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ABSTRACT
The present study on the long-term effect of fertilizers, farmyard manure and lime on changes in soil properties and wheat productivity was carried out at Himchal Pradesh Agricultural University, Palampur (India). The soil was acidic in reaction and classified taxonomically as *Typic Hapludalf*. Soil samples, collected from two depths viz., 0–0.15 m and 0.15–0.30 m after the harvesting of wheat (2015–2016) were analyzed for different soil properties. Regular use of optimal dose of chemical fertilizers and farmyard manure influenced bulk density, porosity, water holding capacity, saturated hydraulic conductivity, mean weight diameter, pH, organic carbon, cation exchange capacity, available nitrogen, phosphorus, potassium, sulfur, DTPA extractable iron, zinc, copper and manganese, microbial biomass carbon, microbial biomass nitrogen and dehydrogenase activity of soil significantly. Highest grain yield of wheat (30.34 q ha^{-1}) was recorded at 100% NPK + FYM which was at par with 100% NPK + lime (27.89 q ha^{-1}). However, imbalanced use of nutrients affected different soil properties and productivity adversely.

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farmyard manure; fertilizers; lime; long-term; soil properties; wheat; yield

Introduction

Wheat (*Triticum aestivum* L.) is the second most important food grain crop being consumed next to rice. It is grown all over the world for its wider adaptability and high nutritive value. Wheat is staple food throughout the world and is also consumed in several ways in a number of industrial and commercial products. Wheat grains are comparatively better source of protein.

Wheat requires a good supply of nutrients for its growth and yield but chemical fertilizers alone are unable to maintain the long-term soil health and crop productivity (Subba Rao and Srivastava 1998), because they are unable to supply many other minor and trace elements. Improper and imbalanced use of chemical fertilizers coupled with less addition of organic manures has resulted in deterioration of soil health in terms of emerging multinutrient deficiencies and deterioration of physical soil properties. The addition of organic manures not only supplies the nutrients for crop growth but also improves different soil physical, chemical and biological properties. Integrated use of fertilizers with organics like farmyard manure, vermicompost and green manure assumes a greater importance as these organics not only improve the soil productivity and sustainability but also bring down the mounting pressure on inorganic fertilizers substantially. Integrated nutrient management is one of the most important components of the modern production technology. Integrated nutrient management approach is holistic and aims to

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optimize nutrient supply to crop plants with an overall objective of adequately nourishing the crops and improving and maintaining the health of soil base. The basic concept underlying the principle of integrated nutrient management is to maintain and possibly improve the soil health for sustaining crop productivity on long-term basis. The advantage of combining organic and inorganic sources of nutrients has proved superior to the use of each component separately (Palaniappan and Annadurai 2007).

Long-term fertilizer experiments provide an ideal base to assess the changes in soil properties as influenced by nutrient management practices in the crop production. In number of field experiments, major attention has been given in general to yield performance of crops under different nutrient management practices and evaluation of effect of these practices on soil health did not receive much attention. Keeping this in view, the present investigation was undertaken to study the long-term effect of different nutrient management practices on physical, chemical and biological properties of soil and wheat productivity.

Materials and methods

Detail of experimental site

The present investigation was carried out in an ongoing long-term fertilizer experiment started during 1972–1973 (*rabi*) at the research farm of Department of Soil Science, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP), India. The experimental area falls under mid hill sub receives an average rainfall of 2600 mm per annum. The soil belongs to the order Alfisol. The physico-chemical characteristics of the surface soil (0–0.15 m) at the initiation of the experiment were: pH (1:2.5, soil: water) 5.8; organic carbon 7.9 g kg^{-1} (Walkley and Black 1934); cation exchange capacity 12.10 c $mol(p^{+})$ kg^{-1} (Piper 1966); available N 736 kg ha^{-1} (Subbiah and Asija 1956); 0.5 M $NaHCO_3$-extractable Phosphate 12.1 kg ha^{-1} (Olsen et al. 1954); neutral 1 N NH_4OAcextractable Potash 194 kg ha^{-1} (Jackson 1973) and DTPA extractable Fe, Mn, Zn, Cu were 26.0, 24.3, 1.9, 0.4 mg kg^{-1}, respectively (Lindsay and Norvell 1978).

