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Long term effect of fertilizers and amendments on the properties of an acid Alfisol and uptake of primary nutrients and sulfur in maize-wheat rotation in North Western Himalayas

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ABSTRACT
Soil physico-chemical properties and NPKS uptake were studied in a long-term fertilizer experiment at experimental farm of Department of Soil Science, Himachal Pradesh Agricultural University, Palampur (India). All properties were significantly affected by long term application of fertilizers. Bulk density was the highest with 100% N application and the lowest with FYM application. Optimum pH was resulted in lime amended treatment. Organic carbon, CEC, Available N and K were highest in FYM amended treatment. Available P was highest in 150% NPK and that was at par with 100% NPK + FYM. All primary nutrients were decreasing with increasing depth. Application of 100% NPK + FYM recorded highest yield of maize and wheat, which was at par with 100% NPK + lime. Uptake of NPK and S followed the yield trend and resulted in the highest uptake of NPK and S in 100% NPK + FYM and the lowest in control.

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amendments; fertilizers; long-term; maize-wheat; soil properties; uptake; yield

Introduction

Cereals are important dietary protein source throughout the world, because they constitute the main protein and energy supply in most countries (Bos et al. 2005). In India, maize and wheat are major crops of irrigated areas in northern parts of the country. Both the crops contribute 44.42% in food grain production (Anonymous 2014). The acreage under maize and wheat is 8.49 and 29.04 million hectares, respectively (Anonymous 2014). These two crops form about 49.33% of the total food production. Maize and wheat require huge amount of nutrients for producing more yields as both are exhaustive crops. Therefore, raising the viability of this important cropping sequence holds the key to the transformation of agricultural scenario in India. But the over-dependence on high analysis fertilizers has encouraged the process of land degradation. Indiscriminate use of high analysis chemical fertilizers results in the deficiency of secondary and micronutrients in soils (Singh 2007). Consequently, most of the productive soils are becoming unproductive. The continuous application of fertilizers leads to deteriorated soil health with reduced organic matter and multiple nutrient deficiencies. As the consequence, it is a big question to sustain the productivity of maize-wheat system. Long-term fertilizer experiments provide valuable information on soil fertility and crop productivity as influenced by continuous application of fertilizers (Reddy et al. 2006).

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Sustainable increases in crop yields are needed to ensure food security as population is increasing day by day. The population of the country has been projected to be around 1.4 billion by the year 2025. The land area available for cultivation in India is limited and shrinking, whereas human population is increasing resulting in fast decline in per capita availability of arable land area. Rapidly increasing population and shrinking land resources for crop production are putting tremendous pressure on land resource due to intensive cultivation. Careful scientific management of soil will be essential if this demand for cereal production is to be met. Soil management practices have profound impacts on soil organic matter (SOM) levels, which are closely linked to land productivity (Zhou et al. 2013). Organic amendments play an important role in the improvement of SOM levels and thus soils physical properties (Hati et al. 2007). Integrated nutrient management, which includes potential sources of nutrients like chemical fertilizers, bulky organic manures undertaken to evaluate the influence of continuous application of and biofertilizers, could help in mitigating these problems to some extent (Dhaliwal, Virk, and Brar 2007). The chemical fertilizers are one of the key factors contributing to increase in agricultural production of our farming system, but these are known to exhibit deleterious effect on soil environment, if used injudiciously Katyal (2003). The continued low and imbalanced use of nutrients is one of the prime areas of concern for agricultural sustainability. The low and imbalanced uses of nutrients led to the soil quality deterioration and keep the production level low Sharma and Subehia (2003). Application of organo-inorganic combination is very effective in realization of high yield and high responses to added nutrients (Sarkar, Lal, and Singh 1997), while imbalance use of nutrients has detrimental effect. To meet these challenges, long-term experiments (LTEs) are extremely valuable in understanding decade-scale transformations in grain yield and soil properties, that's why the present study was fertilizers and amendments on the soil physical and chemical properties with the yield and nutrient uptake by maize-wheat.

Materials and methods

The present investigation was carried out in the ongoing long-term fertilizer experiment initiated during 1972 at experimental farm of Department of Soil Science, CSK HPKV, Palampur, located at 31°6/N latitude and 76°3/E longitude, 1290 meters above mean sea level. The climate of the study area was wet temperate with average annual rainfall of 2500–3000 mm, most of which is received during the wet season (June–September). The soil of the experimental site was silty loam and classified taxonomically as "Typic Hapludalf." At the initiation of the experiment, soil of the experimental field was having pH 5.8, organic carbon (OC) 7.9 g kg^{-1}, available N (Nitrogen) 736, available P (Phosphorus) 12 and available K (Potassium) 194 kg ha^{-1}, respectively. Initially, the experiment comprised of 10 treatments. The 11th treatment viz., 100% NPK (-S) was introduced in *kharif* 1981. The experiment has been laid out in randomized block design. The detail of treatments has been given in Table 1. Due to build up in available P, the treatments have been modified slightly from *kharif* 2011, the optimal and super optimal dose of P has been reduced by 50% and in case of sub optimal dose of NPK, FYM (Farm Yard Manure) @ 5t ha^{-1} has also been included.

The recommended dose of N (Nitrogen), P_2O_5 (Phosphorus) and K_2O (Potassium) for wheat was 120, 60 and 30 kg ha^{-1} and for maize 120, 60 and 40 kg ha^{-1}, respectively. Half dose of N and full dose of P and K were applied at the time of sowing in both the crops. The remaining half nitrogen was top dressed in two equal splits at maximum tillering and flowering stage of wheat and knee high and pre-tasseling stages in maize crop, respectively. The sources of N, P and K were urea, single super phosphate and muriate of potash, respectively. In NPK (-S), P was applied through diammonium phosphate (DAP) to assess the effect of 'S' (Sulfur) free high analysis P fertilizer in crop production. Zinc was applied in T_5 as zinc sulfate @ 25 kg ha^{-1} every year to both the crops till *rabi* 2010–11. FYM was applied @ 10 t ha^{-1} on fresh weight basis to maize crop only, which corresponds to the practice

Table 1. Effect of long-term use of fertilizers and amendments on grain and stover/straw yield of maize and wheat crops.

	Maize (q ha^{-1})			Wheat (q ha^{-1})		
Treatments	Grain	Straw	Biological	Grain	Stover	Biological
T_1: 50% NPK	35.96	62.88	98.84	19.22	35.33	54.55
T_2: 100% NPK	42.04	74.22	116.26	20.78	37.66	58.44
T_3: 150% NPK	39.83	71.11	110.94	16.78	32.11	48.89
T_4: 100% NPK + HW	43.97	77.55	121.52	23.11	41.78	64.89
T_5: 100% NPK + Zn	41.15	68.44	109.59	19.61	35.72	55.33
T_6: 100% NP	23.14	41.44	64.58	11.78	21.56	33.34
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK + FYM	59.32	105.11	164.43	32.33	57.56	89.89
T_9: 100% NPK (-S)	25.58	45.55	71.13	11.67	21.00	32.67
T_{10}: 100% NPK + lime	55.46	100.00	155.46	31.56	55.11	86.67
T_{11}: Control	9.33	19.11	28.44	3.66	7.67	11.33
CD (P = 0.05)	4.29	7.91	11.53	4.41	5.88	10.20

Table 2. Analytical methods used for soil and plant analysis.

