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Change in soil chemical properties under different depths after 42 years rice-wheat cropping system in sub-tropical Mollisols of India

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ABSTRACT

In a 42 years long term experiment, the impact of continuous application of organic manures and inorganic fertilizers on soil chemical properties of Mollisol after rice-wheat sequence was studied at the Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The experiment was comprised of ten treatments *viz.,* T_1 (50% NPK), T_2 (100% NPK), T_3 (150% NPK), T_4 (100% NPK + hand weeding), T_5 (100% NPK + Zn), T_6 (100% NP), T_7 (100% N), T_8 (100% NPK + FYM), T_9 (100% NPK (-S)) and T_{10} (control). Significant build-up in soil fertility in terms of alkaline $KMnO_4$-N, Olsen-P, NH_4OAc-K and $CaCl_2$-S as well as soil organic carbon (SOC), and available Zn were observed under balanced fertilization with organics with in 0-60 cm soil depths. The highest values of available nutrients were maintained in FYM + NPK treated plots. The extent of change in available nutrients in sub-surface (15-60 cm) soil was low as compared to the surface soil (0-15 cm). These results conclude that for sustainable crop production and maintaining soil health, input of organic manure like FYM alongwith chemical fertilizers is of major importance and should be strictly recommended in the nutrient management practices for improving chemical properties of soils under rice-wheat system.

1. INTRODUCTION

Now a day's sustainability of rice-wheat cropping system is a burning issue, as it provides food for the major population of South Asian countries. India occupies an area of 9.2 million ha (M ha) over the Indo-Gangetic plains (Timsina *et al.,* 2010; Hossain *et al.,* 2016) with an average of 85% contribution to cereal production of India (Timsina and Connor 2001; Choudhury *et al*., 2014). It was estimated that rice and wheat production has to be increased by 1.1% and 1.7% per annum, respectively, for assuring South Asian food security in next four decades (Ladha *et al.,* 2003; Gathala *et al*., 2013). Fertilizers play a vital role in enhancing the production and productivity of any crop, but continuous and imbalanced use of high analysis chemical fertilizers are negatively affecting production potential and soil health. Judicious use of chemical fertilizers alongwith organic manure is essential to improve the soil health (Prasad *et al.,* 2010). Under integrated nutrient management practices, repeated applications of organic manures are often advocated to maintain soil fertility and crop productivity (Subehia and Sepehya, 2012). Continuous integrated use of organic manures and fertilizers would be promising for improving the sustainability of crop yield, and plant nutrition *vis-à-vis* soil health.

Long-term fertilizer experiments (LTFE) provide the needful information on effect of continuous application of different levels of fertilizer nutrients alone and in combination with organic manure under intensive cropping on soil health and crop productivity. These experiments can be used for accurate monitoring of changes in soil environment and productivity, and could be of outstanding contribution in solving the complex problems related to soil fertility management. There is a concern that use of chemical fertilizers over the years might damage the physical and chemical properties, and fertility of soils as well (Chouhan *et al.,* 2017; Pant and Ram, 2018). Hence, long-term field experiments having different nutrient management practices can provide direct information of changes in soil health and fertility, and can help in prediction of future soil productivity and soil environment interactions (Li *et al.,* 2010; Shen *et al*., 2010). Applications of organic and inorganic nutrients in rice-wheat cropping system in long-term experiments would be a suitable option for increasing productivity, improving nutrient availability as well as managing soil health in sub-tropical Mollisols of India (Choudhury *et al.,* 2018). Integrated use of manure with chemical fertilizer under long-term experiments resulted in enhancement of soil available nutrients much more effectively than that of chemical fertilizer alone (Prasad and Sinha, 1995). It was also suggested that application of organic manure has a great importance in rice-wheat system, not only for higher crop productivity but also for supporting soil environment to fight against emergence of multiple nutrient deficiencies finally leading to better soil health.

Prudent use of fertilizers and organic manure is necessary for increasing soil organic carbon status and nutrient turnover to secure sustainable crop productivity and soil quality in a long-term rice–wheat cropping system under irrigated mollisols (Pant *et al.,* 2017).

The integration of organic manures alongwith inorganic favours availability of plant nutrients throughout crop growing period, as well as improves soil physical, chemical, and biological environment which promotes favourable ecosystem functions. Our present study is aimed at figuring out the influence of nutrient management practices on soil nutrient availability from different soil depths for long-term rice-wheat cropping system in sub-tropical Mollisols of foothills of Himalayas.

2. MATERIALS AND METHODS

Site Descriptions

The present field experiment on rice–wheat cropping system was initiated in monsoon season of the year 1971 at the Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand under the network of All India Coordinated Research Project (AICRP) on LTFE. The experimental field is located at 29ºN latitudes, 79º30' longitudes at an altitude of 243.8 m above the mean sea level (AMSL). The experimental site falls in the Tarai region of northern India and lies just below the foothills of Himalayas. The climate of the experimental site is sub-humid sub-tropical with an average annual rainfall of 1433 mm, of which about 85% is received during short monsoon period of 2-3 months spreading from July to September. Occasional rains occur during winter months also. The maximum temperature may rise up to the 43ºC in May and minimum may fall below 2ºC in January. The soil of the area is Mollisol derived from the calcareous alluvium, rich in organic matter content, silty clay loam in texture, alkaline in reaction and free from salinity occurring on nearly level to very gently sloping land. Clay mineralogy is dominated by Chlorite and Illite. Taxonomically, the soil belongs to Aquic Hapludoll (Deshpande *et al.,* 1971). Initial soil characteristics of experimental site are given in Table 1.

