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Long-term effects of fertilizer and manure application on soil quality and sustainability of jute-rice-wheat production system in Indo-Gangetic plain

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Abstract: A long-term fertilizer experiment was initiated in 1971 in sandy loam soil (*Eutrochrept*) of Barrackpore, West Bengal to study the effects of applying organic and inorganic sources of nutrients on yield of jute-rice-wheat system and soil health. The unfertilized soil supported yields of 0.8 t ha^{-1} of jute fibre, 1.5 t ha^{-1} of rice grain and 0.7 t ha^{-1} of wheat grain (average yield of 42 years). Application of 150% recommended NPK through chemical fertilizers produced maximum yields of jute (2.1 t ha^{-1}), rice (3.8 t ha^{-1}) and wheat (2.8 t ha^{-1}). The yields obtained with 150% NPK fertilizers were 5%, 2.7% and 12% higher than that with 100% NPK fertilizers +FYM. Combined application of 100% NPK fertilizers and FYM, however, increased soil organic carbon, available nitrogen, phosphorus and potassium from 5.60 to 8.90 g kg^{-1}, 270 to 316 kg ha^{-1}, 40.7 to 120 kg ha^{-1} and 139 to 236 kg ha^{-1} respectively. Maximum DTPA-extractable micronutrients in soil were also observed with 100%NPK fertilizers+FYM. Applying FYM together with NPK fertilizers increased microbial biomass from 221 to 435 mg kg^{-1} and microbial quotient from 3.95 to 4.89 with concomitant increase in dehydrogenase, phosphatase and fluorescein-diacetate-hydrolyzing activities in the soil. The acid phosphatase activity (139 to 275 µg $PNPg^{-1}$ h^{-1}) was much lower than alkaline phosphatase activity (479 to 616 µg $PNPg^{-1}$ h^{-1}). The enzymes assayed showed significant correlation with microbial-C and organic C. Beneficial effects of integrated nutrient management (NPK+FYM) on soil health were reflected on the yields of all the crops.

Keywords: Indo-Gangetic plains, Jute-rice-wheat, NPK uptake, Soil fertility, Yield sustainability

INTRODUCTION

Intensive cropping with continuous application of only inorganic fertilizers at high doses and indiscriminate use of agrochemicals on soils has resulted in declining yield trend and multinutrient deficiencies in many soils. Long term fertilizer experiments are vital tools to examine the sustainability of modern intensive cropping. These experiments provide valuable information regarding the impact of continuous application of fertilizers in varying combinations on soil health, and crop productivity which can be used for precise monitoring of changes in soil fertility and trends in crop yields (Blair *et al*., 2006, Manna *et al*., 2007, Li *et al.,* 2010).

The jute-rice-wheat rotation is an important and profitable crop rotation practised in West Bengal, contributing most of the food and responsible for food security of this region. The production of this cropping system, however remain stagnant even after the introduction of high yielding cultivars. Depletion of soil nutrients, inadequate, imbalanced and inefficient use of applied nutrients might be the possible causes of plateau in yield. Balanced application of nutrients through organics and inorganic sources, therefore, will be essential to improve and sustain crop yields and maintain soil fertility. Long term studies have shown that practices like balanced use of fertilizers, organic manuring, residue incorporation, crop rotation, and green manuring improved physical, chemical and biological properties of soil (Walia *et al*., 2010; Sharma and Subehia, 2014).

Soil quality does not depend just on the physical and chemical properties of the soil but also on the biological properties. Enzymes are important soil components involved in dynamics of soil nutrient transformations, and enzyme activity is considered to be a major contributor of overall soil microbial activity (Frankenberger and Dick, 1983) and soil quality (Visser and Parkinson, 1992; Dick, 1994). Among different enzymes, dehydrogenase and phosphatase are important in the transformation of different plant nutrients, and soil enzymatic activity analysis is considered one of the microbiological indicators of soil quality (Winding *et al*., 2005). Continuous application of fertilizer and manure has a significant effect on enzyme activity (Masto *et al*., 2006).

In India, several long term studies have shown wide variability in crop productivity and it is essential to monitor the long term changes in crop yields, soil nutrient status, and nutrient supplying capacity to ensure and improve crop productivity. Relatively less information is available on the trend of yield, nutrient availability and enzymatic activities under long term jute-rice-wheat rotation (Majumdar *et al.,* 2014). Therefore, the present study focuses on long term agroecosystem sustainability of jute-rice-wheat system under different fertilizer treatments. The objectives of the present

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study were to assess the long-term impacts of nutrient management practices on sustainability and soil quality of jute-rice-wheat rotation in the Eastern region of India.

MATERIALS AND METHODS

Site description: All India Coordinated Research Project on Long Term Fertilizer Experiment with jute-rice-wheat cropping sequence was initiated in 1971 at the experimental farm of CRIJAF, Barrackpore, located in the eastern region of India (22°45'N latitude and 88°26'E longitude and a mean elevation of 9 m above mean sea level). The climate of this region is tropical and sub-humid to humid. Average maximum and minimum temperature is 31.1 and 20.8°C, respectively, with average annual rainfall of 1559.9 mm. The soil of the experimental site is classified as *Eutrochrept* (Nilganj series) in New Gangetic Alluvial tract, with EC 0.23 dS m^{-1}, pH 7.1, low in organic carbon (4.2 g kg^{-1}), medium in available N (223 kg ha^{-1}), high in available P (41.5 kg ha^{-1}) and medium in available K (143 kg ha^{-1}). DTPA extractable zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) were 1.3, 3.6, 31 and 60 ppm, respectively.