Treatment details

Eleven treatments consisting of combination of chemical fertilizers and amendments (FYM and lime) at different levels were tested in randomized block design replicate thrice with a plot size 5.0 m × 3.0 m. The eleven treatments consisting of: T_1 −50% nitrogen, phosphorus and potassium (NPK); T_2 −100% NPK; T_3 −150%; NPK T_4 −100% NPK + Hand weeding (HW); T_5 −100%; NPK + Zinc (Zn); T_6 −100% NP; T_7 −100% N;T_8 −100% NPK + FYM; T_9 −100% NPK (-S); T_{10} −100% NPK + lime; T_{11} – control. Due to marked buildup of available P, the original treatment structure was slightly modified from *kharif* 2011, optimal and super optimal doses of P were reduced by 50% and in case of sub optimal dose (i.e., 50% NPK), addition of FYM @ 5 t ha^{-1} on dry weight basis to maize crop only was also included. The recommended dose of fertilizers for wheat was 120:26:25 (N: P_2O_5: K_2O) for wheat. Half the dose of N and full dose of P and K were applied at the time of sowing of wheat crop. The remaining half of the N was top dressed in two splits, that is, at maximum tillering and flowering stages of wheat. The nutrients, that is, N, P and K were supplied through urea, single super phosphate and muriate of potash, respectively. To study the effect of sulfur free P fertilizer on crop performance, that is, in 100% NPK (-S) treatment, P was applied through di-ammonium phosphate. Zinc was applied in T_5 as zinc sulfate at the rate of 25 kg ha^{-1} every year till 2011. Farmyard manure application was made at the rate of 5 tonnes ha^{-1} on dry weight basis. The FYM used in the experiment contained 60% moisture and the contents of N, P and K were 1.01, 0.26 and 0.40%, respectively. In T_{10},

Table 1. Effect of regular use of fertilizers, FYM and lime on physical properties of soil.

	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)		Water holding capacity (%)		Saturated hydraulic conductivity (cm h^{-1})		Mean weight diameter (mm)	
Treatment	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30
T_1	1.27	1.29	2.43	2.45	47.66	47.27	58.33	55.00	3.21	3.19	1.65	1.52
T_2	1.26	1.27	2.44	2.44	48.43	47.88	58.00	56.67	3.42	3.36	1.93	1.82
T_3	1.28	1.30	2.44	2.45	47.61	47.00	56.67	54.67	3.44	3.21	1.56	1.43
T_4	1.24	1.26	2.43	2.44	48.90	48.15	62.00	59.67	3.58	3.40	2.22	2.05
T_5	1.28	1.29	2.43	2.44	47.32	47.19	56.33	52.00	3.32	3.20	1.62	1.45
T_6	1.31	1.32	2.45	2.46	46.45	46.41	55.00	53.33	2.79	2.54	1.57	1.51
T_7	1.39	1.42	2.46	2.46	43.28	42.39	50.67	49.00	2.65	2.48	0.95	0.65
T_8	1.21	1.24	2.44	2.43	50.34	48.90	63.00	61.00	5.39	4.35	4.61	3.59
T_9	1.31	1.33	2.43	2.44	46.16	45.63	56.33	54.67	3.50	3.08	1.59	1.44
T_{10}	1.23	1.26	2.43	2.43	49.31	48.22	61.00	58.00	4.06	3.82	3.64	3.04
T_{11}	1.37	1.40	2.46	2.46	44.52	43.30	51.33	46.67	2.53	2.52	1.02	0.93
CD ($P = 0.05$)	0.03	0.05	NS	NS	1.47	1.99	3.54	4.66	0.23	0.30	0.27	0.16

application of lime was done at the rate of 900 kg ha^{-1} as marketable lime ($CaCO_3$). The regular application of lime was continued up to 1979 when the soil pH was reached to about 6.5. Whereas, the application of lime in the subsequent years was made only when the soil pH declined to about 6.3. In the present investigation, wheat (*rabi*) crop was sown on 19 November 2015 and harvested on 4 May 2016. The wheat crop was irrigated at the crown root initiation, tillering, late jointing, flowering and dough stages. Chemical weed control was followed except in T_4 (100% NPK + Hand Weeding) where weeds were removed manually and incorporated in the same plot. After the harvest of wheat (2015–2016), data on grain and straw yields were recorded.

Analytical details

The soil samples collected from a depth of 0–0.15 m and 0.15–0.30 m after the harvest of wheat (2015–2016) were used for the determination of various physical, chemical and biological parameters. The processed soil samples were analyzed for bulk density, particle density, porosity, water holding capacity, aggregate analysis, saturated hydraulic conductivity pH, organic carbon, cation exchange capacity (CEC), available N, P, K and S, DTPA extractable Fe, Zn, Cu, Mn, microbial biomass carbon, microbial biomass nitrogen and dehydrogenase activity following standard analytical methods.

Statistical analysis

The data recorded on soil properties and productivity of wheat were analyzed as per the standard statistical procedure. The analysis of variance (ANOVA) for RBD was performed using an "*F*" test as per the procedure suggested by Gomez and Gomez (1984) to draw the inferences.