Experimental Design and Treatments

The field experiment on rice-wheat cropping system was designed under AICRP-LTFE with 12 different nutrient management treatments in a randomized block design with four replications. For the present study, 10 treatments in three replications were selected. The treatment details for this study are given in Table 2.

The fertilizer doses 120 kg N, 60 kg P_2O_5, and 40 kg K_2O were adopted based on the soil test values for available N, P, and K in the year 1971. Nitrogen, P, and K were applied through urea/diammonium phosphate, single super phosphate and muriate of potash, respectively. Zinc was applied at the rate of 50 kg $ZnSO_4$ ha^{-1}, whereas, treatment 100% NPK-S+Zn received Zn through 25 kg ZnO ha^{-1}. Farmyard manure at the rate of 15 t ha^{-1} was applied once in a cropping

Table: 1
Initial soil characteristics of experimental site

S.No.	Characteristics	Value
1.	Particle size distribution	
	Sand (%)	32
	Silt (%)	39
	Clay (%)	29
	Soil texture	Silty clay loam
2.	pH (1: 2.5)	7.30
3.	Electrical conductivity (1: 2.5)	0.35 dS m^{-1}
4.	Cation exchange capacity	20.0 c mole (p+) kg^{-1}
5.	Organic carbon	1.48%
6.	Total N	0.13%
7.	Available N	392.0 kg ha^{-1}
8.	Available P	18.0 kg ha^{-1}
9.	Available K	125.0 kg ha^{-1}
10.	Available Zn	0.85 mg kg^{-1}
11.	Dominant clay mineral	Chlorite and illite

Table: 2
Details of treatments followed in the experiment

Treatment no.	Treatment detail
T_1	50% NPK+ Zn
T_2	100 % NPK
T_3	150% NPK
T_4	100% NPK + HW* + Zn
T_5	100% NPK + Zn
T_6	100% NP + Zn
T_7	100% N + Zn
T_8	100% NPK + 15 t ha^{-1} FYM
T_9	100% NPK - (S) + Zn
T_{10}	Control - no NPK or manure

**HW = Hand Weeding*

cycle each year before the sowing of wheat crop. The gross plot size was 25 m x 12.5 m.

Crop Management

For the experiment, the rice variety PR 113 was transplanted on July 9, 2012, in the puddled plots at a distance of 20 cm row to row and 10 cm plant to plant while wheat variety PBW-502 was sown on December 4, 2012, at 23 cm row to row distance. Treatment wise half dose of nitrogenous fertilizer and full dose of phosphorous, potassium and zinc were applied as basal dose in both the crops. Remaining half dose of nitrogen was top dressed equally at 3 and 6 weeks after transplanting of rice and at first and second irrigation in wheat crop.

In the treatment T_8 (100% NPK+15 t ha^{-1} FYM) fully decomposed FYM was applied just before first plowing. Till 1993, foliar application of Zinc fertilizer was done twice in rice only in T_5(100% NPK+Zn) treatment but afterwards changed to soil application. From 1993, Zn was also included in treatment T_1 (50% NPK+Zn), T_4 (100% NPK+HW+Zn), T_5 (100% NPK+Zn), T_6 (100% NPK+Zn), T_7 (100% N+Zn), and T_9 (100% NPK (-S)+Zn) which were earlier Zn free. Weeds were controlled manually in T_4 (100% NPK+HW+Zn) while in other treatments controlled chemically. From the initiation of experiment, each selected variety of rice and wheat was grown only for 5 years. Rice was harvested on 5th November 2012 and wheat on April 15, 2013. Irrigation and other agronomic practices were carried out as and when required.

Soil Sampling

After completion of 42 cycles of rice-wheat cropping sequence, soil samples from surface (0-15 cm) and sub-surface (15-30, 30-45 and 45-60 cm depths) were collected. In each plot, the soil was collected from ten random points, and mixed into one sample. After removing the surface organic matter and fine roots, each mixed soil sample was air-dried in shade, ground to pass through a 2 mm sieve and used for the estimation of soil chemical properties. Electrical conductivity (EC) and pH of the soil were determined using conductivity and pH meter, respectively, in 1:2.5 soil-water suspensions (Jackson, 1967); organic carbon (OC) in soil by potassium dichromate oxidizing method (Walkley and Black, 1934); mineralizable soil N by alkaline potassium permanganate method (Subbiah and Asija, 1956); Olsen-P was extracted with 0.5 M sodium bicarbonate (pH 8.5) and determined using ascorbic acid method (Olsen *et al.,* 1954) with the help of spectro-photometer; available potassium (NH_4OAc-K) was extracted with neutral 1 N ammonium acetate (Hanway and Heidel, 1952); available sulfur with 0.15% $CaCl_2$ (Williams and Steinbergs, 1959) and sulphur content in the extract was estimated by turbidimetric method (Chesnin and Yien, 1950); and the available Zn was determined by using Diethylene Triamine Penta Acetic Acid (DTPA) extractant (Lindsay and Norvell, 1978).