Soil property	Method employed
Bulk density	Singh (1980)
Soil pH (1:2.5)	Jackson (1973)
Soil organic Carbon	Walkley and Black (1934)
Cation exchange capacity	Piper (1966)
Available nitrogen	Subbiah and Asija (1956)
Available phosphorus	Olsen et al. (1954)
Available potassium	Merwin and Peech (1951)

S. No	Plant analysis	Method employed	Reference
1	Nitrogen	Micro Kjeldahl method	Jackson (1973)
2	Phosphorus	Vanado-molybdo-phosphoric acid	Jackson (1973)
3	Potassium	Flame photometer	Black (1965)
4	Sulfur	Wet digestion	Chesnin and Yein (1951)

being followed by the farmers of the region. The FYM applied contained 60% moisture and its average nutrient content on dry weight basis was 1.01, 0.26 and 0.40% of N, P and K, respectively. Lime was added in T_{10} @ 900 kg ha^{-1} as marketable lime ($CaCO_3$) passed through 100 mesh sieve to maize crop only. Lime application continued till the soil pH was raised to about 6.5. Lime application in the subsequent years was restored only when the soil pH declined to about 6.3. In case of wheat, irrigations were given at critical growth stages. In case of maize crop, 1 pre-sowing irrigation was given. Thereafter, the crop met its water requirement through rainfall. Chemical weed control measures were followed in both the crops except in T_4 (100% NPK + hand weeding) where weeds were removed manually. Grain and stover/straw yields of both crop maize (2014) and wheat (2014–15) were recorded and discussed.

Soil samples were collected from a depth of 0–0.15, 0.15–0.30 and 0.30–0.45 m after the harvest of maize. These samples were used for the determination of cation exchange capacity (CEC), available nitrogen, available phosphorus and available potassium. Surface soil samples were also analyzed for bulk density, pH and organic carbon. Standard methods of analysis for these physico chemical properties are given in Table 2.

The nutrient uptake for N, P, K and S was calculated by multiplying per cent concentration of a particular nutrient with grain and straw/stover yields. The uptake of the nutrients obtained in respect of grain and straw/stover yield was summed up in order to compute the amount of total nutrients removed by the crop. Standard methods for determining the nutrient content are given in Table 2.

Table 3. Effect of long-term use of fertilizers and amendments on soil bulk density (Mg m^{-3}), pH, and soil organic carbon (g kg^{-1}).

Treatments	Bulk density	pH	Soil organic carbon
T_1: 50% NPK	1.24	5.31	10.12
T_2: 100% NPK	1.23	5.21	10.28
T_3: 150% NPK	1.24	4.83	10.15
T_4: 100% NPK + HW	1.19	5.23	11.10
T_5: 100% NPK + Zn	1.23	5.17	9.76
T_6: 100% NP	1.26	5.07	9.35
T_7: 100% N	1.40	4.44	8.85
T_8: 100% NPK + FYM	1.14	5.45	13.75
T_9: 100% NPK (-S)	1.24	5.11	9.60
T_{10}: 100% NPK + lime	1.22	6.27	10.65
T_{11}: Control	1.35	5.67	7.95
CD ($P = 0.05$)	0.02	0.08	0.25
Initial	1.31	5.8	7.9

Results

Soil properties

Effect of fertilizers and amendments on bulk density: Bulk density of surface soil (0–0.15 m depth) was significantly affected by the treatments and ranged from a minimum value of 1.14 Mg m^{-3} in 100% NPK + FYM (T_8) to maximum value of 1.40 Mg m^{-3} in 100% N (T_7) given in Table 3. All treatments recorded a significant decrease in bulk density as compared to control except 100% N. Application of balanced fertilizers alone (100% NPK) or in combination with organics decreased bulk density of soil significantly over control. The highest reduction in bulk density was recorded in treatment T_8 (FYM + Chemical fertilizers), where it decreased from initial value of 1.31 Mg m^{-3} to 1.14 Mg m^{-3} after forty-three cropping cycles.

Effect of fertilizers and amendments on soil pH: Soil pH measured in water (soil:water: 1:2.5) indicate the active acidity of surface soil and results showed that the soils were strongly to moderately acidic, with pH values varied from a minimum value of 4.44 in 100% N to the maximum value of 6.27 in 100% NPK + lime (Table 3). Continuous cropping and fertilizer use over the years reduced the soil pH except the treatment involving use of lime (100% NPK + lime) compared to the soil pH value of 5.8 recorded in 1972 at the initiation of the experiment. Addition of FYM along with NPK also increased the soil pH as compared to the use of NPK alone.

Effect of fertilizers and amendments on organic carbon: The soil organic carbon varied from a maximum value of 13.75 g kg^{-1} in 100% NPK + FYM plots (T_8) to a minimum value of 7.95 g kg^{-1} in control plot (T_{11}) as given in Table 3. The treatment T_8 was followed by 100% NPK + HW (11.10 g kg^{-1}) and 100% NPK + lime (10.65 g kg^{-1}). All the treatments recorded an increase in organic carbon content as compared to its initial value (7.9 g kg^{-1}). However, soils receiving no fertilizers (control) or use of chemical fertilizers in imbalanced form (100% N, 100% NP) showed significant decline in the soil organic carbon content as compared to other treatments. The decline of 9.04, 13.91 and 6.61% was recorded in 100% NP, 100% N and 100% NPK (-S) over 100% NPK, respectively.

Effect of fertilizers and amendments on cation exchange capacity (CEC): The cation exchange capacity (CEC) in surface layer (0–0.15 m) varied from the lowest value of 6.73 c mol (p^+) kg^{-1} in 100% N treatment (T_7) to the highest value of 13.20 c mol (p^+) kg^{-1} in 100% NPK + FYM treatment (T_8) (Table 4). The decrease in CEC had been found in almost all the treatments as compared to initial value, except 100% NPK + FYM and 100% NPK + lime wherein the initial status of 12.1 c mol (p^+) kg^{-1} was almost maintained. About 9.09 and 4.13% increase was noticed in FYM and lime amended treatments over initial value of CEC in the surface layer. The decline of 38.84, 44.38 and 20.08% in cation exchange capacity was observed in control, 100% N and 100% NP treated plots, respectively as compared to initial value of the experiment. The 100%

Table 4. Effect of long-term use of fertilizers and amendments on soil chemical properties.

	Chemical properties			
Treatments	CEC	Available N	Available P	Available K
		0–0.15 m		
T_1: 50% NPK	9.40	310.30	50.40	146.70
T_2: 100% NPK	10.20	329.30	99.68	155.70
T_3: 150% NPK	10.80	365.90	183.68	175.80
T_4: 100% NPK + HW	11.00	334.50	99.68	153.40
T_5: 100% NPK + Zn	10.53	360.60	103.60	153.40
T_6: 100% NP	9.67	345.00	113.12	126.60
T_7: 100% N	6.73	350.20	6.50	135.50
T_8: 100% NPK + FYM	13.20	376.30	179.20	194.90
T_9: 100% NPK (-S)	9.80	329.30	116.48	170.20
T_{10}: 100% NPK + lime	12.60	339.70	117.60	171.40
T_{11}: Control	7.40	261.30	6.72	117.60
CD (P = 0.05)	0.77	28.40	7.43	2.79
Initial	12.1	736	12.0	194.20
		0.15–0.30 m		
T1: 50% NPK	8.60	220.10	37.0	138.88
T2: 100% NPK	9.20	245.65	90.30	147.84
T3: 150% NPK	9.67	261.33	168.0	166.88
T4: 100% NPK + HW	10.20	235.20	91.80	144.48
T5: 100% NPK + Zn	9.60	256.11	90.70	145.60
T6: 100% NP	8.60	282.24	101.9	116.48
T7: 100% N	6.40	266.56	5.80	132.16
T8: 100% NPK + FYM	12.33	308.37	164.60	190.40
T9: 100% NPK (-S)	9.33	271.79	106.40	164.64
T10: 100% NPK + lime	11.73	287.47	101.90	166.88
T11: Control	6.60	172.48	6.0	113.12
CD (P = 0.05)	0.75	36.21	7.17	3.05
Initial	–	–	–	–
		0.30–0.45 m		
T1: 50% NPK	7.20	104.50	16.91	128.80
T2: 100% NPK	7.93	109.80	19.60	135.50
T3: 150% NPK	8.13	120.20	36.06	146.70
T4: 100% NPK + HW	8.80	135.90	16.46	132.20
T5: 100% NPK + Zn	8.33	125.40	12.32	133.30
T6: 100% NP	7.40	109.80	28.45	105.30
T7: 100% N	4.87	135.90	4.37	115.40
T8: 100% NPK + FYM	10.20	172.50	24.86	173.60
T9: 100% NPK (-S)	7.27	130.70	17.14	146.70
T10: 100% NPK + lime	9.93	146.30	18.93	151.20
T11: Control	5.40	109.80	4.03	99.70
CD (P = 0.05)	0.98	24.95	1.13	4.13
Initial	–	–	–	–

NPK + Zn, 150% NPK and 100% NPK treated plots were statistically at par with each other. In case of subsurface soil layers, the CEC decreased as compared to surface layer. All the treatments in subsurface layers followed the similar trend as surface layer.