Results and discussion

Bulk density

Long-term use of recommended dose of fertilizers along with FYM/lime influenced bulk density of the soil significantly (Table 1). A significant reduction in bulk density with balanced application of chemical fertilizers (100% NPK) was found as compared to imbalanced application of fertilizers, that is, 100% N (T_7) and 100% NP (T_6). Compared to initial value (1.31 Mg m^{-3}), the bulk density of soil was reduced to 1.21, 1.23 and 1.24 Mg m^{-3} in plots receiving 100% NPK along with FYM, 100% NPK plus lime and 100% NPK + HW, respectively. Highest reduction in bulk density in 100% NPK + FYM plot may due to continuous addition of organic matter that might have resulted in soil aggregation and ultimately in total porosity. These results corroborate the findings of Singh et al. (2014). The bulk density increased with increase in soil depth. However, treatment wise effect in subsurface layer was almost similar as observed under surface layer.

Particle density

Particle density of surface soil (0–0.15 m depth) varied from a minimum value of 2.43 Mg m^{-3} to maximum value of 2.46 Mg m^{-3}. In 0.15–0.30 m soil layer, the particle density ranged between 2.43 mg m^{-3} and 2.46 mg m^{-3}. Particle density did not show any significant change due to continuous application of fertilizers and manures. These results are in accordance with the findings of Nandapure et al. (2011).

Porosity

The soil porosity in surface layer (0–0.15 m) varied from the lowest value of 43.28% in 100% N treatment (T_7) to the highest value of 50.34% in 100% NPK + FYM treatment (T_8). In case of subsurface soil layer, the porosity in 0.15–0.30 m layer ranged from 42.39% under 100% N to 48.90% under 100% NPK + FYM treatment (Table 1). Increase in porosity of soil under 100% NPK + FYM was recorded in both the layers which might be due to the increase in organic matter content of soil which improved soil physical conditions. Addition of FYM along with NPK also increased the soil porosity as compared to the use of NPK alone. The subsurface layer (0.15–0.30 m) recorded a decrease in porosity as compared to surface layer. The organic materials incorporated in the soil are decomposed through micro-organisms. As a result, different organic compounds like polysaccharides are produced which act as strong binding agents and lead to the formation of large and stable soil aggregates. This ultimately results in improvement in the physical properties of the soil (Nandapure et al. 2011; Kannan et al. 2013).

Water holding capacity

Application of chemical fertilizers alone or in combination with organic manure/lime significantly increased water holding capacity of soil (Table 1). Application of fertilizers except 100% N alone increased the water holding capacity of soil significantly over control. This increase could be attributed to better root growth and more plant residues addition under these treatments. Water holding capacity decreased with increase in soil depth. The highest water holding capacity recorded under 100% NPK + FYM (T_8) was at par with 100% NPK + lime (T_{10}) and 100% NPK + HW (T_4). The regular addition of organic manure influenced the water holding capacity positively which could be attributed to the improvement in structural properties of soil. These results are in line with the findings of Katkar et al. (2012) who observed similar effect of integrated nutrient management on water holding capacity under sorghum-wheat cropping sequence in Vertisol.

Saturated hydraulic conductivity

The saturated hydraulic conductivity (SHC) varied from 2.53 to 5.39 cm hr^{-1} in the surface soil samples (0–0.15 m) and 2.48 to 4.35 cm hr^{-1} at 0.15–0.30 m soil depth (Table 1). Application of 100% NPK (T_2) increased saturated hydraulic conductivity significantly over 100% NP. Highest saturated hydraulic conductivity (5.39 cm hr^{-1}) was recorded in the plots where FYM was applied in conjunction with recommended dose of fertilizers and was significantly higher in comparison to rest of the treatments. The improvement in saturated hydraulic conductivity with FYM application may be because of increase in organic carbon contents of soils which increased soil aggregation, reduced bulk density and increased total porosity. Katkar et al. (2012) also reported that direct application of organic matter through FYM increased the SHC. Relatively higher saturated hydraulic conductivity was recorded in upper soil layer than in the lower layer which might be due to increased compaction in lower layer (Ali 2011). The surface soil having relatively higher organic matter content was less compact as compared to the subsurface soils that might have led to easy passage of water through surface layer.

Mean weight diameter

The minimum mean weight diameter (MWD) was recorded in the treatment where P and K were omitted for last 44 years, that is, 100% N (T_7). But with the addition of P with 100% N, the MWD increased significantly as compared to 100% N. Further, with the addition of K in 100%

Table 2. Effect of regular use of fertilizers, FYM and lime on pH, SOC, CEC, Available N, P and K.

