure 2 Response of grain yields of maize and wheat to different doses of fertilizers, FYM and their combinations

170.0-339.4, 30.3-60.1, 102.0-178.9 and 0.369-0.775 kg ha⁻¹, respectively. The highest uptake of N, P and K by the system was recorded under 100% NPK + FYM @ 5t ha⁻¹ (Brar et al., 2002) followed by 100% NPK while highest removal of Zn was with 100% NPK + Zn @ 5kg ha⁻¹ followed by 100% NPK + FYM @ 5t ha⁻¹, however, the system removed the least amount of nutrients under controlled condition. The highest uptake of N, P and K in 100% NPK+ FYM@ 5 t ha⁻¹ was due to the application of balance amount of N, P and K which supplied better nutrients content to the crop moreover during the decomposition of FYM, incorporated additional amount of nutrients into the soil matrix as well as helps to release and become available for plants (Ram et al., 2016; Meena et al., 2018). Significantly lower Zn withdrawal in Zn omitted treatments compared with Zn treatment suggested that continuous cropping with a different combination of NPK fertilizer and FYM without Zn led to lesser removal of Zn (Singh & Ram, 2005). More uptakes of N, P, and K was noticed with increasing NPK fertilizer dose with FYM from sub-optimal to optimal as compared to without FYM and cowpea intercropping with FYM over without intercropping. This shows that FYM inclusion with NPK with maize crop did respond more to nutrients removal as compared to sole NPK or FYM with legume intercropping by the system.

3.6 Response of grain yield of maize and wheat to chemical fertilizers and FYM

During the four years of continuous application of NPK fertilizers, biofertilizer, FYM, and their combinations in maize and wheat crops, the response of maize and wheat grain yields to nutrient management was diverse and in general positive (Figure 2). This was owing to marked variation in the nutrient availability to the crops supplied by different combinations of NPK fertilizer, biofertilizer, and FYM. Results also indicated that wheat in terms of yield responded 2.8- 40.2% more as compared to maize (-3.0 to 33.8%) under different nutrient management practices. Maximum yield response was obtained with 100% NPK followed by 50% NPK for both crops while least with cowpea intercropping and zinc for maize and wheat, respectively. This was attributed to the fact that a higher supply of N, P, and K through NPK fertilizer in both crops led to greater availability of nutrients than other sources. However, no marked differences in yield response of 25.5 and 26.7% for 50% NPK, 18.3 and 19.5% for cowpea with FYM @ 10t ha⁻¹ + *Azotobacter* and 3.7 and 2.8% for Zn @ 5kg ha⁻¹ were recorded for maize and wheat, respectively, indicating that both crops are almost equally responsive to these nutrients. For the maize grain yield, cowpea intercropping produced slightly negative yield response (-0.14 t ha⁻¹) as the cowpea was competitive for nutrients and sunlight against maize but the incorporation of

cowpea biomass and N fixation increased yield response to the succeeding wheat crop (0.14 t ha^{-1}). The yield response trend for different nutrient management practices was recorded in the increasing order of cowpea intercropping, Zn @ 5 kg ha^{-1} , FYM @ 5 t ha^{-1} , cowpea with FYM @ 10 t ha^{-1} + *Azotobacter*, FYM @ 10 t ha^{-1} + *Azotobacter*, 50% NPK, and 100% NPK for maize and Zn 5 kg ha^{-1} , cowpea intercropping FYM @ 5 t ha^{-1} , cowpea with FYM @ 10 t ha^{-1} + *Azotobacter*, FYM @ 10 t ha^{-1} + *Azotobacter*, 50% NPK and 100% NPK for wheat.

3.7 Relationship between the yield of maize and wheat with soil organic carbon and pool

The regression analysis revealed the positive relationship between the yield of maize and wheat with SOC and SOC pool (Figure 3a & 3b). During the four years, the grain yield of maize and wheat owing to different fertilizer management practices varied from 38.6-60.2% and 28.5-49.6% by SOC content and SOC pool/storage, respectively. The maize grain yield altered more by

Figure 3 Relationship between grain yield of maize and wheat and soil organic carbon and soil organic carbon pool in a maize-wheat cropping system

soil organic carbon as R^2 value (0.6015) fitted good between maize grain yield and SOC, however R^2 values were found low between wheat grain yield and SOC (0.3864) and between SOC pool and grain yield of maize (0.4957) and wheat (0.2852) which emphasizes the significance of SOC for maize yield. The coefficient of determination (R^2) also indicated more influence of SOC and SOC pool on maize than wheat yield. Thus higher the content of SOC and SOC pool in mollisol, more is the yield of maize compared to wheat.

Conclusion

Over the years, continuous application of a recommended dose of NPK fertilizers with FYM @ 5t ha⁻¹ brought out a marked increase in productivity and nutrient uptake by maize and wheat that enhanced the soil organic carbon content and sequestration in maize-wheat rotation in a mollisol hence may be the best option for higher crop yields. However organic mode of nutrient application almost failed to sustained yield. Cowpea intercropped maize with FYM @ 10t ha⁻¹ also not suitable as it reduced the grain yield of maize however may be beneficial for succeeding wheat crop as it increased soil organic carbon. Incorporation of farmyard manure @ 5 t ha⁻¹ along with a half dose of recommended NPK fertilizer in maize crop accomplished grain yield at par with 100% NPK fertilizer for both the crops. Use of half dose of recommended nutrients, state practice (farmyard manure @ 5 t ha⁻¹), and control led to a reduction in the crop yields and SOC sequestration rates.

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Conflict of interest

The authors declare that they have no conflict of interest

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