Effect of fertilizers and amendments on available nitrogen: The continuous manuring and cropping for 43 years showed considerable decline in available N content of the soil in all the treatments as compared to initial value (736 kg ha^{-1}) as given in Table 4. The available N content of surface layer (0–0.15 m) varied from a minimum value of 261.3 kg ha^{-1} in control to a maximum value of 376.3 kg ha^{-1} in 100% NPK + FYM. In comparison to the initial content, the application of 100% N, 100% NP and 100% NPK resulted in 52.42, 53.12 and 55.26% of soil N depletion, respectively. Application of 100% NPK + FYM and 150% NPK recorded about 14.2 and 11.1% higher available N as compared to 100% NPK alone. The highest value of available N in 100% NPK + FYM (T_8) was at par with 150% NPK (T_3) while the lowest value of available N in control was significantly inferior to rest of the treatments. In subsurface soil layers 0.15–0.30 m and 0.30–0.45 m, available nitrogen in 0.15–0.30 m layer ranged from 172.48 kg ha^{-1} in control to 308.37 kg ha^{-1} in 100% NPK + FYM whereas in 0.30–0.45 m layer the values of N varied from 109.8 kg ha^{-1} in control to 172.5 kg ha^{-1} in 100% NPK + FYM. The values of available N were decreasing with increase in soil depth. However, the treatment wise trend was similar down the soil profile.

Effect of fertilizers and amendments on available phosphorus: In surface soils (0–0.15 m), available phosphorus varied from 6.50 kg ha^{-1} in 100% N (T_7) to 183.68 kg ha^{-1} under 150% NPK treatment (T_3) (Table 4). The plots where continuous use of graded doses of phosphorus at the rate of 50, 100 and 150% of its recommended level in combination with nitrogen and potassium were made, the soil available phosphorus content increased significantly over untreated plots with the values of 50.40, 99.68 and 183.68 kg ha^{-1}, respectively. The decrease in available P was observed only in control and 100% N treated plots over initial status and this decrease was 44 and 45.83%, respectively. The available P under 100% NPK + HW and 100% NPK + Zn were at par with 100% NPK alone (T_2). Application of FYM, lime and zinc along with NPK increased the available P content to 167.2, 105.6 and 91.6 kg ha^{-1} over its initial status (12.0 kg ha^{-1}), respectively. Application of FYM along with 100% NPK resulted in an increase of P by 79.52 kg ha^{-1} P over 100% NPK (T_2). In subsurface soil layers 0.15–0.30 m and 0.30–0.45 m, the lowest value of available P (5.8 kg ha^{-1}) was recorded in 100% N and the highest (168.0 kg ha^{-1}) was recorded under 150% NPK in 0.15–0.30 m layer, whereas in 0.30–0.45 m the lowest value was 4.03 kg ha^{-1} and the highest was 36.06 kg ha^{-1} in control and 150% NPK, respectively. Both the subsurface layers had lower content of available phosphorus as compared to surface layer. However, the treatment effects at both the depths were comparable.

Effect of fertilizers and amendments on available potassium: Available K in surface layer varied from the lowest value of 117.6 kg ha^{-1} under control (T_{11}) to the highest value of 194.9 kg ha^{-1} under 100% NPK + FYM (T_8) (Table 4). Due to continuous omission of K for the last forty-three years the decline in available K in control, 100% N and 100% NP treated plots was 39.44, 30.23 and 34.81%, respectively as compared to its initial value. The treatments, 100% NPK + HW and 100% NPK + Zn were at par. The available K content in the subsurface soils was less as compared to surface layer in all the treatments. The effect of different treatment on available K content at subsurface layers was similar in trend to surface layer.

Yield and uptake of nutrients

Effect of fertilizers and amendments on maize yield**:** The highest grain (59.32 q ha^{-1}) and stover (105.11 q ha^{-1}) yield of maize was obtained in 100% NPK + FYM, which was at par with 100% NPK + lime (Table 1). The continuous application of N alone through urea (100% N (T_7)) for forty three years resulted in zero yields of maize. Except 100% N treatment the lowest grain and stover yield was obtained in control (9.33 & 19.11 q ha^{-1}) due to zero fertilization and continuous cropping in this treatment. Imbalanced application of nutrients in 100% NP and 100% NPK (-S) resulted in significant reduction in maize production as compared to 100% NPK with sulfur. About 39 and 45% reduction in grain yield was recorded in 100% NPK (-S) and 100% NP as compared to 100% NPK, respectively. This showed the significance of sulfur and potassium in nutrition of maize. Application of lime with 100% NPK also resulted in increasing the maize yield. The treatment in which zinc was also applied with 100% NPK resulted in lower yield of maize as compared to 100% NPK.

Effect of fertilizers and amendments on nitrogen uptake by maize: Nitrogen uptake by maize grains varied from 12.44 in control to 97.81 kg ha^{-1} in 100% NPK + FYM treatments (Table 5). Both FYM and lime amended plots recorded significantly higher N uptake over rest of the treatments Nitrogen uptake by maize grains in FYM and lime amended plots was 97.81 and 87.27 kg ha^{-1}, respectively. Application of 100% NP alone (without K), 100% NPK (-S) and 50% NPK

Table 5. Effect of long-term use of fertilizers and amendments on NPKS uptake by maize-wheat.

Maize

	Nitrogen			Phosphorus		
Treatments	Grain	Stover	Total	Grain	Stover	Total
T_1: 50% NPK	47.95	38.40	86.35	8.38	2.63	11.01
T_2: 100% NPK	63.52	49.29	112.81	10.65	3.85	14.50
T_3: 150% NPK	63.73	49.12	112.85	12.08	4.79	16.87
T_4: 100% NPK + HW	69.89	51.25	121.14	10.82	4.52	15.34
T_5: 100% NPK + Zn	64.84	43.38	108.22	10.13	3.68	13.81
T_6: 100% NP	34.47	28.17	62.64	5.06	1.92	6.98
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK + FYM	97.81	82.30	180.11	23.01	7.34	30.35
T_9: 100% NPK (-S)	35.47	28.84	64.31	6.48	1.87	8.35
T_{10}: 100% NPK + lime	87.27	65.89	153.16	18.43	5.79	24.22
T_{11}: Control	12.44	10.36	22.80	1.81	0.59	2.40
CD (P = 0.05)	8.92	5.61	12.61	2.03	1.08	2.58