Experimental design and treatment: The experiment included three crops per year, jute (April-July), rice (August-November) and wheat (Nov-Mar) with 10 treatment combinations as given in Table 1. 100% NPK treatment consisted of 60 kg N; 13 kg P; 50kg K per hectare for jute, 120 kg N; 26 kg P; 50kg K per hectare for rice and wheat. The 50% and 150% NPK treatments comprised half and one half times the above doses of N, P and K, respectively. The NPK fertilizers were applied in the form of urea, DAP, SSP, and MOP. All P, K and organics were applied as basal fertilizers whereas N (urea) was applied in half as basal and rest half as top dress. Farmyard manure at the rate of 10 tons ha^{-1} only once was applied each year before the sowing of jute crop. In the 100% NPK+Zn treatment, Zn was applied as $ZnSO_4$ at the rate of 10 kg ha^{-1} before sowing of wheat. 100%NPK+HW (hand weeding) refers to the manual removal of weeds throughout the course of study. In all the treatments, except 100% NPK+HW, weeds were controlled chemically.

Soil sampling and analysis: Soil samples were collected from 0 to 15 cm layer from all the replications after harvesting of the wheat crop in 2013. The soil samples were analysed for organic carbon (Walkley and Black, 1934), available N (Subbiah and Asija, 1956), available P (Olsen et al., 1954), available K (Hanway and Heidel, 1952), DTPA- extractable Cu, Fe, Zn and Mn (Lindsay and Norvell, 1978), pH (1:2 soil: water suspension) and EC (1:2 soil: water suspension). Dehydrogenase activity was determined by using the method of Klein *et al.* (1971). Acid and alkaline phosphatase enzyme activities were determined by the method of Tabatabai and Bremner (1969). The sustainable yield index (SYI suggested by Singh *et al.*, 1990) is defined as

$$SYI = Y - sd / Ymax$$

where SYI is sustainable yield index, Y is the average yield of jute, rice and wheat over years and sd is the standard deviation and Y_{max} is the observed maximum yield in the experiment over the years of cultivation. Analysis of variance (ANOVA) was carried out by using the randomized complete block design. The significant difference among the means of different treatments were analysed by Duncan's multiple-range test using SAS v9.2.

RESULTS AND DISCUSSION

Jute, rice and wheat yield: For yields averaged over years, the comparison of treatments revealed that the percent yield increase in treated plots over control ranged from 77 to 149% in jute , 79 to 152% in rice and 144 to 288 % in wheat. Mean yields of jute, rice and wheat observed under unfertilized control treatment suggests that the soil of our experimental field is capable of supporting average yield of jute, rice and wheat to the tune of 0.8, 1.5 and 0.7 t ha^{-1}, respectively without any external application of nutrient inputs. All the crops responded to application of nutrients through inorganic fertilizers, increasing average yield of jute, rice and wheat to 1.9, 3.5 and 2.3 t ha^{-1}, respectively with 100% NPK. Yield data recorded over the period 1971-2013 clearly demonstrate the superiority of integrated use of FYM with chemical fertilizers, which provided greater stability in crop production as compared to 100% NPK. This could be associated with other benefits of organics apart from N, P and K supply such as improvements in microbial activities, better supply of macro and micro-nutrients such as S, Zn, Cu and B, which are not supplied by inorganic fertilizers and less losses of nutrients from soil (Yadav *et al.,* 2000). Average fibre yield of jute and the grain yield of rice and wheat obtained with 150% NPK surpassed the yields obtained with 100% NPK+FYM (Table 2).

Table 1. Details of treatments and nutrients doses of NPK (kg ha^{-1}) in different crops.

Treatment	Treatment details	NPK doses (kg ha^{-1})		
		Jute	Rice	Wheat
T_1	50% NPK	30-6.5-25	60-13-25	60-13-25
T_2	100% NPK	60-13-50	120-26-50	120-26-50
T_3	150% NPK	90-19.5-75	180-39-75	180-39-75
T_4	100% NPK + Hand weeding	60-13-50	120-26-50	120-26-50
T_5	100% NPK+$ZnSO_4$@10 kg ha^{-1} in wheat	60-13-50	120-26-50	120-26-50
T_6	100% NP	60-13-0	120-26-0	120-26-0
T_7	100% N	60-0-0	120-0-0	120-0-0
T_8	100% NPK+ F Y M @ 10 t ha^{-1}	60-13-50	120-26-50	120-26-50
T_9	100% NPK as sulphur free source	60-13-50	120-26-50	120-26-50
T_{10}	Control (no input)	0-0-0	0-0-0	0-0-0

Table 2. Average yields, long term sustainable yield indices of jute, rice and wheat under different management practice over forty two years (1971 - 2013).

