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Effects of long-term balanced and imbalanced use of inorganic fertilizers and organic manure (FYM) on soil chemical properties and yield of rice under rice-wheat cropping system

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Abstract
To examine the effect of long-term balanced and imbalanced use of inorganic fertilizers and FYM on chemical properties of soil, a field experiment with rice at the Crop Research Centre, Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, under a rice–wheat system was conducted. The experiment comprised 14 treatment combinations viz., N, P and K fertilizer application as individual component and use of chemical fertilizers in conjunction with farm yard manure. The experimental treatments were replicated four times. Combined application of inorganic fertilizer and FYM resulted in a positive influx of nutrients by increasing soil pH, electrical conductivity, cation exchange capacity, organic carbon content, available nitrogen, available phosphorus, available potassium and yield of rice in both the surface and sub-surface layer of soil. Lowest physico-chemical properties were recorded in control in both the surface and sub-surface layer while, the highest were recorded due to combined application of inorganic fertilizer along with organic manure. The highest EC (0.34 and 0.33 dsm^{-1}) was recorded under $N_{120}+P_{40}+K_{40}$+FYM while, the highest CEC (36.40 and 28.50 Cmol (p+) kg^{-1}), organic carbon (1.24 and 0.81 %), available N (293.20 and 1189.54 kg ha^{-1}), and P (29.35 and 12.18 kg ha^{-1}) was recorded due to $N_{180}+P_{80}+K_{40}$+Zn(F)+FYM. The highest available K (225.81 and 110.73 kg ha^{-1}) was recorded due to $N_{120}+P_{40}+K_{40}$+FYM. The lowest yields (grain, straw, and biological) were recorded in control while, the highest crop yields were recorded under $N_{180}+P_{80}+K_{40}$+Zn(F)+FYM. The present investigation clearly points out the significance of balanced and imbalanced use of nutrients including FYM in rice-wheat cropping system for improving the various physico-chemical soil quality indices and yield of rice crop over a long period.

Keywords: Long-term fertilizer experiment, rice, FYM, chemical indices, soil quality

Introduction
Rice and wheat are important food grain crops of Asia. In India these two crops accounts for 60% of the total area and contribute nearly three-forth of total food grain production and receive 60-65% of total fertilizers consumed in the country. Presently, the rice-wheat cropping system in the Indo-Gangetic plains is showing sign of 'fatigue' due to continuous cropping of this highly nutrient and water exhaustive cereal-cereal system. Imbalance use of chemical fertilizers alone tends to decline soil quality and fertility over a period of years with given inputs. Therefore, the most logical way to manage long-term fertility and productivity of soil is integrated use of inorganic and organic sources of plant nutrients. For the development of sustainable food production system maintenance and management of soil fertility is pivotal (Doran *et al.*, 1988) [12]. Thus, the logical way emerging to manage long-term fertility and productivity of soil is integrated use of organic and inorganic sources of plant nutrients to address the concern of excess and/ or depletion of nutrients (Aulakh and Grant, 2008) [1].
Combined application of manure with inorganic fertilizers was more effective as compared to inorganic fertilizers alone in building up fertility status of soil and increasing the productivity of rice and wheat (Karlen *et al.*, 1992) [15]. Dhiman *et al.* (1998) [11] reported that organic carbon, available P and K were highest where an additional manure application was made. Soil organic matter and total nitrogen levels were increased by about 120 % over 150 years in the manured plots. Such carbon stores might have appreciated the sink for global carbon (Tillman, 1998) [32]. Availability of nutrients in soil is governed by several ongoing chemical processes such as weathering and buffering, and properties like organic matter content, CEC and potential of hydrogen (pH). Reganold and Palmer (1995) [22] used certain chemical parameters related to nutrient availability as a measure of soil quality like CEC, total N, P and pH; and extractable P, S, Ca, Mg and K. It was suggested that total and available plant nutrients and nutrient cycling rates should also be considered in soil quality measurement (Karlen *et al.*, 1992) [15].

Under continuous cropping, changes in soil fertility and the resultant crop productivity can be related with nutrient imbalances, which have been recognized as one of the most important factors that limits crop yield. Even the applications of recommended NPK fertilizers, devoid of organic manure have not sustained soil quality. There are many reports based on the 10-15 years old experiments on the chemical and physical properties from the long term experiments in India and abroad separately, however very scanty information is available in respect of varying nutrient management practices in the rice-wheat cropping system and their impact on quality of Tarai soil.