	Nitrogen			Phosphorus		
Treatments	Grain	Stover	Total	Grain	Stover	Total
T_1: 50% NPK	11.50	36.65	48.15	7.21	8.23	15.44
T_2: 100% NPK	15.27	50.29	65.56	11.22	11.64	22.86
T_3: 150% NPK	14.59	50.54	65.13	11.15	10.91	22.06
T_4: 100% NPK + HW	15.94	53.54	69.48	12.64	12.38	25.02
T_5: 100% NPK + Zn	14.00	39.07	53.07	11.41	12.95	24.36
T_6: 100% NP	6.47	17.89	24.36	6.94	6.95	13.89
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK + FYM	23.94	86.92	110.86	18.86	20.69	39.55
T_9: 100% NPK (-S)	7.87	23.56	31.43	3.60	4.71	8.31
T_{10}: 100% NPK + lime	19.98	65.81	85.79	17.05	15.35	32.40
T_{11}: Control	2.68	9.07	11.75	1.14	1.59	2.73
CD (P = 0.05)	2.76	7.78	9.43	2.49	1.69	3.88

Wheat

	Nitrogen			Phosphorus		
Treatments	Grain	Stover	Total	Grain	Stover	Total
T_1: 50% NPK	30.79	16.14	46.93	6.79	2.22	9.01
T_2: 100% NPK	33.78	18.20	51.98	7.84	3.15	10.99
T_3: 150% NPK	27.76	16.07	43.83	6.80	3.21	10.01
T_4: 100% NPK + HW	37.68	20.49	58.17	8.49	3.14	11.63
T_5: 100% NPK + Zn	33.33	16.91	50.24	6.48	2.03	8.51
T_6: 100% NP	18.50	8.50	27.00	4.03	1.11	5.14
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK + FYM	57.98	36.45	94.43	14.51	4.98	19.49
T_9: 100% NPK (-S)	18.96	9.50	28.46	4.46	1.18	5.64
T_{10}: 100% NPK + lime	54.47	29.55	84.02	13.03	4.06	17.09
T_{11}: Control	5.65	2.84	8.49	0.99	0.29	1.28
CD (P = 0.05)	6.97	3.19	9.88	1.67	0.91	2.10

	Nitrogen			Phosphorus		
Treatments	Grain	Stover	Total	Grain	Stover	Total
T_1: 50% NPK	6.89	22.60	29.49	4.50	0.64	5.14
T_2: 100% NPK	8.26	25.24	33.50	5.81	0.83	6.64
T_3: 150% NPK	6.85	23.60	30.45	5.04	0.54	5.58
T_4: 100% NPK + HW	8.75	26.18	34.93	7.29	0.93	8.22
T_5: 100% NPK + Zn	6.72	23.59	30.31	6.02	0.86	6.88
T_6: 100% NP	2.70	8.23	10.93	3.54	0.32	3.86
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK + FYM	14.66	47.22	61.88	10.99	1.16	12.15
T_9: 100% NPK (-S)	4.09	13.85	17.93	1.76	0.28	2.04
T_{10}: 100% NPK + lime	11.59	41.33	52.92	9.47	1.13	10.60
T_{11}: Control	0.95	3.78	4.73	0.50	0.09	0.59
CD (P= 0.05)	1.53	4.19	5.51	1.30	0.16	1.45

resulted in significant reduction of N uptake as compared to optimum application of NPK. Furthermore, 100% NPK + Zn, 100% NPK + HW, 150% NPK and 100% NPK were statistically alike with respect to N uptake by maize grains.

In case of maize stover, N uptake ranged from 10.36 kg ha^{-1} in control (T_{11}) to 82.3 kg ha^{-1} in NPK + FYM treated plots (T_8). Lime (T_{10}) amended and FYM (T_8) treated plots recorded higher N uptake values over rest of the treatments. Omission of either S (T_9) or K (T_6) resulted in lower N uptake values as compared to balanced treatment.

The total N uptake by maize varied from 22.80 in control to 180.11 kg ha^{-1} in NPK + FYM amended plots (T_8). Lime and FYM treated plots had statistically higher total N uptake over rest of the treatments. Hand weeded plots with uptake value of 121.14 kg ha^{-1} was statistically at par with 100% NPK alone (112.81 kg ha^{-1}). The total N uptake in 100% NPK + Zn, 150% NPK and 100% NPK was 108.22, 112.85 and 112.81 kg ha^{-1}, respectively and all were statistically alike. Omission of S (T_9) and K (T_6) led to 42.9 and 44.5% reduction in N uptake by maize, respectively over the balanced fertilization (T_2). Compared to balanced treatment (T_2), sub optimal treatment had 26.46 kg ha^{-1} lower N uptake.

Effect of fertilizers and amendments on phosphorus uptake by maize: The data on phosphorus uptake by maize presented in Table 5 indicated that P uptake by maize grains ranged from 1.81 kg ha^{-1} in control (T_{11}) to 23.01 kg ha^{-1} in 100% NPK + FYM (T_8). P uptake in 100% NPK + lime (T_{10}) and 100% NPK + FYM (T_8) was significantly higher than all the other treatments. Phosphorus uptake in 100% NPK + Zn (T_5), 100% NPK alone (T_2), 100% NPK + HW (T_4) and treatment with super optimal dose of NPK (T_3) was statistically at par. Among the graded doses of NPK, application of 100 and 150% NPK registered 27.0 and 44.1% increase in P uptake over sub optimal treatment, respectively. 100% NPK (-S), application of NP alone (T_6) and control (T_{11}), recorded significantly lower P uptake as compared to optimal fertilization (T_2).

The P uptake by maize stover varied from 0.59 kg ha^{-1} in control (T_{11}) to 7.34 kg ha^{-1} in 100% NPK + FYM (T_8). Phosphorus uptake by maize stover followed almost similar trend as that of maize grains. Further, P uptake by stover in T_8 and T_{10} was found significantly higher in comparison to other treatments. Whereas, 100% NPK + Zn (T_5), 100% NPK alone (T_2), 100% NPK + HW (T_4) and treatment with super optimal dose of NPK (T_3) were statistically at par with P uptake values of 3.68, 3.85, 4.52 and 4.79 kg ha^{-1}, respectively. Further, 100% NPK (T_2) and 150% NPK (T_3) showed 46.4 and 82.1% increase in P uptake by stover over 50% NPK (T_1).

The total P uptake by maize ranged from 2.40 kg ha^{-1} in control to 30.35 kg ha^{-1} in 100% NPK + FYM treated plots. Optimum fertilization and 100% NPK + Zn were statistically at par in respect of total P uptake, while control, 100% NP, 100% NPK (-S) and sub optimal dose of NPK recorded significantly lower P uptake as compared to optimal use of NPK. The values of total P uptake in 100% NPK along with lime (T_{10}) and FYM (T_8) were statistically higher than other treatments.

Effect of fertilizers and amendments on potassium uptake by maize: It may be conjectured from the data presented in Table 5 that the potassium uptake in maize grains varied from 2.68 kg ha^{-1} in control to 23.94 kg ha^{-1} in 100% NPK + FYM (T_8). Potassium uptake by maize grain in 100% recommended dose of fertilizers alone (15.27 kg ha^{-1}), was found to be at par with 100% NPK + Zn (14.00 kg ha^{-1}), 150% NPK (14.59 kg ha^{-1}) and 100 NPK + HW (15.94 kg ha^{-1}) . Whereas, control (T_{11}), 100% NP (T_6) and 100% NPK (-S) (T_9) showed a decline of 82.4, 57.2 and 48.5%, respectively over 100% NPK. Application of 50% NPK showed a decrease of 32.8% over the plots treated with optimal doses (T_2).

In case of maize stover, K uptake (Table 5) ranged from 9.07 kg ha^{-1} in control (T_1) to 86.92 kg ha^{-1} in 100% NPK + FYM (T_8). Application of FYM (T_8) and lime (T_{10}) along with 100% NPK significantly increased the K uptake by maize stover as compared to other treatments. Treatments where either K (T_6) or S (T_9) was omitted from application schedule showed a significant decline in K uptake in comparison to the application of 100% NPK (T_2). Among the graded doses of chemical fertilizers, 50% NPK registered a decrease of 37.2% over 100% NPK, while super optimal treatment (T_3) was at par with optimal fertilization (T_2) in respect of K uptake by stover.