Treatments	Average yield (t /ha)			% increase over control			Long term SYI		
	Jute	Rice	Wheat	Jute	Rice	Wheat	Jute	Rice	Wheat
T_1	1.5	2.7	1.8	77	79	144	0.28	0.27	0.25
T_2	1.9	3.5	2.3	125	129	215	0.39	0.35	0.32
T_3	2.1	3.8	2.8	149	152	288	0.45	0.41	0.40
T_4	1.8	3.3	2.3	117	121	210	0.37	0.35	0.32
T_5	1.7	3.1	2.3	109	103	211	0.32	0.30	0.31
T_6	1.7	3.3	2.2	100	117	201	0.33	0.33	0.31
T_7	1.6	3.0	2.0	88	97	167	0.29	0.29	0.26
T_8	2.0	3.7	2.5	143	142	238	0.45	0.40	0.35
T_9	1.8	2.9	2.3	112	89	212	0.35	0.29	0.33
T_{10}	0.8	1.5	0.7	--	--	--	0.11	0.15	0.09

Table 3. Effect of chemical fertilizer and organic manures on soil physicochemical properties after forty two years of cropping (Means in a column followed by a common lower case letter are not significantly different by DMRT at P=0.05).

Treatments	pH	EC (dS/m)	Organic carbon (g/kg)	Available nutrients (kg/ha)		
				N	P	K
T_1	7.62b	0.16d	6.80b	282ef	65.0f	176d
T_2	7.62b	0.17cd	7.10b	290de	88.9d	212b
T_3	7.56c	0.17cd	7.10b	321a	107b	232a
T_4	7.61b	0.16d	7.40b	306bc	89.1d	195c
T_5	7.60b	0.17c	7.60b	312ab	87.5d	209b
T_6	7.62b	0.16d	7.10b	306bc	101c	131e
T_7	7.63b	0.17c	6.90b	303bcd	40.0g	135e
T_8	7.50d	0.23a	8.90a	316ab	120a	236a
T_9	7.63b	0.18b	7.10b	294cde	82.4e	188c
T_{10}	7.66a	0.16d	5.60c	270f	40.7g	139e

Table 4. Long-term effect of manure and fertilizer use on microbial biomass carbon, microbial quotient and enzymatic activities (Means in a column followed by a common lower case letter are not significantly different by DMRT at P=0.05).

Treatments	DTPA extractable micronutrients (mg/kg)			
	Zn	Fe	Cu	Mn
T_1	0.55e	20.0d	3.86d	6.84d
T_2	0.67d	22.4bc	3.93cd	7.05bc
T_3	0.84c	26.5a	4.08b	7.33a
T_4	0.56e	23.0b	3.92cd	6.90cd
T_5	0.92b	23.3b	3.93cd	7.10bc
T_6	0.65d	24.0ab	3.95cd	7.01bcd
T_7	0.52e	17.5e	3.57e	6.97bcd
T_8	1.11a	26.8a	5.03a	7.12b
T_9	0.64d	21.4cd	3.97c	7.06bc
T_{10}	0.46f	17.7e	3.42f	6.36e

The lower jute and rice yields obtained with sulphur free fertilizer treatments as compared to S bearing fertilizer treatments were possibly due to depletion of S reserve in the soil under intensive cropping with S free fertilizers over the years. The SYI values in Table 2 revealed that among various treatments analysed, 150% NPK and 100 % NPK+FYM sustained the jute, rice and wheat yields more than other treatments. SYI value with 150% NPK was comparable to 100% NPK+FYM in all the crops indicating need of organic manuring, besides recommended NPK level of NPK fertilizers for sustaining high crop yields in *inceptisols* of Barrackpore. The SYI was greatest for jute, followed by rice and wheat, indicating those jute and rice yields are more sustainable than wheat yield.

Nutrient uptake: For calculating nutrient uptake, leaf, bark and wood in jute, and straw and grain in rice and wheat were considered. During all the years N, P and K uptake by jute, rice and wheat was higher in fertilized plots as compared to the unfertilized control. Nitrogen uptake was highest in 150% NPK treatment. Incorporation of farmyard manure (along with chemical NPK fertilizers) increased the N uptake over 100% NPK (Fig.1). Nitrogen uptake was highest in rice followed by wheat and jute. Uptake of P and K was more in jute and rice whereas it was less in wheat. Data on addition and removal of nutrients (N+P+K) by all three crops revealed that total quantity of nutrients (N, P and K) added were less than the nutrients removed. For N and P, addition of nutrients was observed to be larger than removal. For instance application of nitrogen in 100% NPK treatment (300 kg $ha^{-1}yr^{-1}$) was larger than the uptake (283.32 kg $ha^{-1}yr^{-1}$) and the same was true for P. But the reverse was true for K. The uptake of K by all the three crops was much higher (313.65 kg $ha^{-1}yr^{-1}$) than the amount of K added through fertilizer (150 kg $ha^{-1}yr^{-1}$) in all the crops. Thus, on an average 164 kg K per hectare is mined from soil every year. If this situation continues for years, K deficiency would appear as yield limiting nutrient and would derail the sustainability of the system. Larger application of P than its uptake was reflected by increase in soil P. However, proportional increase in N was not recorded which indicates loss of N from the system.