Materials and methods

The present investigation was carried out in an ongoing long-term experiment, after twenty nine years, located at Norman. E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, Uttarakhand which was initiated in 1984. The experimental site lies in *Tarai* plains about 30 km southward of foothill of shivalik range of Himalayas at 29^0 N latitude, 79^0 29' E longitude and at an altitude of 243.8 m above the mean sea level. The chemical analysis of top 15 cm soil showed that it was rich in organic matter and medium in phosphorus and potassium and neutral to slightly alkaline in reaction. The field experiment has been laid in Randomized Block Design (RBD) in four replications with fourteen treatments comprising control, N, NP, NPK, a varying doses alone and with FYM. The N, P and K were provided as per treatment details through urea, single super phosphate and potassium, respectively. In one treatment N and P was provided using Di-ammonium phosphate. The FYM was applied @5 ton ha^1 only in rice

Collection of soil samples and processing

Individual soil samples from each plot were collected from two depths (0-15 and 15-30 cm) after harvesting of rice crop in the year 2013-14. The pH was determined in 1:2 Soil: Water ratio and after half an hour of equilibrium, the pH was determined with the help of a glass electrode on microprocessor based pH meter (Jackson, 1967) [14]. Electrical conductivity of the soil was measured in 1:2 Soil: Water suspension at 25^0C with digital microprocessor based conductivity meter (Bover and Wilcox, 1965) [7]. The cation exchange capacity in soil was determined by ammonium acetate method (Bache, 1976) [2]. The organic carbon content in soil was determined by following the modified Walkley and Black (1934) [35] method as described by Jackson (1967) [14]. Available nitrogen in soil was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956) [31]. Available phosphorus in soil was extracted by using sodium bi-carbonate extractant (0.5 M $NaHCO_3$) adjusted to pH 8.5 (Olsen *et al*., 1954) [18]. Available K was determined by neutral ammonium acetate (1N NH_4OAc; pH 7) method outlined by Black, (1965) [6].

Statistical analysis

The experimental data were analyzed using the statistical program STPR of G. B. Pant University of Agriculture and Technology, Pantnagar in a Randomized Block Design. Analysis of Variance and critical difference (CD) between treatments was calculated at 5% level of significance. Correlation coefficients were computed using SPSS version 16.

Results and Discussion

Soil pH

The data in respect of the pH at surface and sub-surface depth of soil as influenced due to application of nutrients in rice crop for twenty-nine years through fertilizer and /or FYM is presented in Table-1. The soil pH at 0-15 cm depth varied significantly after twenty-ninth cycle of rice crop however in sub-surface layer no significant impacts of fertilizer application was observed. The lowest pH in the surface soil after rice crop was registered under control while the highest pH to the tune of 8.16 was recorded due to $N_{120}+P_{40}+K_{40}$+Zn(F). There was no remarkable variation in soil pH due to various treatments of nutrient management through chemical fertilizers alone or in combinations with FYM for 29 years. An application of chemical fertilizers over a long period leads in increase in pH (Tyagi, 1989) [33]. However, fertilizer application in conjunction with FYM reduced the impact in comparison to control. Similar findings have been recorded earlier by Sime (2001) [27]; Sharma (2004) [24] and Bhatt (2012) [15]. It may be attributed to buffering action of soils that does not permit to alter the soil pH.

Electrical Conductivity

An application of nutrients through fertilizer alone and along with FYM had non-significant influence on soil EC at surface as well as sub-surface depths after harvest of rice crop (Table-1) The lowest electrical conductivity was recorded in control ($0.28dsm^{-1}$ and $0.24dsm^{-1}$) in both surface and sub-surface soil while the highest electrical conductivity ($0.34dsm^{-1}$ and $0.31dsm^{-1}$) was recorded with the treatment $N_{120}+P_{40}+K_{40}$+FYM in surface and sub-surface soil. Addition of NPK fertilizers increases accumulation of salt concentration in soil which contributes to increased electrical conductivity of soil. A slight increase in electrical conductivity due to continuous fertilizer use under intensive cropping was reported (Sime, 2001) [27] Similar results were obtained by Singh and Nand Ram (2007) [29]. The enhanced electrical conductivity due to FYM was attributed to the decomposition of organic matter.