A further examination of the data revealed that the total K uptake by maize ranged from 11.75 kg ha^{-1} in control (T_1) to 110.86 kg ha^{-1} in 100% NPK + FYM (T_8). Application of 100% NPK + FYM (T_8) and 100% NPK + lime (T_{10}) increased the K uptake to 69.1 and 30.8% over 100% NPK (T_2). Total K uptake by maize in treatments comprising 100% NP (K excluded) and 100% NPK (S excluded) were statistically at par but significantly lower than 100% NPK (T_2). Among graded doses of NPK, total K uptake in 100 and 150% NPK levels increased by 36.1 and 35.3%, respectively over sub optimal treatment (T_1).

Effect of fertilizers and amendments on sulfur uptake by maize**:** Data on uptake of sulfur by maize crop (grain, stover and total) have been presented in Table 5. The plot receiving 100% N was unable to produce any yield due to which the sulfur uptake in that plot could not be determined. Sulfur uptake by maize grain and stover varied from 1.14 to 18.86 and 1.59 to 20.69 kg ha^{-1}, respectively. The lowest and the highest uptake of sulfur by grain and stover was in control (T_{11}) and in organically amended treatment (T_8), respectively. Sulfur uptake by grain in the control plot was statistically comparable with 100% NPK (-S). In 100% NP treated plots, sulfur removal by maize grains and stover was significantly higher than the plots receiving 100% NPK (-S) and control. Addition of P along with N (100% NP) brought about an increase in the uptake of sulfur as compared to 100% NPK (-S).

The sulfur uptake in 100% NPK by maize grain and stover was significantly higher than 100% NP. Where sub optimal dose of NPK was applied, the sulfur uptake was 7.21 and 8.23 kg S ha^{-1} by grain and stover, respectively, and this S uptake was less as compared to 100% NPK (optimal dose). Lower sulfur uptake was recorded with application of 150% NPK than 100% NPK, however the values were non-significant. 100% NPK + lime also resulted in significantly higher sulfur uptake by grain and stover (17.05 and 15.35 kg S ha^{-1}, respectively) than 100% NPK.

Effect of fertilizers and amendments on wheat yield: In 100% N treatment, the imbalanced and sole application of nitrogen for 43 years resulted in zero yields of wheat (Table 1). In other treatments except 100% N, the grain and stover yield varied from 3.66 q ha^{-1} and 7.67 q ha^{-1}, respectively in control to 32.33 q ha^{-1} and 57.56 q ha^{-1} in 100% NPK + FYM. Exclusion of sulfur and potassium in treatment T_9 and T_6 resulted in 44 and 43% reduction in grain yield of wheat as compared to balanced application of nutrients i.e. 100% NPK, respectively. Continuous application of lime along with 100% NPK recorded the grain, straw and biological yield at par with 100% NPK + FYM and these treatments were significantly better than rest of the treatments. The wheat yield decreased with super optimal dose of NPK. Integration of chemical fertilizers with FYM resulted in 56 and 53% higher grain and straw yield of wheat as compared to 100% NPK. Further, application of K along with N and P (100% NPK) resulted in significantly higher grain and straw yields of wheat over 100% NP.

Effect of fertilizers and amendments on nitrogen uptake by wheat: The data on N uptake by wheat grain and straw have been presented in Table 5. The N uptake in 100% N was zero as there was no yield. Due to complete degradation of soil the wheat productivity declined to zero level, which resulted in zero uptake of N in 100% N. Nitrogen uptake by wheat grain varied from 5.65 kg ha^{-1} in control to 57.98 kg ha^{-1} in 100% NPK + FYM. The treatment receiving no S for last forty-three years showed a reduction of 14.82 kg ha^{-1} in nitrogen uptake by wheat grains as compared to 100% NPK with S. A close look on the data revealed that N uptake by wheat grain in 100% NP treatment increased significantly by 12.85 kg ha^{-1} over control. The continuous omission of K in plant nutrition had resulted in substantial decline in crop yields, thereby reduction in N uptake as compared to 100% NPK. When K was also added with 100% NP (100% NPK) the N uptake by wheat grain increased to 33.78 kg ha^{-1}, which was significantly higher than 100% NP and control. The 100% NPK + FYM and 100% NPK + lime amended plots recorded significantly higher N uptake over rest of the treatments. N uptake by wheat grain increased from 30.79 kg ha^{-1} to 33.78 kg ha^{-1} by increasing the fertilizer dose from 50% NPK to 100% NPK. Treatments *viz.,* 100% NPK, 100% NPK + HW and 100% NPK + Zn showed N uptake values of 33.78, 37.68 and 33.33 kg ha^{-1}, respectively, and these were statistically at par with each other. A reduction of 15.28 kg ha^{-1} in N uptake by wheat grains was noted in 100% NP treated plots as compared to 100% NPK treated plots.

Nitrogen uptake by wheat straw varied from 2.84 kg ha^{-1} in control to 36.45 kg ha^{-1} in 100% NPK + FYM. The 100% NP and 100% NPK (-S) treatment showed the uptake values of 8.50 and 9.50 kg ha^{-1} in wheat straw, respectively and were at par with each other. Likewise, 50% NPK, 100% NPK and 150% NPK were statistically comparable with each other but with the increasing dose of fertilizers, N uptake by wheat straw also increased up to 100% NPK but with super optimal dose, the N uptake decreased as compared to the optimal dose (100% NPK). The treatments comprising 100% NPK + FYM and 100% NPK + lime resulted in significantly higher N removal than rest of the treatments. Total N uptake by wheat varied from 8.49 kg ha^{-1} in control to 94.43 kg ha^{-1} in 100% NPK + FYM. Total N uptake in control was significantly lower than rest of the treatments. Total N uptake in 100% NP treated plots was statistically at par with 100% NPK (-S). FYM and lime amended plots showed an increase of 42.45 and 32.02 kg ha^{-1} in total N uptake over 100% NPK, respectively. Total N uptake by wheat in 50% NPK, 100% NPK and 150% NPK was statistically comparable among each other. Likewise, total N uptake in 100% NPK + HW and 100% NPK + Zn was at par with 100% NPK. Application of 100% NP and 100% NPK (-S) resulted in 24.98 kg ha^{-1} and 23.52 kg ha^{-1} reduction in total N uptake as compared to 100% NPK treatment.

Effect of fertilizers and amendments on phosphorus uptake by wheat: The pertinent data on P uptake by wheat crop have been given in Table 5 and the data indicated that P uptake in wheat grains varied from 0.99 kg ha^{-1} in control (T_{11}) to 14.51 kg ha^{-1} in 100% NPK + FYM (T_8). Treatment receiving only 100% N as urea for last forty-three years resulted in zero uptake of phosphorus as there was no grain as well as straw yield. Application of 100% NPK + lime (T_{10}) with P uptake of 13.03 kg ha^{-1} was at par with 100% NPK + FYM and both of these treatments resulted in significantly higher removal of P over rest of the treatments. Zero fertilization (T_{11}), 100% NP (T_6) and 100% NPK (-S) (T_9) registered a decline of 6.85, 3.81 and 3.38 kg ha^{-1} in P uptake, respectively over 100% NPK. 50% NPK, 100% recommended dose of fertilizers alone (100% NPK) and 150% NPK with uptake values of 6.79, 7.84 and 6.80 kg ha^{-1}, respectively, were statistically alike with each other. Application of zinc with recommended dose of fertilizer recorded a significantly lower value of P uptake by grain (6.48 kg ha^{-1}) as compared to 100% NPK + HW (8.49 kg ha^{-1}). Application of FYM along with 100% NPK and 100% NPK + lime resulted in 6.67 and 5.19 kg ha^{-1} higher P uptake in grain over 100% NPK alone.