	Soil pH		Soil organic carbon (g kg^{-1})		Cation exchange capacity (c mol (p^{+}) kg^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Available S (kg ha^{-1})	
Treatment	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30
T_1	5.34	5.39	10.20	7.17	10.11	9.40	342	254	57.9	43.3	151	126	28.0	23.5
T_2	5.23	5.30	10.17	7.42	10.42	9.41	351	277	67.6	60.5	163	138	29.5	26.7
T_3	4.88	4.97	10.10	7.54	10.24	9.18	373	286	156.8	148.7	187	157	36.8	30.9
T_4	5.28	5.37	11.20	8.61	11.30	9.67	357	279	80.3	73.3	159	138	27.3	23.1
T_5	5.19	5.32	9.68	7.31	10.06	8.25	353	261	82.2	67.2	165	138	26.7	22.8
T_6	5.15	5.32	9.30	6.22	9.14	7.50	348	267	100.1	87.2	120	109	24.8	22.4
T_7	4.34	4.58	8.73	5.87	6.27	5.91	335	258	15.1	8.1	130	109	17.5	13.4
T_8	5.49	5.70	13.75	9.13	12.47	11.09	390	307	131.8	118.7	198	167	32.5	26.9
T_9	5.20	5.27	9.50	6.20	9.53	8.32	353	256	113.9	100.8	168	154	16.4	14.6
T_{10}	6.25	6.50	10.65	7.36	12.18	10.72	358	268	75.8	69.8	164	153	28.7	25.4
T_{11}	5.68	5.85	7.95	6.08	8.53	6.29	262	183	15.3	8.3	113	91	14.9	13.3
CD (P= 0.05)	0.15	0.08	0.27	0.66	0.85	0.42	17.5	15.1	11.03	15.51	13.1	10.7	5.3	4.7

NP the mean weight diameter increased significantly to 1.93 mm. The increase in the MWD in T_8 treatment over control (T_{11}), 100% N (T_7) and 100% NPK (T_3) treatments was 77.87, 79.39 and 66.16%, respectively. The increase in soil aggregates due to the incorporation of organic matter is attributed to the fact that organic substances added through FYM are capable of binding the soil particles together (Bandyopadhyay et al. 2010).

Application of 100% NPK + lime also recorded significantly higher MWD value over 100% NPK alone (Table 1). This may be due to the beneficial effect of calcium ions in the formation of large sized aggregates as calcium is a flocculating agent. Since Ca is an excellent flocculent for negatively charged colloids, one might expect that temperate regions soils would reflect the direct effects on aggregation of additions of Ca from liming. Moreover, liming improves soil structure through its indirect effect upon organic matter production and microbial activity.

Soil pH

Soil pH varied from a lowest value of 4.34 in 100% N treatment (T_7) to the highest value of 6.25 in 100% NPK + lime treated plots (T_{10}) in the surface layer (Table 2). Slightly higher values of soil pH were recorded in the subsurface layer. The soil pH in case of 100% N treatment (4.34) was significantly lower compared to other treatments. Use of lime in combination with NPK improved the soil pH near to neutrality with a value of 6.25. The regular addition of FYM along with NPK also increased the soil pH as compared to the use of NPK alone. Marked decrease in pH due to the application of fertilizers alone could be attributed to the acid producing nature of nitrogenous fertilizers (Magdoff, Lanyon, and Liebhardt 1997) which upon nitrification releases H^+ ions which is potential source of soil acidity. However, marginal increase in soil pH recorded under conjoint use of organic manures and fertilizers might be due to moderating effect of organic manures as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules (Hue 1992). The soil pH increased significantly with application of lime at both the depths due to the neutralizing effect of lime. The ameliorating effect of lime on soil acidity has been reported earlier by Chimdi et al. (2012).

Soil organic carbon

Forty four annual applications of FYM with recommended rate of NPK registered highest increase (74.0%) in SOC content over the initial SOC content (7.90 g kg^{-1} soil) in 1972 (Table 2). The soil organic carbon (SOC) showed slight build up in all the treatments except control, after a time period of forty four years over the initial value. The soil organic carbon contents in 100% NPK + HW treatment (T_4) were significantly higher than 100% NPK, 150% NPK, 100% NPK + Zn and 100% NPK (-S). The highest content of organic carbon was recorded in plots that were amended with FYM for forty four years. The SOC in this treatment was significantly higher as compared to unfertilized control and this can be attributed to the direct addition of organic carbon through FYM and addition of crop residues and root biomass. Similar results were reported for maize–wheat system by other researchers from elsewhere. (Brar et al. 2015) Significantly higher soil organic carbon content in case of manual weeding (T_4) compared to the plots where chemical weed control was practiced (T_2) might be ascribed to continuous addition/recycling of weed biomass in these plots. It is noteworthy that use of chemical fertilizers in imbalanced form (100% N, 100% NP) or zero fertilization showed significant decline in the soil organic carbon content as compared to other treatments. This might be due to the poor crop growth in these plots leading to low return of root and plant biomass.

