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Effect of Continuous Application of Fertilizers, Farmyard Manure and Lime on Soil Fertility and Productivity of the Maize-Wheat System in an Acid Alfisol

Hari Mohan Meena [a], R. P. Sharma[a], N. K. Sankhyan[a], and Swapana Sepehya[a]

[a]Department of Soil Science, CSK HPKV, Palampur, India

ABSTRACT

A study on the long-term effect of fertilizers and amendments on crop productivity and changes in soil fertility in maize-wheat cropping system in an acid Alfisol was carried out in randomized block design (RBD) with 11 treatments. Continuous application of chemical fertilizers along with farmyard manure (FYM) or lime significantly influenced the grain and straw/stover yield and the uptake of nutrients by wheat and maize crops significantly. The organic carbon content increased from 7.9 to 12.1 g kg^{-1}, cation exchange capacity (CEC) from 12.1 to 14.6 cmol (p^{+}) kg^{-1} and available phosphorus from 21.9 to 75.2 kg ha^{-1} through the integrated use of organic and fertilizers for the last 42 years while the status of available nitrogen (N) and potassium (K) declined over the years in all the treatments. Continuous application of urea alone resulted in a drastic decline in soil pH at both depths. Imbalanced use of fertilizers led to a significant reduction in the productivity of both crops and depleted the soil fertility.

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Fertilizers; lime; long-term experiment; maize-wheat system; soil fertility; yield and nutrient uptake

Introduction

Cereal-based cropping systems are important cropping systems in India. Maize-wheat is the most important cropping system of Himachal Pradesh. A bulk of the food production in the state comes from these two crops, forming about 85% of the total share. Rapidly increasing population and shrinking land resources for crop production are putting tremendous pressure on land resource due to intensive cultivation. Overexploitation of natural resources is resulting in the total loss of soil health. Therefore, there is urgency for enhancing and sustaining the productivity of land in India.

Fertilizers play a vital role in the production and productivity of any crop, but the continuous and imbalanced use of high-analysis chemical fertilizers negatively influences the production potential and soil health. Consequently, most of the productive soils become unproductive and the problem is more severe in acid soils, which are under intensive cropping. Organic manures hold promise to supply a good amount of plant nutrients, improve soil health and can contribute to crop yields substantially. A soil cannot be considered healthy unless it contains an adequate amount of organic matter. Organic matter supports the growth and proliferation of soil micro-flora and –fauna, thereby making the soil a living system. Overexploitation of natural resources and the indiscriminate and irrational use of synthetic inputs like inorganic fertilizers in order to produce more and more from a unit piece of land are being increasingly realized, which have seriously impaired the ecological balance, deteriorated the soil health and placed the environment in jeopardy. Food and nutrition securities have become serious issues because of the increasing population, shrinking natural resource base and management constraints. Since the late nineties, however, crop productivity has

CONTACT Hari Mohan Meena harimohanmeena46@gmail.com Village - Ramapura, Post - Khohari, Teh. & Dist. - Karauli-322243, Rajasthan, India.

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started showing a stagnation/declining trend due to several possible reasons including the deterioration in the natural resource base, especially soils, and the inefficient use of inputs.

Efficient use of nutrients is one of the major factors in any program designed to bring about an economic increase in agricultural production. The continued imbalanced use of nutrients is a major area of concern. Soil degradation due to fertility depletion as a result of imbalanced and improper nutrient use has largely been responsible for the reduction in crop productivity. Maintenance of soil health through balanced nutrition is vital for sustaining crop productivity.

Nutrient mining from the soil has a direct bearing on soil productivity. Intensive agriculture, while increasing food production, has caused second-generation problems with respect to nutrient imbalance including the greater mining of primary soil nutrients, emerging deficiencies of secondary and micronutrients, decreasing organic carbon content and overall deterioration in soil health. Therefore, the necessity for nutritional security on the one hand and environmental sustainability on the other makes it inevitable to resort to the integrated nutrient management system. The integrated nutrient management of fertilizers and organic manures, therefore, is one of the viable options for sustaining soil health vis-à-vis crop productivity (Bajpai et al. 2006).