The P uptake by straw varied from 0.29 kg ha^{-1} in control to 4.98 kg ha^{-1} in 100% NPK + FYM. Application of 100% NPK + FYM (T_8) with P uptake of 4.98 kg ha^{-1} was significantly higher than 100% NPK + lime (T_{10}) (4.06 kg ha^{-1}). The treatment receiving 100% NPK + FYM (T_8) was significantly superior as compared to rest of the treatments. The treatment, 150% NPK with P uptake 3.21 kg ha^{-1} was statistically comparable with 100% NPK + lime. The treatment receiving sub optimal dose of NPK resulted in significantly lower P uptake by wheat straw (2.22 kg ha^{-1}) as compared to recommended dose of fertilizer. Application of 100% NPK, 150% NPK, 100% NPK + HW with P uptake 3.15, 3.21 and 3.14 kg ha^{-1}, respectively, were at par with each other and significantly superior over zero fertilization, 100% NPK (-S), 100% NP and 50% NPK. Exclusion of either K (T_6) or sulfur (T_9) from the fertilizer schedule resulted in a significant decline in P uptake in comparison to the application of 100% NPK (T_2), the decrease being 64.76 and 62.54%, respectively.

Further, the data revealed that the total P uptake by wheat varied from a minimum value of 1.28 kg ha^{-1} in control to a maximum value of 19.49 kg ha^{-1} in 100% NPK + FYM. The highest

P uptake was recorded in 100% NPK + FYM followed by 100% NPK + lime (17.09 kg ha^{-1}). Total P uptake in 100% NPK was statistically at par with super optimal dose (150% NPK) and sub optimal dose (50% NPK) of fertilizers. Further, the total P uptake was significantly reduced in 100% NPK + Zn treatment over 100% NPK treatment. Total P uptake in 100% NP and NPK (-S) was 5.14 and 5.64 kg ha^{-1}, respectively.

Effect of fertilizers and amendments on potassium uptake by wheat: The perusal of the data in respect of potassium uptake has been presented in Table 5, revealed that potassium uptake by wheat grains varied from 0.95 kg ha^{-1} in control to 14.66 kg ha^{-1} in 100% + FYM. The K uptake in the 50% NPK (T_1), 100% NPK (T_2) and 150% NPK (T_3) was statistically alike among themselves with the uptake of 6.89, 8.26 and 6.85 kg ha^{-1} by grain, respectively. Compared to optimal dose of NPK (T_2), there was a significant reduction in the uptake of K by wheat grains with the application of 100% NP, 100% NPK (-S) and 50% NPK, the decrease being 5.56, 4.17 and 1.37 kg ha^{-1}, respectively. Generally, the trend of uptake of K was similar as the yield trend of wheat.

Regarding wheat straw, K uptake varied from 3.78 kg ha^{-1} in control (T_{11}) to 47.22 kg ha^{-1} in the plots receiving FYM with 100% NPK. Application of 100% NPK + FYM recorded significant increase in K uptake as compared to rest of the treatments. Likewise, application of lime recorded significantly higher K uptake than rest of the treatments except 100% NPK + FYM. Application of graded doses of fertilizer from 50, 100 and 150% NPK, 100% NPK + HW and 100% NPK + Zn resulted in the K uptake of 22.60, 25.24, 23.60, 26.18 and 23.59 kg ha^{-1}, respectively and these uptake values were statistically alike with each other. A significant decrease in K uptake by wheat straw was recorded in the treatments where S and K were excluded from the fertilizer application schedule and the decline of 17.01 kg ha^{-1} and 11.39 kg ha^{-1} in T_6 and T_9 treatments respectively was recorded as compared to 100% NPK.

A further glance on the data indicated that total K uptake by wheat varied from 4.73 kg ha^{-1} in control plot to 61.88 kg ha^{-1} under FYM amended plots. Again the FYM treatment was found statistically superior over rest of the treatments. Total K uptake in 100% NPK treated plots was 4.01 kg ha^{-1}, higher than sub optimal dose of NPK. Whereas, with 150% application of NPK the total K uptake was 3.05 kg ha^{-1}, lower than 100% NPK. Omission of potassium (T_6) and sulfur (T_9) decreased the potassium uptake by 67.37 and 46.48% as compared to recommended dose of NPK (T_2). Application of FYM and lime registered an increase of 84.72 and 57.97% in K uptake over 100% NPK, respectively.

Effect of fertilizers and amendments on sulfur uptake by wheat: A perusal of data presented in the Table 5 revealed that uptake of sulfur by wheat grain and straw varied from 0.50 to 0.09 kg ha^{-1} in control and 10.99 to 1.16 kg ha^{-1} in 100% NPK + FYM, respectively. The application of P along with N (100% NP) resulted in an increase in sulfur uptake (3.54 and 0.32 kg ha^{-1} in grain and straw, respectively) by wheat crop and this increase was significant over 100% NPK (-S) in case of grain and non-significant in case of straw. Sulfur uptake by wheat grain and straw in 100% recommended dose of fertilizer (100% NPK) was significantly higher than 100% NP treated plot.

The treatment receiving super optimal dose (150% NPK) resulted in a lower sulfur uptake of grain and straw (5.04 and 0.54 kg S ha^{-1}, respectively) with a significant decrease in case of straw and non-significant decrease in case of grain over 100% NPK (5.81 and 0.83 kg S ha^{-1} in grain and straw, respectively). 100% NPK + FYM recorded the highest sulfur uptake in grains and straw (10.99 and 1.16 kg S ha^{-1}, respectively), while 100% NPK + lime resulted in second highest sulfur uptake in wheat grain and straw (9.47 and 1.13 kg S ha^{-1}, respectively). Among the treatments amended with FYM and lime the S uptake by wheat grain was significantly higher in FYM amended plots as compared to lime amended plots whereas the uptake of S by straw was statistically alike in both the treatments. The S uptake in 100% NPK + HW (7.29 and 0.93 kg S ha^{-1} in grain and straw, respectively) and 100% NPK + Zinc (6.02 and 0.86 kg ha^{-1} in grain and straw, respectively) was statistically comparable.

Regarding total S uptake by wheat crop the total S uptake varied from 0.59 kg ha^{-1} in control to 12.15 kg ha^{-1} in 100% NPK + FYM. The lowest uptake of S was recorded in control which was followed by treatment where S was omitted from last forty-three years. The S uptake in 100% NP (3.86 kg ha^{-1}) was significantly higher than no S application. Among the graded doses of fertilizers, the S uptake in 100% NPK (6.64 kg ha^{-1}) was significantly higher than 50% NPK (5.14 kg ha^{-1}), but the application of 150% NPK resulted in the reduction of S uptake (5.58 kg ha^{-1}) as compared to 100% NPK (6.64 kg ha^{-1}) but the reduction was statistically comparable with recommended dose of fertilizer. Total S uptake in 100% NPK + HW (8.22 kg ha^{-1}) and 100% NPK + Zn (6.88 kg ha^{-1}) was statistically alike. The highest total S uptake was recorded in treatment amended with FYM followed by lime amended treatment (10.60 kg ha^{-1}).

Discussions

Soil properties

Effect of fertilizers and amendments on bulk density: The highest value (1.40 Mg m^{-3}) of bulk density in surface soil layer was recorded in T_7 treatment which received 100% N which may be due to the degradation of soil as a result of low organic matter content in soil and formation of compact layer. Continuous application of chemical fertilizers along with organics for forty-three cropping cycles caused significant decrease in the bulk density of soil which may be due to the addition of organic matter that resulted in increase in pore space and good soil aggregation (Chaudhary and Thakur 2007; Sharma, Mishra, and Singh 2007; Rasool, Kukal, and Hira 2008; Verma et al. 2010). Significant reduction in bulk density in NPK treated plots over control could be ascribed to the increased root biomass production that might have increased the organic matter content of the soil.