Statistical Analysis

For statistical analysis of data, SPSS-16 statistical package (SPSS, Inc., Chicago, IL, USA) was used. Analysis of variance (ANOVA) was done as per the procedure outlined by Gomez and Gomez (1984). To compare between treatment means, least significant difference (LSD) was worked out at 5% level of probability.

3. RESULTS AND DISCUSSION

Soil pH and Electrical Conductivity

Continuous 42 years and combined application of organics and mineral fertilizers had no significant effect on soil pH (Table’s 3 and 4). Electrical conductivity after rice

Table: 3
Effect of fertilizer treatments on soil pH and EC after rice crop

Treatments	Soil pH				Electrical conductivity (dS m^{-1})			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
50% NPK	7.80	7.90	8.03	8.02	0.34	0.32	0.29	0.27
100% NPK	7.67	8.06	8.08	8.11	0.34	0.33	0.29	0.26
150% NPK	7.63	8.02	8.03	8.00	0.34	0.32	0.28	0.28
100% NPK + H.W.	7.67	7.99	8.00	8.00	0.35	0.33	0.31	0.27
100% NPK + Zn	7.88	8.04	8.07	8.08	0.35	0.32	0.29	0.26
100% NP	7.64	7.97	7.91	7.96	0.33	0.31	0.29	0.26
100% N	7.91	8.07	8.19	8.15	0.34	0.31	0.29	0.26
100% NPK + FYM	7.66	7.9	8.04	8.08	0.36	0.34	0.33	0.29
100% NPK (-S)	7.87	8.05	8.23	8.14	0.34	0.31	0.28	0.25
Control	7.76	7.98	8.11	8.07	0.28	0.26	0.24	0.20
SEm±	0.05	0.04	0.03	0.03	0.009	0.008	0.01	0.01
LSD (5%)	NS	NS	NS	NS	0.03	0.02	0.03	0.03
Initial	7.30				0.35			

H.W. - Hand Weeding; SEm± - Standard Error of Mean; LSD - Least Significant Difference

Table: 4
Effect of fertilizer treatments on soil pH and EC after wheat crop

Treatments	Soil pH				Electrical conductivity (dS m^{-1})			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
50% NPK	7.61	7.87	8.03	7.95	0.35	0.31	0.24	0.17
100% NPK	7.57	7.78	7.94	8.13	0.34	0.32	0.25	0.19
150% NPK	7.54	7.74	7.93	7.91	0.35	0.32	0.26	0.21
100% NPK + H.W.	7.67	7.78	8.00	8.21	0.35	0.33	0.24	0.18
100% NPK + Zn	7.51	7.89	8.02	8.05	0.35	0.32	0.24	0.19
100% NP	7.58	7.77	8.01	8.18	0.31	0.30	0.23	0.19
100% N	7.55	8.00	8.14	8.26	0.31	0.30	0.21	0.16
100% NPK + FYM	7.60	7.71	8.07	8.01	0.35	0.34	0.24	0.18
100% NPK (-S)	7.71	7.83	7.95	8.17	0.32	0.30	0.20	0.18
Control	7.66	7.96	8.18	8.29	0.29	0.24	0.17	0.13
SEm±	0 .10	0.04	0.06	0.04	0.006	0.009	0.009	0.013
LSD (5%)	NS	NS	NS	NS	0.02	0.03	0.03	0.04
Initial	7.30				0.35			

H.W. - Hand Weeding; SEm± - Standard Error of Mean; LSD - Least Significant Difference

and wheat crops due to different treatments ranged from 0.28 to 0.36 dS m^{-1} and 0.29 to 0.35 dS m^{-1} in surface soil, respectively. All the fertilizer treatments had significantly higher EC than control. In sub-surface soil, the range of EC was observed between 0.26 dS m^{-1} to 0.34 dS m^{-1} and 0.24 dS m^{-1} to 0.34 dS m^{-1} at 15-30 cm, 0.24 dS m^{-1} to 0.33 dS m^{-1} and 0.17 dS m^{-1} to 0.26 dS m^{-1} at 30-45 cm depth, 0.20 dS m^{-1} to 0.29 dS m^{-1} and 0.13 dS m^{-1} to 0.21 dS m^{-1} at 45-60 cm depth after rice and wheat crops, respectively. Addition of NPK fertilizers increases accumulation of salt concentration in soil which contributes an increase in electrical conductivity of soil under different fertilizer treatments. Slightly more electrical conductivity under 100% NPK+FYM might be ascribed to deposition of additional salts in surface soil by incorporation of FYM. These results corroborate with the findings of Chawla and Chhabra (1991); Santhy *et al*. (1998) and Stalin *et al*. (2006).