Changes in soil quality parameters: Data presented in Table 3 revealed that after the 42[nd]cycle of wheat crop, pH of the surface soil increased in comparison to its initial status (pH 7.1). After wheat harvest, the experimental soils had pH 7.50 to 7.66 in 0-15cm and it indicates that continuous application of fertilizers and manures for 42 years increased pH by 0.4 to 0.6 units. The increase in pH may be attributed to more intake of anions like nitrate, phosphate, borate and molybdate besides H^+ ions by roots and in turn excretion of HCO_3^- and OH^- ions in soil solution to maintain electrical neutrality. It is interesting to note that increase in pH was less with application of FYM along with chemical fertilizers as compared to application of chemical fertilizers alone and this might be attributed to production of organic acids during decomposition of organic manures. In addition to this, preferential intake of more monovalent cations by cereals from soil colloids resulting in increased divalent cations (Ca^{2+}, Mg^{2+}) in soil may be argued for raising the soil pH. Reports also showed that on an average about 15 t ha^{-1}green jute leaves are added into a field, which adds nearly 22 kg Ca to the soil. The electrical conductivity (EC) of the soil varied from 0.16 to 0.23 dS m^{-1}(Table 3). Continuous application of fertilizers and organic manures for 42 years in jute-rice-wheat cropping system resulted in significantly higher soil organic carbon (SOC) content over control. Application of fertilizers alone or in combination with organic manure has also increased the SOC content in surface soil by 62% to 112% over the initial value. The higher stubble and root biomass retention with concomitant higher yields in fertilized plots might have improved SOC in surface soil. The lowest SOC in unmanured/ unfertilized control (5.60 g kg^{-1}) may be attributed to lower residue return to the soil. Similar results of build up of SOC in long term fertilizer experiments due to continuous cropping and combined use of chemical fertilizers and manures were also reported earlier (Rudrappa *et al*., 2006; Walia *et al*., 2010). SOC concentration in the surface soil under all the treatments except control and 100% NPK+FYM were statistically at par.

Soil available N, P and K contents were significantly affected by different fertilization treatments (Table 3). Available N status of the soil increased to 270 kg ha^{-1} in control plot from initial value of 223 kg ha^{-1} after wheat harvesting. Long term manure application along with chemical fertilizers led to significantly higher values of soil available N compared to other fertilization treatments. Increase in soil available N and available P due to long-term use of organic manure have also been reported by several other researchers (Motavalli and Miles, 2002, Shahid *et al*., 2013 and Shahid *et al*., 2015). It was observed that under no fertilizer control (T_{10}) and P- omitted plots, available P in the surface soil decreased from the initial value of 41.5 kg ha^{-1} to 40.7 kg ha^{-1} while it increased under all other treatments. Higher soil P status may be due to lower utilization of P by the crop from applied sources, which resulted in build up of P in the soil. Decomposition of organic manure (FYM) produced various organic acids which solubilize phosphate and other phosphate bearing minerals and thereby increase P availability in soil (Verma *et al.,* 2005; Urkurkar *et al*., 2010). Increased availability of K with 100% NPK+FYM application might be due to the direct addition of K to the available pool of the soil, mineralization of organic sources and solubilization from native sources during the decomposition (Subehia and Sepehya, 2012). The soil available K in 150% NPK was statistically at par with 100% NPK+FYM treatment and was significantly greater than other treatments. The available K content in control plot did not differ from the T_6 (100% NP) and T_7(100% N) treatments and a slight reduction (nearly 2.6 to 8.9%) from the initial level of available K status was observed in these treatments, respectively.

Forty two years of continuous cropping, fertilization and manuring resulted in depletion of DTPA-extractable Zn, Fe, Cu and Mn (Table 4). DTPA extractable Zn in the soil under different treatments ranged from 0.46 to 1.11 mg kg^{-1}. The observed decrease in Zn in soil from its initial level might be due to the higher uptake of Zn by crops associated with higher crop yield. Relatively higher values of DTPA-extractable Zn in FYM amended plots could be ascribed to the better supply of Zn by conversion of less soluble fractions of Zn to more plant-available fractions resulting from the addition of organic matter in the form of FYM. There was significant difference among the treatments with respect to DTPA-extractable Fe content in the soil after wheat harvest and it varied from 17.7 to 26.8 mg kg^{-1}. This decline in DTPA-extractable Fe with continuous cropping has occurred because of Fe removal by successive crops from the native reserve of this micronutrient cation. The results are in accordance with those reported earlier by Singh *et al.* (1995) and Behera *et al.* (2009). Behera *et al*. (2009) reported that available Fe content declined in all the treatments from the initial level of 10.6 mg kg^{-1}, as a result of continuous cropping and fertilization for 32 years. The magnitude of depletion ranged from 3.82 mg kg^{-1} to 4.89 mg kg^{-1} under various treatments. In addition to this, it was also reported that available Mn in surface soil declined from the initial level of 20.0 mg kg^{-1} recorded in 1971. The reduction ranged from 1.22 to 3.99 mg kg^{-1} at pre maize and 0.15 to 3.92 mg kg^{-1} at post wheat stages. The DTPA-extractable Fe and Mn declined from their respective initial (1971) values as a result of continuous cropping and fertilizer application. This is ascribed to the continuous uptake by the crops over the years in addition to their non-replenishment in the form of fertilizers.