Cation exchange capacity

An application of fertilizer nutrients alone and in combination with FYM influenced soil CEC significantly in surface soil as well as sub-surface soil after harvest of rice (Table-1). In both surface and sub-surface soil layer lowest cation exchange capacity (26.20 and 22.20 Cmol (p^+) kg^{-1} soil) was recorded in control. On the other hand an application of $N_{180}+P_{80}+K_{40}$+Zn(F)+FYM over a period of twenty-nine years favored the highest cation exchange capacity (36.40 and 28.50 Cmol (p^+) kg^{-1} soil) in both the surface and sub-surface soil layer. The balanced and imbalanced use of inorganic chemical fertilizers along with FYM increased the CEC of soil in comparison to control. The increase in CEC might be due to improvement in organic matter content of soil. CEC and exchangeable Ca^{2+} content of the soil improved with the application of organic sources of nutrients either alone or in combination with fertilizers when used over a long period of time. Long-term FYM/manure addition increases CEC due to the colloidal nature of organic matter (Patiram and Singh, 1993; Sinha *et al*., 1997) [19, 30]. The CEC was also found to be lowest in plots receiving N only and it increased with increase in soil pH.

Table 4.1: Effect of long-term fertilizer application at varying levels on soil pH, EC and CEC after twenty-ninth cycle of rice crop at different depths under rice-wheat cropping system

Treatments		pH		EC (dSm^{-1})		CEC (Cmol (p^+) kg^{-1} soil)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Control	7.81	8.13	0.28	0.24	26.20	22.20
T_2	N_{120}	7.86	8.03	0.32	0.29	27.30	23.10
T_3	N_{120}+P_{40}	8.00	8.18	0.29	0.27	28.80	23.60
T_4	P_{40}+K_{40}	8.02	8.17	0.29	0.28	29.80	24.00
T_5	N_{120}+K_{40}	8.05	8.20	0.32	0.27	31.50	24.70
T_6	N_{120}+P_{40}+K_{40}	8.07	8.22	0.33	0.30	32.70	25.60
T_7	N_{120}+P_{40}+K_{40}+Zn(F)	8.16	8.10	0.31	0.28	32.10	26.30
T_8	N_{120}+P_{40}+K_{40}+FYM	8.12	8.11	0.34	0.31	33.20	28.40
T_9	N_{120}+P_{40}+K_{40}+Zn(F)+FYM	8.14	8.22	0.32	0.29	34.40	27.80
T_{10}	N_{180}+P_{80}+K_{40}+Zn(F)+FYM	7.95	8.12	0.28	0.24	36.40	28.50
T_{11}	N_{150}+P_{40}+K_{40}	7.97	8.02	0.31	0.29	31.40	27.90
T_{12}	N_{180}+P_{80}+K_{40}+Zn(F)	8.03	8.08	0.32	0.29	33.30	26.60
T_{13}	N_{180}+P_{80}+Zn(F)	8.14	8.18	0.29	0.25	30.80	26.70
T_{14}	N_{120}+P_{40}+K_{40} (DAP)	8.01	8.13	0.31	0.29	30.50	26.30
S.Em±		0.07	0.05	0.01	0.01	0.92	0.70
C.D. (5%)		0.19	NS	NS	NS	2.69	2.05
C.V. (%)		1.66	1.33	8.98	8.88	5.08	4.70