Soil Organic Carbon (SOC)

The SOC, one of the most important factors for soil health and sustainable agricultural production, also improved under integrated nutrient management (Table 5). The results indicated that overall treatments effects on SOC were statistically significant in surface and sub-surface soil after harvest of both rice and wheat crops. SOC after rice and wheat crops due to different treatments ranged from 0.50% to 1.59% and 0.52% to 1.63% in surface soil, respectively. In sub-surface SOC ranged from 0.44% to 1.26% and 0.44% to 1.28% at 15-30 cm, 0.33% to 0.88% and 0.35% to 0.79% at 30-45 cm, 0.23% to 0.61% and 0.25% to 0.62% at 45-60 cm depth after rice and wheat crops, respectively.

Table: 5
Effect of fertilizer treatments on soil organic carbon (%) after rice-wheat cropping system

Treatments	Soil organic carbon (%)							
	Rice crop				Wheat crop			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
50% NPK	0.84	0.68	0.53	0.37	0.86	0.76	0.52	0.40
100% NPK	0.79	0.64	0.54	0.35	0.83	0.66	0.51	0.38
150% NPK	0.86	0.73	0.56	0.38	1.03	0.88	0.69	0.45
100% NPK + H.W.	0.79	0.65	0.55	0.37	0.83	0.77	0.56	0.42
100% NPK + Zn	0.88	0.73	0.57	0.37	0.90	0.81	0.58	0.45
100% NP	0.82	0.61	0.44	0.33	0.97	0.82	0.47	0.38
100% N	0.90	0.62	0.48	0.34	0.94	0.66	0.49	0.35
100% NPK + FYM	1.59	1.26	0.88	0.61	1.63	1.28	0.79	0.62
100% NPK (-S)	0.84	0.70	0.55	0.35	0.87	0.80	0.54	0.40
Control	0.50	0.44	0.33	0.23	0.52	0.44	0.35	0.25
SEm±	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02
LSD (P = 0.05)	0.08	0.10	0.08	0.06	0.05	0.08	0.07	0.07
Initial (1971)	1.48							

H.W. - Hand Weeding; SEm± - Standard Error of Mean; LSD - Least Significant Difference

A decrease in SOC content with depth was observed in both the crops. Data revealed that all the fertilizer treatments resulted in significantly higher SOC over the control in both the crops. The treatment 100% NPK+FYM recorded significantly higher SOC content than all other treatments in different depths of soil after harvest of rice and wheat crops. It was followed by 100% NPK + Zn in all soil depths during both crops.

As a result of intensive cropping for four decades without using any fertilizer or manure, initial status of SOC of 1.48% reduced to about one third (0.50%) under control and it accounts for loss of 66%. The loss of SOC is because of its rapid rate of mineralization, resulting from intensive cropping on one hand and attaining a stable equilibrium with the changing soil crop environment on the other. Maximum loss in SOC was observed under control, which was minimized with the balanced use of NPK fertilizers and manures. However the original status was maintained by combined use of FYM and 100% fertilizer dose (1.63%). Such beneficial effects on SOC might be due to incorporation of FYM which increases number and activity of micro-organism hence increased organic matter in soil. These results are in agreement with those of Yaduwanshi *et al*. (2013); Nand Ram (1995); Mathur (1997). Continuous use of NPK fertilizers over the years reduced the SOC status as compared to its value at initiation of study in 1971 leading to a decline in the availability nutrients in soil (Santhy *et al.,* 1998), whereas FYM incorporation alongwith NPK fertilizers increased the organic carbon status of soil which consequently caused higher availability of NPK in soil.

Available Nitrogen

Continuous manuring and cropping for 42 years significantly decreased available N content of soil in all the treatments in comparison to its initial status (392.0 kg ha^{-1}) (Fig's 1a and 1b). Available nitrogen was observed lower in deeper soil layers (15-60 cm) than in surface layer (0-15 cm). Highest available nitrogen in all the profile depths was observed in case of 100% NPK+FYM, which was significantly higher than all the other applied nutrient treatments, except 150% NPK. The treatment 150% NPK was at par with 100% NPK+FYM. Available nitrogen in soil after rice and wheat crops due to different treatments ranged from 178.13 to 362.94 and 186.49 to 367.96 kg ha^{-1} in surface soil, respectively. All the treatments had significantly higher available N than control. In sub-surface soil, the range of available N was observed from 123.35 kg ha^{-1} to 255.06 kg ha^{-1} and 154.85 kg ha^{-1} to 277.04 kg ha^{-1} in 15-30 cm depth, 74.01 kg ha^{-1} to 146.34 kg ha^{-1} and 85.30 kg ha^{-1} to 169.76 kg ha^{-1} in 30-45 cm depth, 30.53 kg ha^{-1} to 79.44 kg ha^{-1} and 41.81 kg ha^{-1} to 89.06 kg ha^{-1} in 45-60 cm depth after rice and wheat crops, respectively. The different fertilizer treatments recorded more soil available N over the control in sub-surface soil. Graded doses of NPK fertilizers *i.e.* 50%, 100% and 150% NPK increased the available nitrogen by 23%, 33.9% and 89.19% after rice crop and by 19.95%, 31.62% and 86.10% after wheat crop over the control in top 15 cm soil depth.