The lowest and highest amounts of available Fe were recorded under the no-fertilizer conrtol (17.7 mg kg^{-1}) and 100% NPK+FYM (26.8 mg kg^{-1}) respectively. Results showed that DTPA extractable Fe content reduced by more than 50% in control as compared to the initial value of 31 mg kg^{-1} and the reduction was less in NPK and NPK+FYM treatments. This might due to

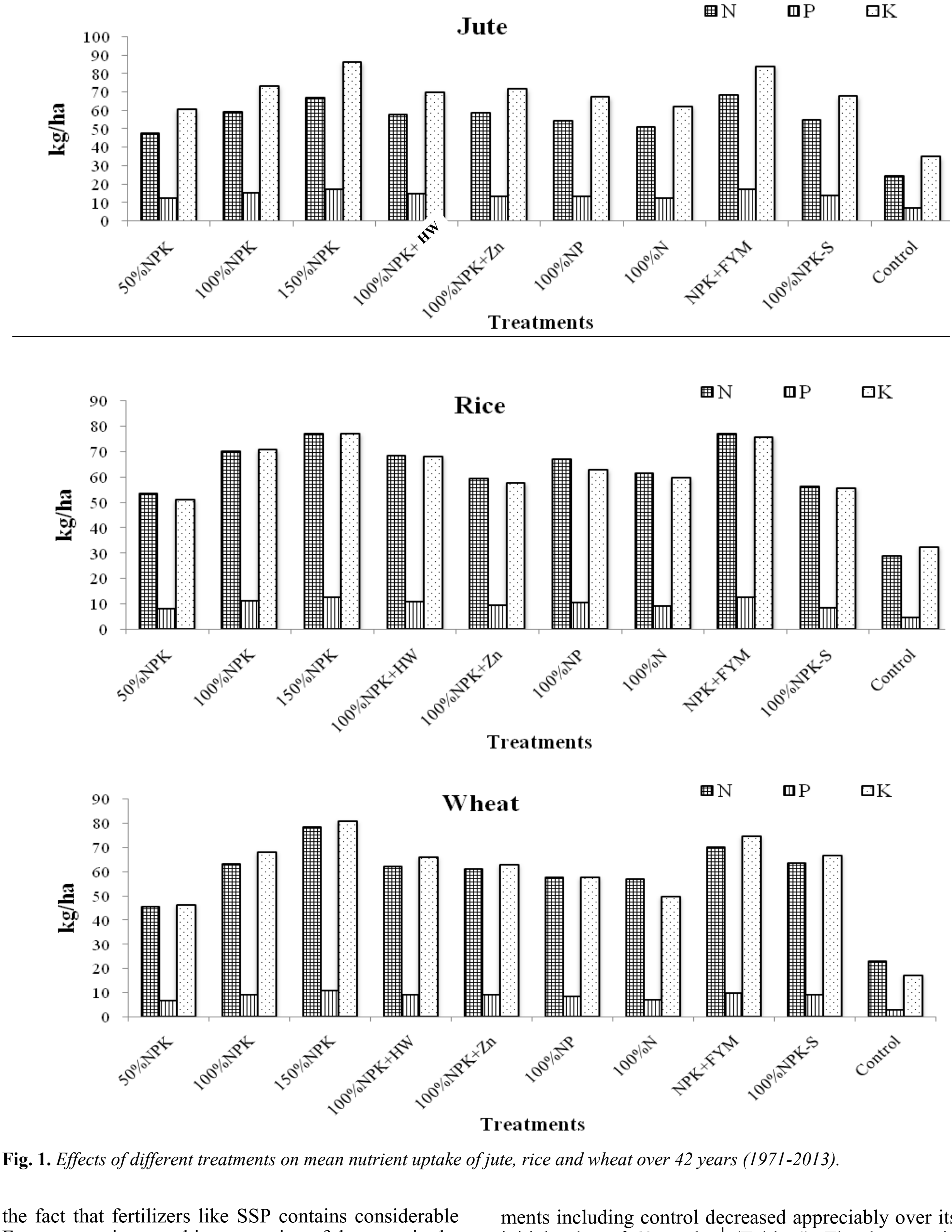

Fig. 1. *Effects of different treatments on mean nutrient uptake of jute, rice and wheat over 42 years (1971-2013).*

the fact that fertilizers like SSP contains considerable Fe as contaminant and incorporation of the same in the field might have helped in checking the diminishing trend of Fe for NPK treated plots. DTPA extractable Mn in the soil under different treatments varied from 6.36 to 7.33 mg kg^{-1}. Perusal of data indicated that DTPA extractable Mn in soil under different treatments including control decreased appreciably over its initial value of 60 mg kg^{-1} (Table 4). The decrease in Mn status of soil over its initial status could be due to repetition of same cropping system year after year thus creating favourable condition for Mn^{2+} oxidizing bacteria or fungi leading to quick depletion of Mn in the rhizosphere zone. This finding is in agreement with the

Table 5: Long-term effect of manure and fertilizer use on microbial biomass carbon, microbial quotient and enzymatic activities (Means in a column followed by a common lower case letter are not significantly different by DMRT at P=0.05).