Cation exchange capacity

Cation exchange capacity (CEC) in surface layer (0–0.15 m) varied from a lowest value of 6.27 c mol (p^+) kg^{-1} to the highest value of 12.47 c mol (p^+) kg^{-1} under 100% N plot (T_7) and 100% NPK + FYM treatment (T_8), respectively (Table 2). The cation exchange capacity in 100% NPK + FYM and 100% NPK + lime plots was significantly higher than 100% NPK treatment (T_2). The increase being 19.7 and 16.9%, respectively. The cation exchange capacity decreased by 29.5, 48.1, 24.4 and 21.2% under control, 100% N, 100% NP and 100% NPK (-S) as compared to initial value, respectively Cation exchange capacity decreased with soil depth. The CEC of soils is a function of negative charges developed on the broken edges of clay minerals. Due to prolong soil acidification by the continuous use of urea fertilizer, the reduction in the CEC value was recorded in T_7 which might be attributed to low pH value of these plots. At such a low pH values, only the permanent charges of the clays and a small portion of the charges of organic colloids hold ions that can be exchanged by cations (Brady and Weil 2007). Similar findings have also been reported by Ogbodo (2013) from their experiment conducted at Ebonyi state of South Nigeria, respectively. Application of chemical fertilizers alone or in conjunction with the organics improved the CEC of the soil. This increase may be due to formation of higher amount of organic colloids (Nkechi et al. 2013). The positive effect of lime on CEC may be attributed to improvement in pH and addition of Ca through it. Irrespective of the treatments, the cation exchange capacity decreased with depth which might be due to lower organic carbon content in the subsurface layer.

Available nitrogen

Application of 100% NPK + FYM (T_8) recorded about 12% higher available N content as compared to 100% NPK (T_2). Available N status of the control plot clearly revealed that cultivation without any addition of fertilizers or manure drastically reduced the soil N availability (Table 2). Application of 50, 100 and 150% NPK increased the available N content by 30.5, 33.96 and 42.36%, respectively over control. Highest increase of 48.8% was recorded in the plots receiving 100% NPK + FYM followed by 150% NPK over control. The lower content in untreated plots is a result of mining of available nitrogen with continuous cropping without fertilization over a period of more than four decades. The higher content under this treatment may be due to additional supply of nitrogen through FYM over the years. Similar effect of addition of FYM was reported by Nkechi et al. (2013) and Singh, Pawar, and Meena (2017). The favorable soil conditions viz. organic carbon, porosity, water holding capacity etc. might have helped the process of mineralization of soil nitrogen thereby leading to buildup of higher available nitrogen. These results corroborate the findings of Urkurkar et al. (2010).

Available phosphorus

The available phosphorus content varied from 15.1 kg ha^{-1} under 100% N (T_7) to 156.8 kg ha^{-1}-under 150% in surface layer. Application of either balanced chemical fertilizer alone or in combination with FYM or lime recorded an increase in the available phosphorus content over control (Table 2). The increase in available phosphorus with the continuous use of FYM and 100% NPK + lime was to the order of 95 and 12.16%, respectively. The increase in available P content with the application of lime might be due to reduction in P fixation due to decrease in exchangeable acidity and increase in mineralization of organic phosphorus present in the soil (Verma, Mathur, and Verma 2012). Substantial buildup of available P in plots receiving fertilizer P can be due to an increase in available pool of the soil P after satisfying the P fixation capacity of the soil. A marked increase in the available P content of the soil with the application of lime and FYM might be due to the inactivation of iron, aluminum and hydroxyl Al ions thereby reducing the P fixation in soil (Singh, Pawar, and Meena 2017). Moreover, increase in available phosphorus with the application of NPK fertilizers in conjunction with organics might be due to the release of organic acids during decomposition which, in turn, helped in releasing phosphorus from native pool of phosphorus in the soil (Thakur et al. 2011).

Available potassium

Application of FYM along with 100% NPK increased available K content as compared to 100% NPK. The integrated use of FYM with 100% NPK was able to maintain the optimum level of K which can be ascribed to additional supply of potassium through FYM (Table 2). Increase in available potassium due to addition of organic manure may be ascribed to the reduction of potassium fixation and release of potassium due to interaction of organic matter with clay, besides the direct potassium addition to the pool of soil (Urkurkar et al. 2010). Such increase in the content of available potassium with the use of organics with chemical fertilizers has also been reported by Singh, Pawar, and Meena (2017). The higher content of available K in 150% NPK treated plot over 100% NPK may be due to the addition of K over and above the recommended level in this plot. The higher content of available K was recorded in 100% NPK (-S) treatment over 100% NPK which may be due to less K uptake because of low yield of crops due to S deficiency in this treatment.

Substantial mining of native pools of K over years occurred in case of control, 100% N and 100% NP treatments because of the omission of potassium for last 44 years. The depletion in native potassium pool even at recommended dose of NPK is due to its more removal compared to the addition in crops (Sharma et al. 2005).