Effect of fertilizers and amendments on soil pH: The continuous use of N alone had the most acidifying effect with pH value declining to 4.44 in the 43rd cropping cycle, which could be attributed to acid producing nature of urea because nitrification of urea releases hydrogen ions in the soil which are responsible for creating acidity in soil (Magdoff, Lanyon, and Liebhardt 1997). The decrease in pH with sole use of nitrogenous fertilizer was also reported by Liu et al. (2010) and Li et al. (2012). The use of lime in combination with NPK increased the soil pH to neutrality (pH 6.27). Caires et al. (2008) observed that the elevation in soil pH through liming increases basic cation (Ca^{2+}) retention due to the increase in negative variable electric charges that are generated on the surface of colloids by the dissociation of H^+ from hydroxyl groups. The moderating effect of lime on soil acidity has been reported earlier by Verma, Mathur, and Verma (2012) and Chimdi et al. (2012). Addition of FYM increased the soil pH as compared to the use of NPK alone. Similarly, moderating effect of FYM on pH has also been reported by Melese and Yli-Halla (2016) and Nwite, Eneruvie, and Nwafor (2016).

Effect of fertilizers and amendments on organic carbon: The highest organic carbon content of the soil was recorded in 100% NPK + FYM (13.75 g kg^{-1}), 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 (Hemalatha and Chellamuthu 2013; Brar et al. 2015). Similarly, in long-term experiment, the SOC was reported higher in soils receiving FYM along with NPK fertilizer than in plots receiving NPK fertilizer alone (Sathish et al. 2011). The higher soil organic carbon content in manually weeded plots in comparison to plots where weeds were controlled with the help of herbicides might be due to the regular addition of weed biomass in these plots. The control and 100% N treatments recorded the least organic carbon, probably due to the low dry matter production and hence low return of crop residues to the soil and lowering of pH. Similar results have been reported by Sathish et al. (2011), Kumari et al. (2013), and Hemalatha and Chellamuthu (2013). The soil organic carbon content improved in fertilized plots as compared to the unfertilized plots due to carbon addition through the roots, crop residues and rhizo-deposition. These results are concordant with the findings of Singh et al. (2009) and Kumari et al. (2013). In this study, slow rate of organic matter decomposition in wet temperate zone could be another reason for buildup of soil organic carbon (Sharma, Subehia, and Sharma 2002; Verma, Mathur, and Verma 2012).

Effect of fertilizers and amendments on cation exchange capacity (CEC): Lime and FYM amended plots showed increase in CEC and this might be due to increase in pH, root biomass, crop residues production and their incorporation in the soil. Similar findings were reported by Sharma and Subehia (2014) with the integrated use of organics and fertilizers in the 20th cropping cycle. All other treatments showed a decrease in CEC which might be due to the acidifying effect of fertilizers which reduced the pH and ultimately reduced the pH dependent negative charge under almost all the treatments and particularly in 100% N treated plots.

Effect of fertilizers and amendments on available nitrogen: Available N decreased in almost all the treatments and the possible reasons behind the overall decline in available N may be leaching losses of N under very high rainfall conditions and the mismatch between its application dose and crop requirement. The higher content under T_8 may be due to additional supply of nitrogen through FYM over the years and addition of organic component. Similar results with FYM were found by Tadesse et al. (2013) and Parewa, Yadav, and Rakshit (2014). N mining in control due to continuous cropping without fertilization over a period of forty-three years may be the reason for the lowest value of available N.

Effect of fertilizers and amendments on available phosphorus: Available P has increased in all the treatments where it has been applied from initiation of experiment. The noticeable build up of available phosphorus with the continuous use of phosphatic fertilizers in these acidic soils may be attributed to low crop recovery of applied phosphorus and its high stability in form of residual phosphorus (Zhang, Mackenzie, and Liang 1995; Sharma and Gupta 1997). The substantial increase in available phosphorus in 150% NPK treated plots might be ascribed to the addition of P at higher rates, than recommended in this treatment. Considerable build up of available P with the application of graded doses of phosphatic fertilizer has also been reported by Rajput, Agarwal, and Intodia (2014). Application of FYM also increased the available P and this may be due to inactivation of potential sources of P fixation (iron, aluminum and hydroxyl aluminum ions) by organic molecules might be responsible for reduction in P fixation and increase in availability of phosphorus.

Effect of fertilizers and amendments on available potassium: As compared to the initial status (194.2 kg K ha^{-1}), the available K declined in almost all the treatments except 100% NPK + FYM (T_8). This showed that there was depletion in native K pools which may be due to more crop removal compared to the additions over a period of forty-three years. Application of FYM along with 100% NPK increased available K content as compared to 100% NPK in the surface layer and it can be ascribed to additional supply of potassium through FYM. The increase in available K due to application of organic manure with inorganic fertilizers was also found by Dhaliwal et al. (2015). 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.

Yield and uptake of nutrients

Effect of fertilizers and amendments on maize yield**:** Sole application of N through urea resulted in zero yield which might be due to increased soil acidity, degradation of soil and toxicity of iron and aluminum. Increasing the fertilization rates of sulfur with NPK from sub-optimal to optimum level resulted in increase in yield of maize crop which might be attributed to the balanced fertilization with nitrogen, phosphorus, potassium and sulfur (through SSP). Khan et al. (2006) reported that with the increase in the rates of S fertilization maize yield increased significantly up to the application of 60 kg S ha^{-1}. The highest yield of maize grain and stover resulted due to application of FYM along with recommended doses of fertilizers. The addition of FYM results in the release of organic acids that can complex Al and Fe, thereby, reducing P retention and inducing greater P availability. Moreover, sulfur was also added through the application of FYM (30 kg S ha^{-1}) which also contributed in increasing maize production. Pillai, Duaisamy, and Myleramy (2006) also reported that the continuous use FYM with recommended doses of fertilizers maximized the productivity of maize crop. Application of lime increased the yield as lime increased the soil pH (6.27) and reduced the toxic effect of Al, Fe and Mn. Because of the antagonistic interaction between Zn and P, application of Zn reduces the yield. In 100% NP the decrease in yield was due to K deficiency as K is required for the activation of enzymes, starch and protein synthesis. Potassium deficiency also leads to various physiological disorders. The hand weeded plots also resulted in higher grain and stover yield of maize as compared to 100% NPK because of better physical properties and increased microbiological growth in this treatment which helps in better root proliferation. Kumar et al. (2013) also ascribed the increase in yield in manually weeded plots, which might be due to the creation of modified micro-climate in turns of physical environment for mechanical manipulation of soil and lower crop – weed competition which might have helped in greater uptake of nutrients resulting in better crop growth.

Effect of fertilizers and amendments on nitrogen uptake by maize: Increased productivity level due to increased level of nutrition led to increase in uptake of N in different fertilized treatments over control. In 100% NPK (-S) plots, the yield was low due to S deficiency, so the N uptake was also low. The use of FYM with 100% NPK improved crop growth and increased maize productivity that resulted in higher uptake of N. The increase in N uptake in balanced fertilization plots compared to the control plots might be due to supply of N through external inputs and better root proliferation. Similar results have been reported by Brar, Dhillon, and Chinna (2001) and Pathak et al. (2005).

Effect of fertilizers and amendments on phosphorus uptake by maize: The higher P uptake values in FYM treated plots might be due to the fact that organic materials form chelates with Al^{3+} and Fe^{3+} resulting in reduction in P fixation. As lime precipitates the Al^{3+} at high pH, there is higher availability of P to the growing crops and hence the higher uptake in lime treated plots is understandable. Similar results were reported by Sepat and Rai (2013). Lower P uptake in 100% NP and 100% NPK (-S) plots may be because of lower productivity of maize as a result of K and S deficiency. In control, lower value of P uptake was recorded which may be due to continuous removal of nutrients and no addition for last forty-three years.