Long-term fertilizer experiments are vital tools to examine the sustainability of modern intensive cropping systems. These experiments provide valuable information regarding the impact of the continuous application of fertilizers on soil health and crop productivity. These experiments can be used for the precise monitoring of changes in soil fertility and trends in crop yields. Hence, the present investigation was undertaken.

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, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur 31°6/N latitude, 76°3/E longitude, 1290 meters above mean sea level. The climate of the study area is wet temperate with an annual rainfall of 2500–3000 mm, mostly received during the wet season (June–September). The mean maximum temperature remains about 31°C during the hottest months of May–June. December–February are the coldest months, with a minimum temperature of about 5°C. The soil of the experimental site was silty loam in texture and classified as Typic Hapludalf as per the Taxonomic System of Soil Classification (Soil Survey Staff 1975).

At the initiation of the experiment, the pH of the soil of the experimental field was 5.8. The contents of organic carbon, available N, available P and available K were 7.9 g kg^{-1}, 736 kg ha^{-1}, 12 kg ha^{-1} and 194 kg ha^{-1}, respectively. The 11 treatments were as follows: $T_{1\ -5}$0% nitrogen, phosphorus and potassium (NPK); $T_{2\ -1}$00% NPK; $T_{3\ -1}$50%; NPK $T_{4\ -1}$00% NPK + Hand weeding (HW); $T_{5\ -1}$00%; NPK + Zinc (Zn); $T_{6\ -1}$00% NP; $T_{7\ -1}$00% N;$T_{8\ -1}$00% NPK + FYM; $T_{9\ -1}$00% NPK (-S); $T_{10\ -1}$00% NPK + lime; T_{11} – control. In this experiment, there were three replications. The experiment was conducted in randomized block design (RBD). The plot size was 15 m^2 (5m × 3m). Due to the marked build-up 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 50% NPK, the addition of farmyard manure (FYM) @ 5 t ha^{-1} on dry weight basis to maize crop only was also included. The 100% NPK dose is 120, 26 and 33 and 120, 26 and 25 kg ha^{-1} N, P and K for maize and wheat, 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 of nitrogen was top dressed in two equal splits at maximum tillering and the 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 (SSP) and muriate of potash (MOP), respectively. In 100% NPK (-S), P was applied through diammonium phosphate (DAP) to assess the effect of "S"-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 application was made @ 10 t ha^{-1} on a fresh weight basis to maize crop only, which corresponds to the practice being

followed by the farmers of the region. The FYM applied contained 60% moisture; and its average nutrient content on a 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 calcium carbonate ($CaCO_3$) passed through a 100-mesh sieve to maize crop only. Lime application continued until 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 the case of maize crop, one pre-sowing irrigation was given. Thereafter, the crop met its water requirement through rainfall, which was very high during the entire crop growth period. Chemical weed control measures were followed in both the crops except in T_4 (100% NPK + hand weeding), where weeds were removed manually.

The wheat crop variety HPW-155 was sown on 12 November 2013 and harvested on 12 May 2014 and the maize crop variety Kanchan Polo was sown on 15 June 2014 and harvested on 14 October 2014. After the harvest of wheat (rabi, 2013–14) and maize (kharif 2014), data on grain and straw/stover yields were recorded for the respective crops. Grain yield of maize was computed at 13% moisture content, while the grain and straw yield of wheat and stover yield of maize were recorded on a dry weight basis. The grain and straw/stover samples of wheat and maize were ground and digested to measure the content of N using the micro-Kjeldahl method (Jackson (1973), P by the vanado molybdo-phosphoric acid method (Jackson (1973)) and K by the flame photometer (Black (1965)). The nutrient uptake was calculated by multiplying the percent concentration of a particular nutrient with grain and straw yields. The uptake of the nutrients obtained with respect to grain and straw/stover yield was summed up in order to compute the amount of total nutrients removed by the crop.

The soil samples collected from a depth of 0–0.15 m and 0.15–0.30 m after the harvest of wheat (2013–2014) were used for the determination of various chemical parameters. The processed soil samples were analyzed for pH, organic carbon, cation exchange capacity (CEC) and available N, P and K. The soil pH was determined by the method outlined by Jackson (1973), organic carbon was determined by method given by Walkley and Black (1934), CEC was determined by the method outlined by Piper (1966), available N was determined by the method outlined by Subbiah and Asija (1956), available P was determined by the method outlined by Olsen et al. (1954) and available K was determined by the method outlined by Merwin and Peech (1950).