Organic carbon

The soil organic carbon content, an indicator of soil fertility, was significantly influenced due to fertilizer application (Table-2). No application of fertilizer/FYM significantly decreased organic carbon (0.73 and 0.61%) content in control both the surface and sub-surface soil layer while, the highest organic carbon (1.24 and 0.81 %) content in both the surface and sub-surface layer was registered due to application of N_{180}+P_{80}+K_{40}+Zn(F)+FYM. The higher level of soil organic carbon content with the long-term fertilizer application along with FYM may be due to enhanced root growth, resulting more organic residue in soil, which after decomposition might have increased the soil organic carbon content. These results are in conformity with the finding of Singh *et al.* (1999) [28] who reported the enhanced soil organic carbon status after ten years of continuous rice-wheat cropping under varying fertilizer and manure treatment in Mollisols at Pantnagar. They observed that the status of organic matter dropped down drastically in all the treatments except in plots receiving FYM. It was ranged from 1.78% in PK to 2.09% with NPK + FYM from its initial value of 2.10 per cent. Continuous application of fertilizers alone and in combination with graded level of FYM for soybean based cropping system was studied by Babhulkar *et al.* (2000) [3] and reported that highest organic C status (6.2 g kg^{-1}) under the application of higher rate of FYM (7.5 Mg ha^{-1}) with half dose of N and P fertilizer. The maximum increase in soil organic carbon content was observed with integrated use of inorganic fertilizers (N+P+K) and organic manure.

Available N

Available nitrogen content in soil as affected by continuous application of balanced and imbalanced fertilization with or without FYM in rice-wheat system over a period of twenty-nine years is summarized (Table-2). All the fertilizer treatments resulted in significantly higher available nitrogen in soil, after harvest of rice over control. The lowest available nitrogen was observed in control (151.92 and 114.21 kg ha^{-1}) in both the surface and sub-surface soil, while the highest value of available nitrogen (293.20 and 189.54 kg ha^{-1}) in surface and sub-surface was recorded due to N_{180}+P_{80}+K_{40}+Zn(F)+FYM. Continuous cropping of rice-wheat system for twenty-nine years increased the available N significantly with the use of fertilizer N in combination with P and K fertilizer, as well as with combined use of inorganic fertilizer and FYM. The increase in available nitrogen content in soil due to application of FYM may be attributed to the mineralization of nitrogen and greater multiplication of soil microbes which converts organically bound N into inorganic form**.** The lowest value of available N in control may be due to mining of nutrients with continuous cropping without fertilization over the years. Application of fertilizers either alone NPK or in conjunction with organics were significantly superior to control. Significantly higher available N in fallow, NPK and N alone plots over control and in 100% NPK + FYM as compared to 100% NPK in silty clay loam at Pantnagar after 6 year of intensive cropping was reported (Bhardwaj, 1983) [4]. Increased available N after 4-year application of FYM and green manuring in soil may be due to early decomposition of green manure crops vis-a-vis FYM (Debnath and Hajra, 1972) [10]. In a long-term fertilizer experiment under rice-wheat system significant effect of fertilizer treatment on available nitrogen content after rice in both the soil depths was observed (Bhatt, 2012) [15]. Available nitrogen was found lower in deeper soil layer (15-30 cm) than in surface layer (0-15 cm) in both the years. Highest available nitrogen in both the profile depth was with 100% NPK+FYM, which was significantly higher than all the applied nutrient treatments except 150% NPK (Bhatt, 2012) [15]

Table 2: Effect of long-term fertilizer application at varying levels on soil organic carbon and available nitrogen after twenty-ninth cycle of rice crop at different depths under rice-wheat cropping system

Treatments		Organic C (%)		Available N (kg ha^{-1})	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Control	0.73	0.61	151.92	114.21
T_2	N_{120}	0.80	0.65	202.09	170.71
T_3	$N_{120}+P_{40}$	0.83	0.69	173.84	151.87
T_4	$P_{40}+K_{40}$	0.77	0.70	181.25	155.01
T_5	$N_{120}+K_{40}$	0.81	0.72	192.68	163.85
T_6	$N_{120}+P_{40}+K_{40}$	0.84	0.73	211.50	168.98
T_7	$N_{120}+P_{40}+K_{40}$+Zn(F)	0.87	0.75	214.64	175.61
T_8	$N_{120}+P_{40}+K_{40}$+FYM	1.19	0.78	255.44	189.54
T_9	$N_{120}+P_{40}+K_{40}$+Zn(F)+FYM	1.18	0.76	250.40	186.40
T_{10}	$N_{180}+P_{80}+K_{40}$+Zn(F)+FYM	1.24	0.81	293.20	189.54
T_{11}	$N_{150}+P_{40}+K_{40}$	0.85	0.72	224.06	176.98
T_{12}	$N_{180}+P_{80}+K_{40}$+Zn(F)	0.88	0.75	246.61	185.01
T_{13}	$N_{180}+P_{80}$+Zn(F)	0.84	0.74	235.44	180.12
T_{14}	$N_{120}+P_{40}+K_{40}$ (DAP)	0.74	0.62	205.23	149.07
S.Em±		0.03	0.02	9.26	4.23
C.D. (5%)		0.08	0.06	26.67	12.15
C.V. (%)		6.17	5.83	8.56	5.03