Treatments	MBC (mg kg^{-1})	MBC/SOC	DHA (µg TPF g^{-1} 24 h^{-1})	FDA (µg fluorescein g^{-1} h^{-1})	AP (µg PNPg^{-1} h^{-1})	AlKP(µg PNPg^{-1} h^{-1})
T 1	273g	4.01	4.9 d	12.3e	151e	557e
T 2	328d	4.62	6.0bc	13.9d	170d	579cd
T 3	331d	4.53	5.7c	16.1b	186b	603b
T 4	345c	4.66	6.4b	14.1d	172d	581cd
T 5	360b	4.74	6.1bc	15.2bc	180bc	588c
T 6	298ef	4.20	4.4de	11.6e	147e	532f
T 7	287f	4.16	4.0e	11.3ef	146e	519g
T 8	435a	4.89	7.1a	19.0a	275a	616a
T 9	305e	4.30	4.6de	14.9cd	176cd	575d
T 10	221h	3.95	2.8f	10.9f	139f	479h

results reported by Nambiar (1994). Nambiar (1994) reported that a marked reduction in available Mn was noted on both Ustochrepts (Delhi) and Vertic-Ustochrepts (Coimbatore), the magnitude of which amounted to 54% and 59%, respectively. Data reported in Table 4 revealed that there was slight increase in the Cu content in FYM ammended plots over its initial value which could due to the chelating action of organic compounds released during decomposition of FYM, which increased the availability of micronutrients by preventing fixation. DTPA-extractable Cu in soil under all the treatments remained more or less similar to the initial value of 3.6 mg kg^{-1} which might be due to continuous addition of nutrients as contaminants through the fertilizers.

Mean values of all the soil biological properties are given in Table 5. Microbial biomass carbon in the soil varied from 221 to 435 mg kg^{-1}, with the highest value recorded under the 100% NPK+FYM treatment and the least in the control plots. These results are in line with the findings of Masto *et al*. (2006) and Nayak *et al*. (2012). Masto *et al*., 2006 reported that application of FYM along with NPK significantly increased the MBC over NPK alone and it increased from 200 to 303 mg kg^{-1}. Similarly Nayak *et al*. (2012) also stated that continuous application of FYM along with NPK resulted in a significantly higher soil MBC over NPK at all four locations. The ratio of MBC to organic carbon (microbial quotient) provides a measure of organic matter dynamics (Anderson and Domsch, 1989; Carter, 1991). Microbial quotient was lowest in no fertilizer and no manure control (3.95) and the highest under 100% NPK+FYM treatment (4.89).

Dehydrogenase, FDA hydrolase, acid and alkaline phosphatase activities in the soil varied from 2.8 to 7.1mg TPF g^{-1} soil 24 h^{-1}, 10.9 to 19.0 µg fluorescein g^{-1} soil h^{-1}, 139 to 275 and 479 to 616µg p-nitrophenol g^{-1}soil h^{-1}, respectively (Table 5).

Correlation study: A correlation matrix (Table 6) developed among different soil properties showed that organic C content was positively and significantly correlated with DTPA-Zn (r = 0.85**), DTPA-Mn (r = 0.90**), DTPA-Fe (r = 0.82**) and DTPA-Cu (r = 0.77**). A significant relationship of soil organic C and DTPA-extractable Zn, Cu, Fe and Mn in soil supports the findings of Follet and Lindsay (1970) which explains the complexing agents generated by organic matter and their effect in increasing the micronutrient mobility/or plant availability. DTPA-Zn, Mn, Fe and Cu did not show any relationship with pH which was in line of the findings of Pati and Mukhopadhyay (2011) and Behera and Shukla (2013). This indicates that distribution of available micronutrient cations are not affected by soil pH. MBC is regarded as one of the most sensitive indicators of the sustainability of the system. In this study, MBC (r = 0.97**) was found to be significantly correlated with organic C. Increase in stubbles and root mass increased the OC content which dictated the trend of soil MBC due to higher substrate availability of the microorganisms. Positive correlation observed between FDA and MBC (r = 0.90**) and organic C (r =0.85**) indicates the improvement in soil quality and similarly DHA showed significant correlation with microbial biomass C (r = 0.92**) and organic C (r =0.84**)

Conclusion

Results of the present study revealed that the recommended doses of NPK fertilizers (60 kg N, 13 kg P and 50kg K per hectare for jute, 120 kg N, 26 kg P, 50kg K per hectare for rice and wheat) alone are inadequate to sustain productivity of jute-rice-wheat system of Indo-Gangetic plain and application of organic manures like FYM (10 tons ha^{-1}) is important for achieving the same. Combined/ integrated use of chemical fertilizers and organic manure maintains optimum physical, chemical and biological properties of the soil under intensive cropping.