The data 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).

Results and discussion

Effect of chemical fertilizers and amendments on the productivity of wheat

The results revealed that due to the continuous application of N alone through urea for 42 years, the grain yield of wheat in 100% N (T_2) had declined to 0.0 q ha^{-1} (Table 1). This might be due to the increased soil acidity and deteriorated soil quality with the continuous use of N over a period of 42 years. Among the rest of the treatments, the grain and straw yield of wheat was the lowest in the control (4.56 q ha^{-1}) and the highest in 100% NPK + FYM (36.55 q ha^{-1}), which was significantly superior to the rest of the treatments except for 100% NPK + lime (32.11 q ha^{-1}), being at par. Increase in grain and straw yield of wheat in 100% NPK+ sulfur over 100% NPK without sulfur treatment was significant, which highlights the significance of sulfur in the nutrition of wheat. Increasing rates of fertilization from suboptimal to optimum level resulted in an increase in the yield of wheat crop, which might be attributed to the balanced fertilization with nitrogen, phosphorus, potash and sulfur. Application of FYM along with the recommended doses of fertilizers resulted in the highest grain and straw yield of wheat. The addition of FYM, besides supplying all the essential nutrients, might have also improved the physicochemical properties of the soil. Moreover, FYM

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

	Wheat (q ha^{-1})			Maize (q ha^{-1})		
Treatments	Grain	Straw	Biological	Grain	Stover	Biological
T_1: 50% NPK	17.11	32.00	49.11	35.96	62.88	98.84
T_2: 100% NPK	21.22	38.11	59.33	42.04	74.22	116.26
T_3: 150% NPK	18.78	36.78	55.56	39.83	71.11	110.94
T_4: 100% NPK+ Hand Weeding	22.11	40.11	62.22	43.97	77.55	121.52
T_5: 100% NPK+ Zn	20.33	37.44	57.77	41.15	68.44	109.59
T_6: 100% NP	13.00	23.51	36.51	23.14	41.44	64.58
T_7: 100% N	0.00	0.00	0.00	0.00	0.00	0.00
T_8: 100% NPK+ FYM	36.55	65.22	101.77	59.32	105.11	164.43
T_9: 100% NPK (-S)	12.33	23.89	36.22	25.58	45.55	71.13
T_{10}: 100% NPK+ lime	32.11	61.22	93.33	55.46	100.00	155.46
T_{11}: Control	4.56	9.22	13.78	9.33	19.11	28.44
CD (p = 0.05)	3.99	6.86	10.78	4.29	7.91	11.53

results in the release of organic acids that can complex Al and Fe, thereby reducing P retention and inducing greater P availability. Wheat yield also increased with the addition of lime. The increase in wheat grain and straw yields in lime-treated plots might be ascribed to the higher nutrient availability due to the ameliorating effect of lime on soil acidity as the pH value increased to 6.38 from its initial value of 5.80.

Effect of chemical fertilizers and amendments on the productivity of maize

The data indicated that due to the continuous application of 100% N alone through urea for 42 years, the productivity of maize declined to zero (Table 1). The data further indicated that in the rest of the treatments, the grain and stover yield varied from 9.33 q ha^{-1} and 19.11 q ha^{-1}, respectively, in the control to 59.32 q ha^{-1} and 105.11 q ha^{-1} in 100% NPK + FYM. Continuous application of FYM along with 100% NPK recorded grain, stover and biological yield at par with 100% NPK + lime and significantly higher than the rest of the treatments. Compared with 100% NPK, the application of 100% NPK + FYM recorded about 41 and 42% higher grain and stover yield of maize, respectively. The application of P along with N (100% NP) significantly increased the grain and stover yield compared with the unfertilized control plot. These results are in conformity with the findings of Brar, Dhillon, and Chinna (2001). Application of K along with N and P (100% NPK) resulted in higher grain and stover yields of maize over 100% NP. Application of FYM along with the recommended dose of fertilizers recorded the highest grain and stover yield of maize. Pillai, Duaisamy, and Myleramy (2006) also recorded a marked effect of the continuous use of 100% NPK + 10 t FYM ha^{-1} on the productivity of maize. Application of 100% NPK + lime also increased the grain and stover yields of maize, which might be attributed to the ameliorating effect of lime by increasing the pH to 6.38 from its initial value of 5.8, thereby increasing the availability of nutrients to plants. Deletion of K from the fertilizer schedule led to a significant loss in productivity as it is required for the activation of a number of enzymes, starch synthesis, nitrogen uptake and protein synthesis.