Effect of fertilizers and amendments on potassium uptake by maize: Low potassium uptake by maize grain and stover in control plots may be due to substantial decline in soil fertility because of the continuous removal of nutrients in the absence of nutrients addition from any external source. Application of FYM along with 100% NPK recorded the highest K uptake which might be due to the favorable conditions of crop growth and supply of K (0.4%) through FYM in addition to chemical fertilizers. Continuous omission of K and S resulted in low yield and therefore, lesser K uptake as compared to balanced fertilization. Moreover, K was not added in the NP treatment continuously and hence lesser K uptake in this plot is obvious. Positive effect of lime on K uptake may be due to the improvement in soil environment and consequently in crop yield. The use of chemical fertilizer alone or in combination with organics increased NPK uptake by maize crop. Similar results have been reported from elsewhere in the country by Nanjappa, Ramachandrappa, and Mallikarjuna (2001), Pathak et al. (2005), and Prasad et al. (2010).

Effect of fertilizers and amendments on sulfur uptake by maize**:** Unfertilized control plot resulted in the lowest uptake of sulfur by grain and stover of maize, which may be attributed to the lowest dry matter yield in the control plot. S uptake in 100% NPK (-S) was statistically comparable with control, which may be due to lower dry matter yield and exclusion of S fertilizer for last forty-three years. The increase in uptake of sulfur in 100% NP can be attributed to the synergistic interaction between P and S similar findings were reported Islam, Hoque, and Islam (2006). Graded doses of fertilizers from 50 to 100% NPK resulted in an increase in sulfur uptake which may be due to the application of increasing levels of sulfur through SSP and also due to increased crop yields from sub optimal to optimal doses of fertilizers. Increase in sulfur uptake with the addition of increasing rates of sulfur was also reported by Teotia, Ghosh, and Srivastava (2000). Application of FYM with 100% NPK resulted in an increase in the sulfur uptake over 100% NPK and this increase may be attributed to addition of sulfur (30 kg S ha^{-1} yr^{-1}) and other macro and micro nutrients through FYM, thus, increasing the availability of all the nutrients in soil. Liming increase the total S uptake which may be due to the liming effect which raised the pH of soil to 6.27 from the initial value 5.8 and pH has a direct effect on nutrient availability in the soil.

Effect of fertilizers and amendments on wheat yield: Application of only N resulted in zero yields. The deleterious effect of sole nitrogenous fertilizers on crop productivity was also reported Mahajan et al. (2007). Application of S increases the wheat yield, Sharma and Manohar (2002) also reported the increase in yield of wheat crop due to addition of sulfur fertilizers. There was a decrease in wheat yield with super optimal dose of fertilizers which was also reported by Rakshit et al. (2015). This might be due to emerging deficiency of secondary nutrients particularly Mg in 150% NPK. The treatment received P along with N (100% NP) increased the grain and straw yield of wheat significantly as compared to no fertilization. These results are in line with the findings of Brar, Dhillon, and Chinna (2001). Application of FYM with 100% NPK resulted in the highest yield of wheat which may be attributed to beneficial effect of FYM on soil physico-chemical properties (Brady and Weil 2002). Single super phosphate (SSP) was used for meeting out the P and S requirement, which might have met the Ca and S requirements but led to the deficiency of Mg. But with the use of Diammonium phosphate (DAP) a high analysis P fertilizer in place of single super phosphate (SSP) a decline in crop yield was obtained in comparison to SSP. Continuous use of DAP led to sulfur mining and resulted in drastic reduction in crop yield.

Effect of fertilizers and amendments on nitrogen uptake by wheat: As compared to control, the N uptake was significantly higher in all treatments receiving fertilizers either alone or in combination with amendments (FYM and Lime). Due to increase in productivity level as a result of higher level of nutrition, the N uptake also increased in all the treatments over control. In 100% NPK (-S) plots, the yield was low due to S deficiency, Thus, the N uptake was also lower. The use of FYM with 100% NPK led to favorable soil environment and proper nutrients supply which improved crop growth and resulted in higher N uptake. Lower yield was also the reason for the lower uptake of N in control (T_{11}). Lower yields in these plots may be due to poor inherent fertility status of these plots. The increase in N uptake in fertilized plots compared to the control plots might be due to N supply through external inputs and because of prolific root system under balanced application of nutrients.

Effect of fertilizers and amendments on phosphorus uptake by wheat: Control plots resulted in lower P uptake and this could be attributed to low yields as continuous cropping without any external inputs decreased native P supply. Comparatively higher P uptake under manual weeding might be due to better physical and chemical environment resulting in more root proliferation and better crop growth. The treatment receiving zinc with 100% NPK resulted in lower uptake of P as there is negative interaction in between P and Zn. When the application of K was omitted for the last forty-three years, potassium might have become limiting nutrient in crop production which resulted in low yields. Otherwise K has synergistic effect on P uptake by the crops. Significant reduction in yield had been recorded when K was excluded as compared to 100% NPK. The treatment where sulfur was not added also recorded a reduction in the uptake of phosphorus due to lower yield as a result of S deficiency, when compared to 100% NPK with S.

Effect of fertilizers and amendments on potassium uptake by wheat: K uptake by wheat grains was significantly higher in FYM amended plots over rest of the treatments, which might be due to the favorable conditions for crop growth in these plots and secondly, supply of K (0.4%) through FYM in addition to chemical fertilizers. Similarly, lime amended plots recorded significantly higher K uptake by wheat grains over rest of the treatments, except 100% + FYM, and which was due to the improvement in soil pH, enhanced nutrient availability and crop yield. Exclusion of K and S from fertilizer schedule resulted in low yield because of K and S deficiency, respectively and therefore lesser K uptake was recorded as compared to balanced use of NPK. Also, K was not added in the NP treatment from last forty-three years and hence resulted in lesser K uptake. The lowest uptake in control after 100% N was the result of complete exhaustion of native nutrients in control plots because of the continuous removal in the absence of nutrients addition from any external source resulted in low productivity and low K uptake by grain and straw of wheat. Positive influence of inorganics alone or in combination with organics on NPK uptake by wheat has also been observed by Pathak et al. (2005), Mann, Brar, and Dhillon (2006), and Prasad et al. (2010) under varied agro-climatic conditions.

Effect of fertilizers and amendments on sulfur uptake by wheat: The lowest uptake of sulfur in grain and straw was recorded under unfertilized plot followed by 100% NPK (-S) treated plot (1.76 and 0.28 kg ha^{-1} in grain and straw, respectively), which may be attributed to the lowest dry matter yield due to poor inherent fertility in these plots and continuous cropping without fertilization. Reduction in sulfur uptake in 100% NPK (-S) treated plots over other differently fertilized plots may also be due to S deficiency which resulted in lower dry matter yield. With graded doses of fertilizers from 50 to 150% NPK, the sulfur uptake increased significantly in both grain and straw up to 100% NPK, which may be due to the application of increasing levels of sulfur through SSP and also due to increased crop yields. Increase in sulfur uptake with the addition of increasing rates of sulfur was also reported by Teotia, Ghosh, and Srivastava (2000).

Conclusion

It can be inferred that, with the application of FYM the bulk density of soil improved. Application of lime resulted in the optimum pH of the soil. CEC, organic carbon, Available N, P, and K also improved in the FYM amended treatment. Available N, P, and K decreased with increased depth of soil. Continuous application of 100% NPK + FYM recorded the highest productivity of both the crops which was at par with 100% NPK + lime, whereas the lowest or zero productivity was recorded with continuous application of 100% N alone in both the crops. Continuous omission of K and S reduced the productivity of both the crops significantly in comparison to balanced fertilization. The nutrients uptake by both wheat and maize crops followed almost similar trend as that of their yields. In general, application of 100% NPK along with amendments like FYM and lime resulted in significantly higher uptake values by both the crops than rest of the treatments.

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