Available sulfur

The available sulfur content varied from 14.9 to 36.8 kg ha^{-1}. The treatment T_9 where single super phosphate (SSP) was replaced with di-ammonium phosphate, that is, 100% NPK (-S) recorded the low content of available sulfur (16.4 kg ha^{-1}) followed by control (14.9 kg ha^{-1}). Sulfur was also omitted in 100% N treatment for last 44 years of cropping which had available sulfur content of 17.5 kg ha^{-1}. The plots receiving 100% NP had significantly higher content of available sulfur (24.8 kg ha^{-1}) as compared to treatment receiving 100% N only. The highest amount of available sulfur was found in 150% NPK treatment (36.8 kg ha^{-1}), which may be due to the addition of higher amount of sulfur than recommended dose for last 44 years (Table 2). The plots receiving FYM with 100% NPK and lime with 100% NPK recorded significantly higher content of available sulfur (32.5 and 28.7 kg ha^{-1}, respectively) as compared to control. A significant decrease in available S was also reported by Verma, Mathur, and Verma (2012) where S was not added externally. The treatment receiving P along with 100% N (100% NP) increased the available sulfur content in soil significantly over 100% N which might be due to the addition of sulfur through SSP along with phosphorus and synergistic effect of N and P. Synergistic interaction between P and S has also been reported earlier by Randhawa and Arora (2000).

Application of FYM with 100% NPK recorded a significant increase in available sulfur content over other treatments except 150% NPK, which could be attributed to continuous application of FYM with recommended rate of N, P and K fertilizers, contributing an additional 30 kg S ha^{-1} yr^{-1}. Reddy et al. (2002) also reported the improvement in the S content of soil with the addition of FYM with 100% NPK. The increasing trend in available sulfur was noted in surface layer with the increase in the rate of sulfur fertilization through single super phosphate. Kumari et al. (2011) have also found similar increase in the availability of sulfur with increasing doses of NPK fertilizers as S was also being added through application of SSP.

Table 3. Effect of regular use of fertilizers, FYM and lime on DTPA extractable micronutrients and microbiological properties of soil.

	DTPA extractable Fe (mg kg^{-1})		DTPA extractable Zn (mg kg^{-1})		DTPA extractable Cu (mg kg^{-1})		DTPA extractable Mn (mg kg^{-1})		Microbial biomass carbon (mg kg^{-1})		Microbial biomass nitrogen (mg kg^{-1})		Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1})	
Treatment	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30	0–0.15	0.15–0.30
T_1	26.53	21.47	1.27	1.09	1.69	1.13	20.07	16.15	380	275	14.9	12.1	29.8	25.2
T_2	28.77	23.28	1.28	1.12	1.70	1.23	22.46	17.72	496	445	18.9	15.1	38.7	33.8
T_3	31.87	26.93	1.31	1.27	1.66	1.12	25.46	19.19	456	400	20.1	16.8	26.8	21.6
T_4	29.77	24.19	1.40	1.22	1.78	1.28	23.72	18.00	561	528	19.8	16.0	41.0	35.5
T_5	26.03	22.13	4.29	2.67	1.71	1.20	22.60	16.88	430	393	17.2	14.8	37.9	32.6
T_6	28.03	23.29	1.24	1.20	1.59	1.08	21.83	17.53	288	245	14.0	12.7	29.9	22.8
T_7	30.80	25.82	1.18	1.07	1.49	1.05	21.91	15.83	178	149	12.2	11.7	13.9	9.7
T_8	35.80	29.88	2.30	1.84	2.18	1.80	35.58	25.39	683	628	25.0	18.3	44.1	39.6
T_9	22.20	20.09	1.23	1.18	1.62	1.09	20.86	15.67	451	377	15.0	14.1	24.5	20.1
T_{10}	24.11	18.65	1.42	1.10	1.75	1.24	23.62	12.19	633	588	22.8	17.0	40.6	37.1
T_{11}	18.27	15.10	0.99	0.96	1.40	1.01	15.24	10.73	276	230	10.4	9.6	19.8	14.6
CD (P= 0.05)	2.35	0.95	0.15	0.19	0.17	0.10	3.17	0.96	12	8	1.25	1.08	2.06	1.92

DTPA extractable micronutrients

Available Fe content varied from a lowest value of 18.27 mg kg^{-1} under control to 35.80 mg kg^{-1}under 100% NPK + FYM (Table 3). The DTPA extractable Fe declined to 18.27 mg kg^{-1} in the plots receiving zero fertilization compared to its initial value of 26 mg kg^{-1}. The treatments namely, FYM with chemical fertilizers (T_8), 100% NPK (T_2), 100% N (T_7) and 150% NPK (T_3), however, registered substantial build up in the DTPA extractable Fe content compared to its content in 1972, increase being 37.7, 10.7, 18.5 and 22.6%, respectively. Higher DTPA extractable Fe under treatments with low pH over control was due to acidic soil environment that favored solubilization of this nutrient. Lime application along with NPK decreased the content of DTPA extractable Fe in soil which may be due to its conversion to insoluble form with the increase in pH. The Fe content was more in plots receiving P fertilizer either alone or in combination with organic manures over control. The increase may be due to contribution of substantial amount of Fe by SSP (single super phosphate).