Increased yield in the treatment of manual weeding along with 100% NPK may be attributed to better physical properties and improvement in biological environment of the soil, which helps in better root proliferation. Bhardwaj, Omanwar, and Sharma (1994) also ascribed the increase in yield in manually weeded plots to increased soil aeration, which might have helped in the greater uptake of nutrients, resulting in better crop growth. Application of 150% NPK (super-optimal level) decreased the productivity probably due to emerging deficiencies of secondary nutrients, particularly Mg. The source of P in the present study was SSP, which contains gypsum, which might have met the Ca and S requirements but led to the deficiency of Mg. Application of high-analysis P fertilizers (DAP) in place of SSP resulted in a considerable decline in crop yield. DAP does not contain sulfur

Table 2. Effect of the long-term use of fertilizers and amendments on NPK uptake by wheat (kg ha^{-1}).

	N			P			K		
Treatment	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
50% NPK	26.90	14.46	41.36	5.69	1.68	7.37	6.09	20.17	26.26
100% NPK	34.39	18.12	52.51	7.65	2.67	10.32	8.04	24.43	32.47
150% NPK	30.11	17.92	48.03	7.43	3.43	10.86	7.26	26.63	33.89
100% NPK+ Hand Weeding	35.85	19.50	55.35	7.64	2.66	10.30	7.90	25.80	33.70
100% NPK+ Zn	34.69	18.12	52.81	6.36	1.75	8.11	7.17	24.24	31.41
100% NP	20.26	9.05	29.31	4.06	0.78	4.84	3.27	9.30	12.57
100% N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100% NPK+ FYM	64.97	40.44	105.41	15.83	5.44	21.27	15.46	52.58	68.04
100% NPK (-S)	20.01	11.10	31.11	4.50	1.21	5.71	4.45	15.21	19.66
100% NPK+ lime	56.10	32.64	88.74	12.74	4.48	17.22	11.87	45.55	57.42
Control	6.99	3.47	10.46	1.31	0.30	1.61	1.25	4.68	5.93
CD (P = 0.05)	6.84	3.53	10.11	1.65	0.73	2.27	1.67	5.22	6.55

and calcium. Its continuous use has, therefore, led to sulfur mining, thereby resulting in a drastic reduction in crop yield.

Nutrient uptake by wheat

Nitrogen uptake

Application of chemical fertilizers either alone or in combination with amendments increased the N uptake by wheat significantly over the control (Table 2). The total N uptake values in the control and 100% NP-treated plots were significantly lower than the rest of the treatments, except for the 100% NPK (-S). The 100% NPK + FYM and 100% NPK + lime-amended plots recorded significantly higher N uptake over the rest of the treatments. The FYM- and lime-amended plots showed an increase of 52.9 and 36.23 kg ha^{-1} in the total N uptake over 100% NPK, respectively. The application of 100% NP, 100% NPK (-S) and 50% NPK resulted in 23.2, 21.4 and 11.15 kg ha^{-1} reduction in the total N uptake compared with the 100% NPK treatment. Since the continuous use of 100% N alone has led to complete degradation of the soil and the wheat productivity declined to the zero level, the NPK uptake was zero in 100% N-treated plots. Exhaustion of native nutrients in the control plots because of their continuous removal in the absence of addition from any external source resulted in low productivity and NPK uptake by wheat. The continuous omission of K in plant nutrition resulted in a substantial decline in crop yields, thereby leading to a reduction in N uptake. Furthermore, the mutualistic action of N and K in increasing crop productivity and thereby N removals has also been reported. In 100% NPK (-S) plots, the yield was low due to S deficiency. Hence, the NPK uptake was also lower. The increase in N uptake in fertilized plots compared with the control plots might be due to N supply through external inputs and because of a well-developed root system under the balanced application of nutrients. The use of FYM with 100% NPK led to a favorable soil environment besides proper nutrients' supply, which improved the crop growth and increased the wheat yield, resulting in higher N uptake.