Available P

The data pertaining to available phosphorus in soil as influenced by continuous balanced and imbalanced fertilization in rice-wheat system are summarized in Table-3. The fertilizer treatments had significant influence on available soil phosphorus after harvest of rice crop. Highest amount of available phosphorus (28.26 and 12.32 kg ha^{-1}) in surface as well as sub-surface soil was recorded under $N_{180}+P_{80}+K_{40}$+Zn(F)+FYM while, the lowest available phosphorus (12.32 kg ha^{-1} and 7.08 kg ha^{-1}) was observed in control both the surface and sub-surface soil. Continuous cropping with combined application of inorganic fertilizers along with FYM increased the available P in soil. In general, the combined application of organics with fertilizers resulted in higher available P content over application of inorganic fertilizers alone. Build-up in available P with the conjoint use of fertilizers and organics could be ascribed to the release of organic acids during decomposition which in turn helped in releasing native phosphorus through solubilizing action of these acids. Also, organic matter forms a coating on sesquioxides and makes them inactive and thus reduces the phosphate fixing capacity of soil, which ultimately helps in release of ample quantity of plant available P. The similar results were obtained by.

Available K

Overall treatment effect on available potassium was statistically significant in surface and sub-surface soil after harvest of rice crop Table-3. The treatments which do not received potassium fertilizer *viz*. $N_{120}+P_{40}$, N_{120} and control had significantly lower amount of available soil potassium than the potassium consisting treatments. The lowest available potassium (173.19 kg ha^{-1} and 87.21 kg ha^{-1}) in soil was observed in N_{120} in both the surface and sub-surface soil layer while the highest amount of available potassium in surface and sub-surface soil layer (225.81 kg ha^{-1} and 110.73 kg ha^{-1}) was measured under ($N_{120}+P_{40}+K_{40}$+FYM). Increase in available K in T_8, T_9 and T_{10} treatments due to combined use of inorganic fertilizers along with FYM may be ascribed to the reduction of K fixation and release of K due to interaction of organic matter with clays, besides the direct K addition to the soil (Urkurkar *et al*., 2010; Subehia and Sepehya, 2012; Sharma and Gupta, 1998) [34, 23, 25]. The higher amount of K in the surface layer could be attributed to more exposure of K bearing minerals to weathering and or upward translocation of K from sub-surface layer by capillary rise or due to addition of K through plant residue, manure and fertilizers (Rao *et al*., 2013) [21].

Table 3: Effect of long-term fertilizer application at varying levels on soil available phosphorus and available potassium after twenty-ninth cycle of rice crop at different depths under rice-wheat cropping system

Treatments		Available P (kg ha^{-1})		Available K (kg ha^{1})	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Control	15.76	7.08	173.19	87.21
T_2	N_{120}	18.00	8.42	167.85	85.57
T_3	$N_{120}+P_{40}$	20.46	9.50	160.57	80.21
T_4	$P_{40}+K_{40}$	22.85	10.84	207.79	94.21
T_5	$N_{120}+K_{40}$	16.78	7.25	213.21	102.33
T_6	$N_{120}+P_{40}+K_{40}$	19.60	9.36	200.89	100.09
T_7	$N_{120}+P_{40}+K_{40}$+Zn(F)	19.12	8.02	182.61	96.45
T_8	$N_{120}+P_{40}+K_{40}$+FYM	28.26	12.32	225.81	110.73
T_9	$N_{120}+P_{40}+K_{40}$+Zn(F)+FYM	26.78	11.24	224.97	108.49
T_{10}	$N_{180}+P_{80}+K_{40}$+Zn(F)+FYM	29.35	12.18	217.13	100.65
T_{11}	$N_{150}+P_{40}+K_{40}$	20.20	8.56	214.05	95.61
T_{12}	$N_{180}+P_{80}+K_{40}$+Zn(F)	26.10	11.65	206.49	92.20
T_{13}	$N_{180}+P_{80}$+Zn(F)	20.60	9.36	204.81	90.57
T_{14}	$N_{120}+P_{40}+K_{40}$ (DAP)	16.89	7.86	192.49	88.13
S.Em±		0.88	0.33	7.41	3.18
C.D. (5%)		2.54	0.94	21.28	9.13
C.V. (%)		8.23	6.85	7.43	6.68