The continuous manuring and cropping for forty four years resulted in decline in DTPA extractable Zn content of the soil in all the treatments except the plots receiving Zn and FYM along with NPK as compared to initial value. The regular use of Zn in the presence of NPK increased the DTPA extractable Zn to 4.29 mg kg^{-1} compared to its initial content of 1.90 mg kg^{-1} in 1972 (Table 3). On the other hand, the decline in DTPA extractable Zn was highest in the zero fertilized plots. Compared to control, there was a significant increase in the contents of DTPA extractable Zn under 100% NPK (T_2), 150% NPK (T_3), 100% NPK + HW (T_4), 100% NPK + Zn (T_5),100% NPK + FYM (T_8) and 100% NPK + lime (T_{10}) treatments. There was a decline in DTPA extractable Zn in the sub surface soil in comparison to the surface layer. The increase in DTPA extractable Zn in FYM treated plots over the years may be due to mineralization of organically bound forms of Zn in the FYM and also possible addition of zinc as impurity through single superphosphate. Organic manures result in the formation of organic chelates of higher stability. Zinc is known to form relatively stable chelates with organic ligands which decrease their susceptibility to adsorption, fixation and/or precipitation. Similar results were also reported by Verma and Mathur (2007).

Variation in Cu content was found from 1.40 mg kg^{-1} under control to 2.18 mg kg^{-1} under 100% NPK + FYM in surface soil. The increase in Cu with the continuous use of FYM along with chemical fertilizers over 100% NPK was to the order of 26%. The contents under 100% NPK + HW and 100% NPK + Zn were at par with 100% NPK alone. Higher content of Cu in FYM treated plots may be due to formation of organic chelates, which decreased their susceptibility to adsorption, fixation and precipitation leading to their enhanced availability in soil. Addition of organic matter to soil encourages proliferation of microorganisms, which aids in the liberation of micronutrients. These results are in conformity with the findings of Zhang, Li, and Yang (2015).

The DTPA extractable Mn varied from 15.24 mg kg^{-1} in control to 35.58 mg kg^{-1} in FYM amended plots. Application of 100% NPK + FYM resulted in 58 and 43% increase in DTPA extractable Mn content over 100% NPK in surface and subsurface layer, respectively. Zero fertilization resulted in 32.14% reduction in DTPA extractable Mn as compared to optimal fertilization for forty four years. Among the graded doses of NPK, 150% NPK had 13.4% higher content in comparison to 100% NPK, respectively. Reduction in DTPA extractable Mn content was observed with the increase in soil depth. The DTPA extractable Mn depleted significantly in treatments receiving only chemical fertilizers. Higher availability in FYM treated plots may be due to formation of organic chelates, which decreased their susceptibility to adsorption, fixation and precipitation resulting in their enhanced availability in soil. The addition of organic matter to soil encouraged microorganisms which aided in the liberation of trace elements. Similar findings have been reported by Sharma and Shweta (2013).

Microbial biomass carbon

The soil microbial biomass carbon varied from 178 mg kg^{-1} in 100% N plot (T_7) to 683 mg kg^{-1} in 100% NPK + FYM plots (T_8). Application of NPK fertilizers either alone or in combination with organics/lime increased the microbial biomass carbon significantly over control (T_{11}) except treatment T_7 (100% N). Among different nutrient management practices, the treatment comprising 100% NPK + FYM recorded highest soil microbial biomass carbon followed by 100% NPK + lime, 100% NPK + HW, while 100% N treatment recorded significantly lowest value (Table 3). The supply and availability of additional mineralizable and readily hydrolyzable carbon due to manure application might be responsible for higher microbial activity and microbial biomass carbon in organic manure treated plots. These results corroborate the findings of Nath et al. (2012). The positive effect of lime on SMB-C may probably be attributed to better root growth and left over crop residues in these plots. Microbial biomass carbon increased under balanced fertilization. It may be due to formation of root exudates and underground roots of previously harvested crops. Higher nutritional stress due to no or inadequate use of nutrients in control, imbalanced and suboptimal fertilizer level (T_{11}, T_6 and T_7) restricted crop production and thus carbon substrate (root exudates) with consequent reduction in biomass carbon.

Microbial biomass nitrogen

Application of 50, 100 and 150% NPK alone increased the microbial biomass nitrogen content by 43.2, 81.7 and 93.2%, respectively, over control. Continuous application of 100% NPK + FYM registered 32.2% increase over 100% NPK (Table 3). The positive effect of balanced fertilization on SMB-N may be due to the better plant growth, root biomass and higher rhizosphere activity, which might be responsible for high mineralization rate of N. Application of chemical fertilizers along with manures resulted in supply of nutrients in balanced proportion which was reflected in terms of productivity and ultimately higher organic carbon in the soil. These results are in accordance with the findings of Chang et al. (2014).