The lower content of available N in control plot is a result of mining of available nitrogen with continuous cropping without application of fertilization over a long period of time. Increase in available nitrogen with applied manures is attributed to its direct effect on enhanced mineralization and build-up of higher available N. Similar results were also reported by Kumar and Singh (2010) for rice-wheat system, and they observed that application of

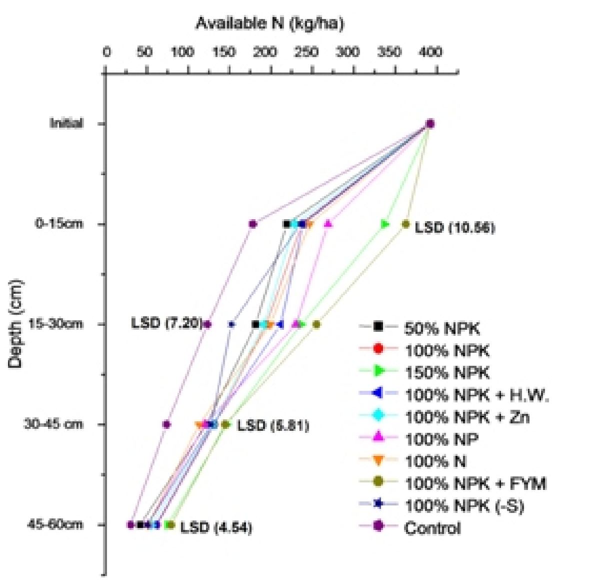

Fig. 1a: Effect of organic and inorganic fertilizers on available nitrogen (kg ha^{-1}) after rice crop

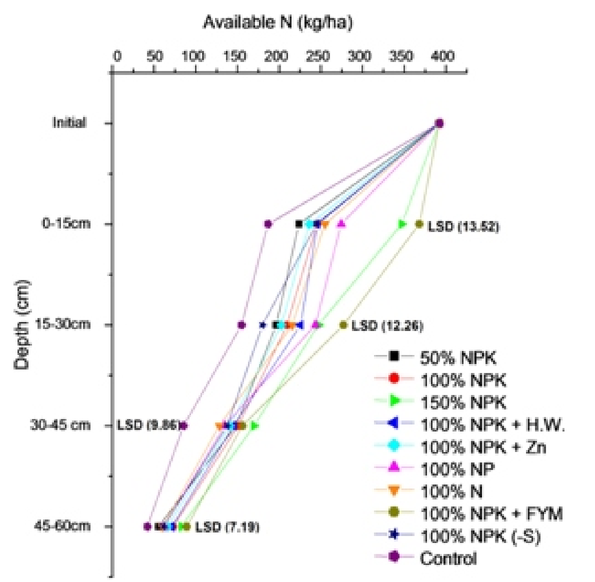

Fig. 1b: Effect of organic and inorganic fertilizers on available nitrogen (kg ha^{-1}) after wheat crop

FYM and alongwith 100% NPK significantly increased the available N content of soil over 100% NPK alone treatment.

Available Phosphorus

A significant increase in available phosphorus (Fig's 2a and 2b) was observed after 42 cropping cycles in all the treatments after both rice and wheat crops. Data indicated that the available P in soil ranged from 7.28 kg ha^{-1} to 37.24 kg ha^{-1} and 9.13 kg ha^{-1} to 32.05 kg ha^{-1} in top soil (0-15 cm) after rice and wheat crops, respectively, while in deeper profile, available P ranged from 4.74 kg ha^{-1} to 33.71 kg ha^{-1} and 5.61 kg ha^{-1} to 26.28 kg ha^{-1} in 15-30 cm, 2.90 kg ha^{-1} to 15.54 kg ha^{-1} and 3.36 kg ha^{-1} to 10.58 kg ha^{-1} in 30-45 cm, 0.66 kg ha^{-1} to 5.53 kg ha^{-1} and 1.28 kg ha^{-1} to 6.25 kg ha^{-1} in 45-60 cm after rice and wheat crops, respectively. The highest available phosphorus of 37.24 kg ha^{-1} and 32.05 kg ha^{-1} was recorded in the plot treated with 150% NPK, which was followed by 100% NPK+FYM (33.58 kg ha^{-1} and 29.48 kg ha^{-1}) in surface soil after rice and wheat crops, respectively. Application of nitrogen alone (100% N) had no significant effect on available P at all the soil depths, but when applied along with P (100% NP), resulted into significantly higher available P in surface and sub-surface soil over 100% N treatment.