Yields

The fertilizer treatments comprising fertilizer alone or with FYM had significant effect on grain yield of rice Table-4. The results obtained indicated that the highest grain yield (6747 kg ha^{-1}) was recorded due to application of $N_{180}+P_{80}+K_{40}+Zn(F)+FYM$ while, the lowest grain yield (2120 kg ha^{-1}) was recorded under control. The results obtained indicated that the highest straw yield was recorded due to application of $N_{180}+P_{80}+K_{40}+Zn(F)+FYM$ while, the lowest straw yield was recorded under control. The highest biological yield was recorded with $N_{180}+P_{80}+K_{40}+Zn(F)+FYM$ while, the lowest biological yield was observed under control. The fertilizer treatments had significant influence on grain, straw and biological yields. The addition of FYM along with inorganic fertilizers produced higher grain yield of rice. It could be due to additional supply and availability of nutrients through FYM on the one hand and improved physical, chemical and biological condition of soil on the other hand. These finding are in conformity with the finding of Sharma *et al.* (1999) [26]. Combination of NPK along with FYM and Zn increased the grain yield of both the crops because of attaining better fertility status resulting good supply of nutrients. Such inference has also been drawn from several long-term fertility experiments conducted all over the India (Nambiar and Abrol, 1989; Nand Ram, 1995; Dawe *et al*., 2000; Yadav and Kumar, 2009) [17, 20, 9, 36]

Table 4: Effect of long-term fertilizer application at varying levels on yield of rice after twenty-ninth cycle under rice-wheat cropping system

Treatments		Rice (kg ha^{-1})		
		Mean grain yield	Mean straw yield	Biological yield
T_1	Control	2120	2420	4540
T_2	N_{120}	3082	3221	6303
T_3	$N_{120}+P_{40}$	5187	5733	10920
T_4	$P_{40}+K_{40}$	3108	3381	6489
T_5	$N_{120}+K_{40}$	2997	3221	6218
T_6	$N_{120}+P_{40}+K_{40}$	5312	5966	11278
T_7	$N_{120}+P_{40}+K_{40}+Zn(F)$	5583	6097	11680
T_8	$N_{120}+P_{40}+K_{40}+FYM$	6705	7007	13712
T_9	$N_{120}+P_{40}+K_{40}+Zn(F)+FYM$	6514	6834	13348
T_{10}	$N_{180}+P_{80}+K_{40}+Zn(F)+FYM$	6747	7189	13854
T_{11}	$N_{150}+P_{40}+K_{40}$	5922	7151	13073
T_{12}	$N_{180}+P_{80}+K_{40}+Zn(F)$	6167	6708	12875
T_{13}	$N_{180}+P_{80}+Zn(F)$	6198	7107	13387
T_{14}	$N_{120}+P_{40}+K_{40}$ (DAP)	5403	5853	11256
S.Em±		220	241.1	467.6
C.D. (5%)		637.5	692.3	1342.6
C.V. (%)		8.7	8.8	8.8

Conclusion

Long-term use of inorganic fertilizers and organic manure (FYM) found superior in comparison to alone application of inorganic fertilizers to sustain the crop productivity and soil fertility. The inorganic fertilizers along with organic manure was found to be a viable option for restoring soil organic carbon and nutrient turnover, thereby improving the availability of nutrients in soil, maintaining soil quality, and helping achieve sustainable productivity of rice crop for the long run under irrigated moisture regimes. Continuous application of NPK with Zn and FYM improve the yield sustainability and soil quality. Cumulative effect of long-term use of fertilizers lowered the risk of soil quality over a single year of application of fertilizers. Therefore, judicious application of inorganic and organic nutrients in an integrated manner is essential for proper nutrient supply, sustaining crop productivity and soil quality in a long-term rice-wheat cropping system.

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