The microbial biomass nitrogen content was lower under imbalanced or no use of fertilizers ($T_{6,}$ T_7 and T_{11}) compared to the plots which received balanced fertilizers (i.e., 100% NPK). Deleterious effect of low pH on soil fertility resulted in zero yield leading to no addition of crop residues in the soil which affected SMB-N adversely. These results corroborate the findings of Kumari et al. (2011). Microbial biomass nitrogen content decreased with increase in soil depth in all the treatments which may be due to low organic carbon in subsurface soil.

Dehydrogenase activity

Soil dehydrogenase activity (DHA) varied from a lowest value of 13.9 µg TPF g^{-1} soil 24 h^{-1} under 100% N (T_7) to a highest value of 44.1 µg TPF g^{-1} soil 24 h^{-1} in the plots which received FYM along with 100% NPK (T_8) in surface layer (Table 3). However, the contents were slightly less in the subsurface layer. Application of chemical fertilizers (NPK) either alone or in combination with FYM/lime increased the soil dehydrogenase activity significantly over control (T_{11}). The plots receiving 100% NPK + FYM, 100% NPK + HW and 100%NPK + lime resulted in 14, 6 and 5% higher DHA content, respectively as compared to the plots receiving 100% NPK over a period of forty four years. Higher dehydrogenase activity in organic manure treated plots may be due to fact that addition of organic source viz. FYM increases the availability of substrate for dehydrogenase activity. Yaseen et al. (2017) also reported similar findings. It was also observed that 100% N treatment recorded significantly lowest dehydrogenase activity. Dehydrogenase activity, as a measure of soil microbial activity, is strongly influenced by the presence of nitrate, which

Table 4. Effect of regular use of fertilizers, FYM and lime on productivity of wheat.

	Yield (q ha^{-1})	
Treatment	Grain	Straw
T_1	19.22	34.56
T_2	20.22	36.44
T_3	17.11	31.33
T_4	23.11	40.89
T_5	19.67	35.67
T_6	9.89	18.11
T_7	0.00	0.00
T_8	30.34	53.22
T_9	9.00	16.55
T_{10}	27.89	49.44
T_{11}	3.56	7.14
CD (P= 0.05)	3.04	5.62

serves as an alternative electron acceptor resulting in low activities when nitrogenous fertilizers are applied to soil (Casida, Klein, and Santoro 1964).

Productivity of wheat

The regular application of FYM along with 100% NPK increased the grain and straw yield of wheat significantly over 100% NPK, the increase being 50.04 and 46.04%, respectively (Table 4). The grain and straw yield recorded under 100% NPK + lime (27.89 and 49.44 q ha^{-1}, respectively) was at par with 100% NPK + FYM (30.34 and 53.22 q ha^{-1}, respectively). Significantly higher productivity with continuous use of FYM for the last forty four years may be attributed to beneficial effect of FYM on physical, chemical and biological properties of soil (Brady and Weil 2007). The significant improvement in wheat productivity due to lime application may be ascribed to ameliorating effect of lime on soil acidity and positive effect of lime application on overall soil health including physical, chemical and biological environment.

Omission of potassium from fertilization schedule resulted in significant reduction in grain and straw yield as compared to 100% NPK. The grain and straw yield in 100% NP (T_6) was 9.89 and 18.11 q ha^{-1}, respectively, and the extent of decrease over 100% NPK was 51.08 and 50.30%, respectively. Likewise, when application of sulfur was omitted, a significant reduction in grain (55.5%) and straw yield (54.6) % was noted. The grain and straw yield in the plots treated with100% NPK (-S) was 9.00 and 16.55 q ha^{-1}, respectively. It is noteworthy that continued absence of K and S in crop nutrition led to drastic decline in the grain yield of wheat. Super optimal dose of NPK (150% NPK) could not increase the grain and straw yield of wheat over 100% NPK. Continuous application of N alone through urea has resulted in zero yield of wheat. It is attributed to sharp decline in pH that accelerated process of land degradation by increasing the concentration of Al and Fe ions. These plots have become completely unsuitable for crop growth.

Conclusion

Integrated use of fertilizers and amendments (FYM/lime) for 44 years improved physical, chemical and biological properties of soil significantly. This has led to sustainable yield of wheat. The use of recommended dose of nutrients (100% NPK through chemical fertilizers), though sustained the crop yields, but does not improve the soil properties to the extent as improved by the combined application of the organics and inorganics, causing a serious threat to soil health. Continuous use of urea alone had deleterious effect on soil properties which ultimately led to zero productivity. Omission of K and S also resulted in significant reduction in wheat yield. It can be concluded from the study that the use of amendments along with chemical fertilizers is absolutely essential to sustain the productivity of acid soils and to maintain the soil health for the use of this natural resource by future generations on long-term basis. To know the effect of different nutrient management practices, it is necessary to monitor the soil health periodically.

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