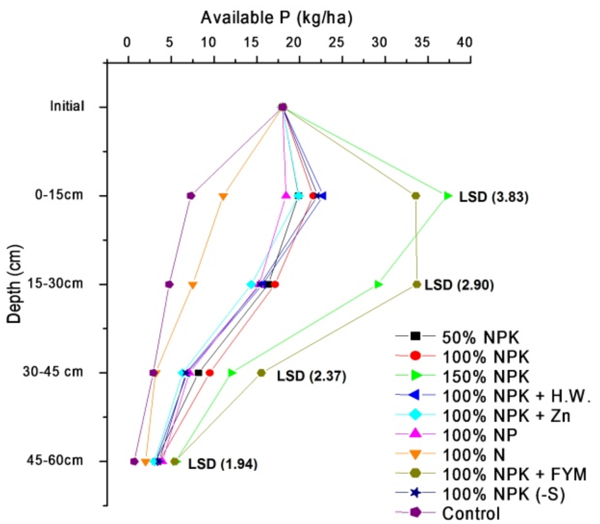

Fig. 2a: Effect of organic and inorganic fertilizers on available phosphorus (kg ha^{-1}) after rice

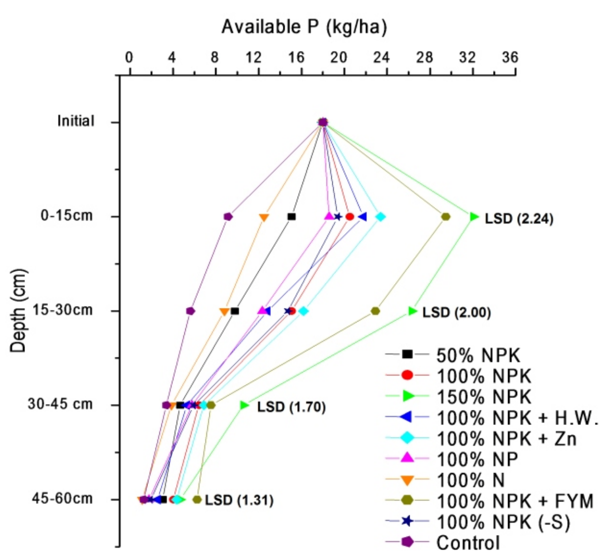

Fig. 2b: Effect of organic and inorganic fertilizers on available phosphorus (kg ha^{-1}) after wheat

Initially during 1971 the available phosphorus was 18.0 kg ha^{-1}, which was enhanced by use of manures and fertilizers for continuous 42 years. Enhancement in available phosphorus with the application of NPK fertilizers alone or in combination with FYM might be due to the release of organic acids during decomposition, which in turn helped in releasing phosphorus through solubilizing action of native phosphorus in the soil (Gupta *et al*., 2006; Sharma and Sepehya, 2014). The soil organic matter (SOM) also forms a protective cover on sesquioxides and makes them inactive, and thus reduces the phosphate fixing capacity of the soil, which ultimately, helps in release of abundant quantity of phosphorus as reported by Urkurkar *et al*., 2010.

Available Potassium

The results in Fig's 3a and 3b revealed that available potassium in surface soil under different treatments varied from 97.36 kg ha^{-1} to 163.41 kg ha^{-1} after rice crop and 104.21 kg ha^{-1} to 175.93 kg ha^{-1} after wheat crop, respectively. The content of available K in deeper soil depth (15-30 cm, 30-45 cm and 45-60 cm) varied from 83.29 kg ha^{-1} to 130.29 kg ha^{-1}, 67.57 kg ha^{-1} to 91.50 kg ha^{-1} and 47.34 kg ha^{-1} to 73.21 kg ha^{-1} after rice crop and 89.57 kg ha^{-1} to 146.74 kg ha^{-1}, 68.02 kg ha^{-1} to 106.11 kg ha^{-1} and 59.53 kg ha^{-1} to 78.90 kg ha^{-1} after wheat crop, respectively. Maximum available K content

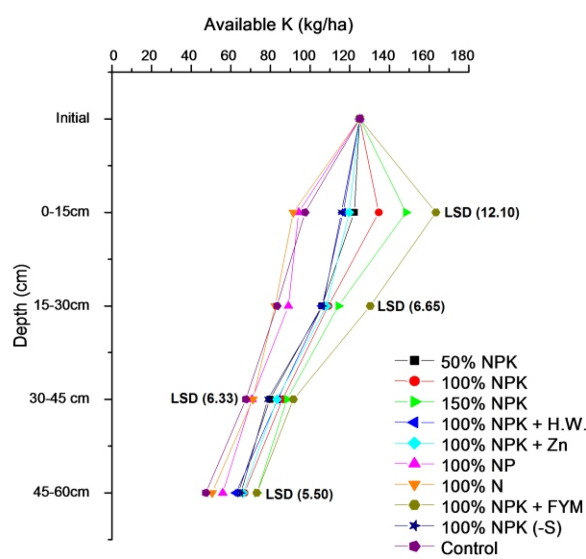

Fig. 3a: Effect of organic and inorganic fertilizers on available potassium (kg ha^{-1}) after rice crop