REFERENCES

Anderson, J.P.E. and Domsch, K.H. (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology and Biochemistry,* 21: 471–479

Behera, S.K. and Sukla, A.K. (2013). Depth-wise distribution of zinc, copper, manganese and iron in acid soils of India and their relationship with some soil properties. *Journal of the Indian Society of Soil Science,* 61(3): 244-252

Table 6. Pearson correlation coefficients illustrating relationship among the soil properties and sustainable yield index of jute (SYIJ), rice (SYIR) and wheat (SYIW).

	OC	N	P	K	Fe	Cu	Mn	Zn	MBC	DHA	FDA	AP	ALKP	pH	EC
SYIJ	0.77**	0.65*	0.81**	0.76*	0.83**	0.52	0.86**	0.68*	0.82**	0.83**	0.78**	0.67*	0.90**	-0.76*	0.50
SYIR	0.75*	0.71*	0.81**	0.69*	0.85**	0.48	0.87*	0.66*	0.80**	0.82**	0.71*	0.63*	0.84**	-0.78*	0.46
SYIW	0.68*	0.67*	0.77**	0.68*	0.75*	0.40	0.75*	0.63	0.74*	0.76*	0.70*	0.53	0.87**	-0.65*	0.35
OC	1	0.60**	0.81**	0.652*	0.82**	0.77**	0.90**	0.85**	0.97**	0.84**	0.85**	0.91**	0.79**	-0.88*	0.84**
N		1	0.69*	0.45	0.64*	0.07	0.70*	0.68*	0.69*	0.53	0.61	0.54	0.54	-0.66*	0.41
P			1	0.74*	0.95**	0.43	0.71*	0.83**	0.87**	0.84**	0.83**	0.76*	0.84**	-0.79**	0.55
K				1	0.73*	0.32	0.63*	0.76*	0.77**	0.86**	0.91**	0.75*	0.92**	-0.75*	0.54
Fe					1	0.56	0.79**	0.84**	0.85**	0.82**	0.82**	0.80**	0.81**	-0.89**	0.62
Cu						1	0.67*	0.49	0.60	0.51	0.51	0.68*	0.48	-0.65*	0.75*
Mn							1	0.75*	0.89**	0.76*	0.79**	0.85**	0.74*	-0.89**	0.79**
Zn								1	0.88**	0.74*	0.90**	0.88**	0.78**	-0.90**	0.77**
MBC									1	0.92**	0.90**	0.90**	0.87**	-0.88**	0.76*
DHA										1	0.83**	0.76*	0.93**	-0.77**	0.53
FDA											1	0.93**	0.90**	-0.89**	0.79**
Acid Phosphatase												1	0.75*	-0.93**	0.94**
AlKali Phosphatase													1	-0.78*	0.54
pH														1	-0.80**
EC															1

*5% level of significance, ** 1% level of significance

Behera, S.K., Singh, D. and Dwivedi B.S. (2009). Changes in fractions of iron, manganese, copper, and zinc in soil under continuous cropping for more than three decades *Communication of Soil Science and Plant Analysis,* 40: 1380–1407

Blair N, Faulkner R, Till A, Poulton P. (2006). Long-term management impacts on soil C, N and physical fertility: Part I: Broadbalk experiment. *Soil and Tillage Research*, 91: 30–38

Carter, M.R. (1991). The influence of tillage on the proportion of organic carbon and nitrogen in the microbial biomass of medium textured soils in a humid climate. *Biology and Fertility of Soils,* 11: 135–139

Dick, R.P. (1994). Soil enzyme activities as indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), defining soil quality for a sustainable environment. SSSA special publication no 35, ASA and SSSA, Madison, WI, p. 104–124

Frankenberger, W.T. and Dick, W.A. (1983). Relationships between enzyme activities and microbial growth and activity indices in soil. *Soil Science Society of American Journal*, 47, 945–951

Follet, R. H. and Lindsay, W. L. (1970). Profile distribution of zinc, iron, manganese and in Colorado soils. *Technical Bulletin* 110, Colorado State university Experiment Station Experiment Station Fort Collins, Co, p 79.

Hanway, J. J. and Heidel, H. (1952). Soil analyses methods as used in Iowa state college soil testing laboratory. *Iowa Agriculture,* 57, 1–31

Klein, D.A., Loh, T.C. and Goulding, R.L. (1971). A rapid procedure to evaluate dehydrogenase activity of soils low in organic matter. *Soil Biology and Biochemistry,* 3: 385–387

Li BY, Huang SM, Wei MB, Zhang HL, Shen AL, *et al.* (2010). Dynamics of soil and grain micronutrients as affected by long-term fertilization in an aquic Inceptisol. *Pedosphere,* 20: 725–735

Lindsay, W. L., Norvell. W. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal*, 2: 421–448

Olsen, S. R., C. V. Cole, F. S. Watanable, and L. A. Dean. (1954). Estimation of available phosphorusin soils by extracting with sodium bicarbonate (Circular No. 939). *Washington, D.C.: U.S. Department of Agriculture*.

Manna, M, Swarup, A, Wanjari, R, Mishra, B, Shahi, D. (2007). Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil and Tillage Research*, 94: 397–409

Masto, R. E., Chhonkar, P. K., Singh, D. Patra, A. K. (2006). Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical inceptisol. *Soil Biology and Biochemistry,* 38: 1577-1582

Majumdar, B., Saha, A.R., Ghorai, A.K., Sarkar, S.K., Chowdhury, H., Kundu, D.K. and Mahapatra, B.S. (2014). Effect of fertilizer treatments on jute (*Corchorus olitorius*), microbial dynamics in its rhizosphere and residual fertility status of soil. *Indian Journal of Agricultural Sciences,* 84 (4): 503-8

Motavalli, P. and Miles, R. (2002). Soil phosphorus fractions after 111 years of animal manure and fertilizer applications. *Biology and Fertility of Soils,* 36:35–42

Nambiar, K.K.M. (1994). Soil fertility and crop productivity under long-term fertilizer use in India. New Delhi, *Indian Council of Agricultural Research.*

Nayak, A.K., Gangwar, B., Shukla, A.K., Mazumdar, S.P. Anjani Kumar, Raja, R. Kumar Anil, Vinod Kumar, Rai, P.K. and Udit Mohan (2012). Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. *Field Crops Research*, (127): 129–139

Pati, R. and Mukhopadhyay, D. (2011). Distribution of cationic micronutrients in some acid soils of West Bengal. *Journal of the Indian Society of Soil Science,* (59): 125-133

Rudrappa, L., Purakayastha, T.J., Singh, Dhyan, Bhadraray, S. (2006). Long-term manuring and fertilization effects on soil organic carbon pools in a typic haplustept of semi-arid sub-tropical India. *Soil Tillage Research,* 88: 180–192 doi:10.1016/j.still.2005.05.008

Shahid M, Nayak A.K., Shukla A.K., Tripathi, R., Kumar, A., Mohanty, S., Bhattacharyya, P., Raja, R. and Panda, B. B. (2013). Long-term effects of fertilizer and manure applications on soil quality and yields in a sub-humid tropical rice -rice system. *Soil Use Management,* (29): 322–332

Shahid, M., Shukla, A.K., Bhattacharyya, P., Tripathi, R., Mohanty, S., Kumar, A., Lal B., Gautam, P., Raja, R. and Panda, B. B. Das, B. and Nayak AK. (2015). Micronutrients (Fe, Mn, Zn and Cu) balance under long-termapplication of fertilizer and manure in a tropical rice-rice system. *Journal of Soils and Sediments* DOI 10.1007/s11368-015-1272-6

Sharma, U. and Subehia, S. K. (2014). Effect of long term integrated nutrient management on rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) productivity and soil properties in North –Western Himalaya. *Journal of the Indian Society of Soil Science*, 62 (3): 248-254

Singh, H., Sharma, K.N. and Arora, B.S. (1995). Influence of continuous fertilization to a maize-wheat system on the changes in soil fertility. *Fertiliser Research,* 40: 719

Singh, R.P., Das, S.K., Bhaskara Rao, U.M. and Narayana Reddy, M. (1990). sustainability index under different management. Annual report central research Institute for Dryland Agriculture, Hyderabad, India

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for the determination of available nitrogen in soils. *Current Science,* 25: 259–260

Subehia, S.K. and Sepehya, S. (2012). Influence of long-term nitrogen substitution through organics on yield, uptake and available nutrients in a rice-wheat system in an acidic soil. *Journal of the Indian Society of Soil Science,* 60(3): 213-217

Tabatabai, M.A. and Bremner, J.M. (1969). Use of P-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry,* (1): 301–307

Urkurkar, J.S., A. Tiwari, S. Chitale, R.K. Bajpai, (2010). Influence of long- term use of inorganic and organic manures on soil fertility and sustainable productivity of rice (Oryza sativa) and wheat (Triticum aestivum) in inceptisols. *Indian Journal of Agricultural Sciences*, 80: 208-212

Verma, A., Nepalia, V., and Kanthaliya, P.C. (2005). Effect of continuous cropping and fertilization on crop yields and nutrient status of a Typic Haplustept. *Journal of the Indian Society of Soil Science*, 53: 365-368

Visser, S., Parkinson, D. (1992). Soil biological criteria as indicators of soil quality: soil microorganisms. *American Journal of Alternative Agriculture,* (7): 33–37

Walia, M. K., Walia, S. S. and Dhaliwal, S. S. (2010). Long-term effect of integrated nutrient management of properties of Typic Ustocrept after 23 cycles of an irrigated rice (Oryza sativa L.) – wheat (Triticum aestivum L.) system. *Journal of Sustainable Agriculture*, 34: 724-743

Winding, A., Hund-Rinke, K. and Rutgers, M. (2005). The use of microorganisms in ecological soil classification and assessment concepts. *Ecotoxicology and Environmental Safety,* 62 (2): 230-248

Walkley, A.J. and Black, C.A. (1934). An estimation of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* 37: 29–38

Yadav R. L., Dwivedi, B. S. and Pandey, P.S. (2000). Rice-wheat cropping system: assessment of sustainability under green manuring and chemical fertilizer inputs. *Field Crop Research*, 65:15-30