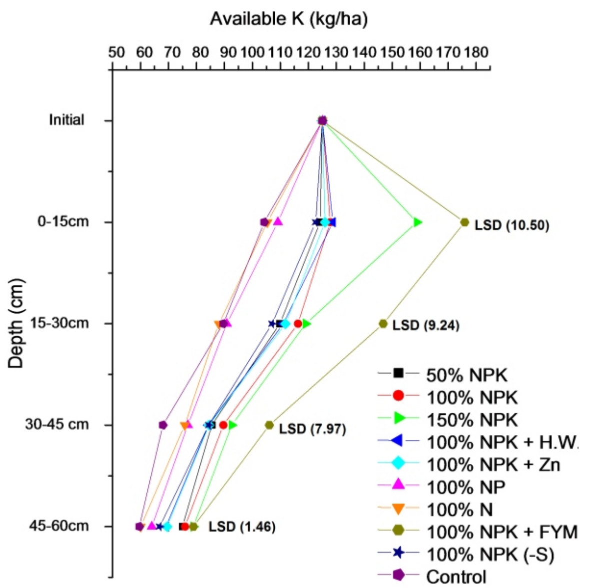

Fig. 3b: Effect of organic and inorganic fertilizers on available potassium (kg ha^{-1}) after wheat crop

was recorded with 100% NPK+FYM followed by 150% NPK in surface soil after rice-wheat sequence. The maximum available K in deeper soil layers (15-30 cm, 30-45 cm and 45-60 cm) was recorded with 150% NPK followed by 100% NPK+FYM after harvest of both the crops.

The different fertilizer treatments recorded significantly more available potassium over control, except 100% NP and 100% N, in both the crops in surface and sub-surface soil layers. Addition of N, P and K, either alone or in combination, enhanced the status of the respective nutrients in the soil. Application of FYM alongwith 100% NPK fertilizers resulted in significantly higher amount of available N, P and K in soil in comparison to 100% NPK fertilizers alone. The possible reason of available K_2O depression in control and inorganically treated plots might be due to higher potassium mining from the soils. Increase in available potassium due to addition of organic manures 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. These findings are in agreement with those of Sharma and Sepehya (2014).

Available Sulphur

The available S content of soil was significantly influenced by application of different treatments (Table 6). The surface soil had more sulphur content than sub-surface soil in both crops. Available sulphur in surface soil after harvest of wheat crop ranged from 10.25 kg ha^{-1} to 30.38 kg ha^{-1}. In sub-surface soil the sulphur varied from 6.59 kg ha^{-1} to 21.41 kg ha^{-1} in 15-30 cm, 2.02 kg ha^{-1} to 8.60 kg ha^{-1} in 30-45 cm and 0.81 kg ha^{-1} to 2.38 kg ha^{-1} 45-60 cm depths, respectively. While after harvest of rice crop available sulphur ranged from 7.57 kg ha^{-1} to 29.45 kg ha^{-1} in 0-15 cm, 3.89 kg ha^{-1} to 16.72 kg ha^{-1} in 15-30 cm, 2.21 kg ha^{-1} to 8.21 kg ha^{-1} in 30-45 cm and 0.84 kg ha^{-1} to 3.79 kg ha^{-1} in 45-60 cm depth. Maximum sulphur content in soil at all depths was obtained where 100% NPK+H.W. was applied followed by 100% NPK+Zn and 100% NPK+FYM treatment, respectively. Graded doses of NPK fertilizers @50%, 100% and 150% application, 100% NP and 100% N progressively increased the available S over control in surface soil as well as in sub surface soil. Available S in soils was observed lower with 100% NPK-S treatment as compared to all treatments even with control, and it is because of no addition of sulphur in this treatment.

Application of 100% NPK alone to both the crops increased the available S content by 176.49% and 86.82%, respectively over control. The application of either fertilizers alone or in combination with organic manures recorded an

Table: 6
Effect of fertilizer treatments on soil available sulphur (kg ha^{-1}) after rice-wheat cropping system

Treatments	Available sulphur (kg ha^{-1})							
	Rice crop				Wheat crop			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
50% NPK	22.82	13.25	6.52	3.36	18.12	12.99	4.02	1.23
100% NPK	20.93	12.20	6.63	2.31	19.15	15.56	5.12	1.83
150% NPK	22.61	13.15	4.00	2.52	21.28	15.76	4.25	1.34
100% NPK + H.W.	29.45	16.72	7.26	3.68	30.38	21.41	8.60	2.38
100% NPK + Zn	28.92	16.30	6.63	3.79	26.79	18.48	4.21	1.80
100% NP	26.50	15.49	6.73	4.31	24.09	17.43	3.66	1.21
100% N	25.66	11.67	7.30	3.05	23.19	17.50	2.57	1.07
100% NPK + FYM	27.24	13.04	8.21	3.36	26.17	20.49	8.60	1.46
100% NPK (-S)	7.99	6.31	2.52	1.37	11.35	7.87	2.75	0.85
Control	7.57	3.89	2.21	0.84	10.25	6.59	2.02	0.81
SEm±	0.90	0.81	0.58	0.33	1.10	0.74	0.44	0.12
LSD (P=0.05)	2.68	2.40	1.73	1.09	3.26	2.20	1.33	0.34

H.W. - Hand Weeding; SEm± - Standard Error of Mean; LSD - Least Significant Difference

increase in the available S content of the soil over control. Low S content in control could be due to no addition of S and its removal by crops, and secondly because of low organic carbon content in these treatments as S is known to be an integral part of soil organic matter. The increase in the available S with the application of fertilizers might be due to the addition of SSP which contained about 12% of S. Addition of FYM resulted in increased S content of the soil over control. These results are in agreement with those of Sharma and Subehia (2014) and Kumar *et al*. (2008).

Available Zinc

The available Zn (Table 7) content in soil after 42 rotations influenced by different treatments varied in surface soil (0-15 cm) from 0.26 mg kg^{-1} to 1.25 mg kg^{-1} and 0.45 mg kg^{-1} to 1.19 mg kg^{-1} after rice and wheat crop, respectively. The results revealed that continuous application of 100% NPK fertilizer without Zn recorded lower availability of Zn in surface as well as sub surface soil and use of FYM alongwith chemical fertilizers was significantly superior over alone and/or recommended dose of chemical fertilizers application.

In sub-surface soil, the available Zn varied from 0.23 mg kg^{-1} to 0.74 mg kg^{-1} and 0.28 mg kg^{-1} to 0.64 mg kg^{-1} in 15-30 cm, 0.13 mg kg^{-1} to 0.36 mg kg^{-1} and 0.14 mg kg^{-1} to 0.34 mg kg^{-1} in 30-45 cm and 0.10 mg kg^{-1} to 0.27 mg kg^{-1} and 0.08 mg kg^{-1} to 0.22 mg kg^{-1} in 45-60 cm depth after rice and wheat crops, respectively. When intensive systems of two or more than two crops are followed with high input use, the secondary and micro-nutrients are also removed in large quantities from the soil along with primary nutrients (NPK) due to higher biomass yield. Since NPK are commonly replenished through high analysis fertilizers, the secondary and micro-nutrients, especially sulphur, zinc, iron, copper and manganese, remain uncared and have started showing up deficiencies in many areas. In rice-wheat areas of north-west India, deficiencies of zinc, iron, copper and manganese were more. Therefore, in recent years, the crops have started responding to these nutrients (Pandey and Dwivedi, 1990). Kharche *et al.* (2013). Also considerable depletion in available Zn status of soil have been observed as compared to their initial status, before 22 years, under only chemical fertilizers. However, integration of organics maintained the level of micro-nutrient cations above the critical level in soil. The continuous use of only chemical fertilizers caused considerable depletion of all the four micro-nutrient cations, which indicates mining of these nutrients due to long-term intensive cultivation of cereal-cereal cropping sequence without addition of any organic manure or crop residues, which further suggests the necessity of regular use of organics for maintaining micro-nutrient status of soils.

4. CONCLUSIONS

After 42 years of experiment, it could be concluded that integration of inorganic fertilizers and organic manures through FYM together was the most efficient management system in accumulating soil available nutrients in 0-60 cm soil depths in a long-term fertilized soil, cultivated intensively with rice-wheat sequence. Integrated use of farmyard manure with fertilizers (100% NPK+15 t ha^{-1} FYM) was observed as the most efficient manuring practice, which improved soil chemical properties like available nitrogen, phosphorus, potassium, sulphur, zinc and organic carbon in all the four soil depths. Results indicated that judicious use of fertilizers with organic manures is important for maintaining soil fertility under rice-wheat system.

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Table: 7
Effect of fertilizer treatments on soil available Zinc (mg kg^{-1}) after rice-wheat cropping system

Treatments	Available Zinc (mg kg^{-1})							
	Rice crop				Wheat crop			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
50% NPK	0.78	0.52	0.26	0.16	0.78	0.56	0.27	0.09
100% NPK	0.67	0.47	0.20	0.16	0.71	0.48	0.27	0.13
150% NPK	0.49	0.43	0.17	0.15	0.66	0.35	0.20	0.08
100% NPK + H.W.	1.02	0.59	0.28	0.25	1.00	0.62	0.34	0.16
100% NPK + Zn	0.97	0.51	0.25	0.27	1.02	0.64	0.33	0.16
100% NP	1.03	0.50	0.30	0.23	0.85	0.48	0.20	0.12
100% N	0.78	0.57	0.24	0.23	0.77	0.48	0.22	0.12
100% NPK + FYM	1.25	0.74	0.36	0.23	1.19	0.58	0.34	0.22
100% NPK (-S)	0.86	0.61	0.23	0.17	0.79	0.51	0.24	0.15
Control	0.26	0.23	0.13	0.10	0.45	0.28	0.14	0.08
SEm±	0.12	0.10	0.06	0.06	0.11	0.08	0.04	0.02
LSD (P=0.05)	0.36	0.31	0.19	0.19	0.33	0.23	0.13	0.06
Initial	0.85							

H.W. - Hand Weeding; SEm± - Standard Error of Mean; LSD - Least Significant Difference

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