Phosphorus uptake

Application of 100% NPK + FYM was significantly superior over all the treatments. A reduction of P uptake by wheat was noted in 100% NP- and 100% NPK (-S)-treated plots, respectively, in comparison to the 100% NPK-treated plots. Application of lime along with 100% NPK significantly increased the P uptake by wheat over 100% NPK. Higher P uptake was recorded in 100% NPK + FYM treatment, followed by 100% NPK + lime compared with the other treatments. When K was excluded (100% NP), significant reduction in yield was recorded; therefore, considerable reduction in P uptake was noticed as K might have become a limiting nutrient in crop production, which otherwise has a synergistic effect on the P uptake by the crops. 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 the increased availability of P in acidic Alfisols that have high P-fixing capacity. Liming material precipitates the Al^{3+} at high pH, thereby making P readily available to growing crops. Moreover, both these amendments improved the productivity appreciably.

Potassium uptake

The combined use of fertilizers and manure removed significantly higher K than the other treatments. In comparison to 100% NPK, the total K uptake increased by 35.56 and 24.94 kg ha^{-1} in FYM- and lime-amended plots, respectively.

Continuous omission of K and S resulted in low yield and, therefore, lesser K uptake compared with balanced fertilization. Moreover, K was not added in the NP treatment continuously and hence lesser K uptake in this plot was recorded. Application of FYM along with an optimal dose of fertilizers recorded the highest K uptake, which might be due to the favorable conditions of crop growth in these plots and, secondly, the supply of K (0.4%) through FYM in addition to chemical fertilizers. The positive influence of lime on K uptake is due to the improvement in soil pH and availability of nutrients, which ultimately increased the productivity. Similar positive influence of inorganics alone or in combination with organics on NPK uptake by wheat was also observed by Singh and Sarkar (2001); Pathak et al. (2005); Mann, Brar, and Dhillon (2006) and Prasad et al. (2010) under varied agro-climatic conditions.

Nutrient uptake by maize

Nitrogen uptake

Lime and FYM-treated plots had statistically higher total N uptake over the rest of the treatments (Table 3). Hand-weeded plots with an uptake value of 121.14 kg ha^{-1} were statistically at par with 100% NPK alone (112.81 kg ha^{-1}). Omission of K (T_6) and S (T_9) led to 44.5 and 42.9% reduction in N uptake by maize, respectively, over the balanced fertilization (100% NPK).

Phosphorus uptake

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. Phosphorus uptake in 100% NPK + lime and 100% NPK + FYM was significantly higher than all the other treatments. Zero fertilization (T_{11}), application of NP alone (T_6) and 100% NPK (-S) recorded significantly lower P uptake compared with optimal fertilization (T_2).

Table 3. Effect of the long-term use of fertilizers and amendments on NPK uptake by maize (kg ha^{-1}).

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

Potassium uptake

A further examination of the data revealed that the total K uptake by maize ranged from 11.75 kg ha^{-1} in the control to 110.86 kg ha^{-1} in 100% NPK + FYM. Application of 100% NPK + FYM and 100% NPK + lime increased the K uptake by 69.1 and 30.8%, respectively, over 100% NPK. The total K uptake by maize in treatments comprising 100% NP (K excluded) and 100% NPK (S excluded) was statistically at par, but significantly lower than 100% NPK.

Substantial soil fertility decline in the control plots because of their continuous removal of NPK in the absence of addition from any external source for the last 42 years resulted in low productivity and NPK uptake by grain and straw by maize. The lower NPK uptake in 100% NP and 100% NPK (-S) plots is because of the lower productivity of maize as a result of K and S deficiency. 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).

Soil pH

Continuous cropping and fertilizer use over the years reduced the soil pH, except for the treatment involving the use of lime (100% NPK + lime) compared with the soil pH value of 5.8 recorded in 1972 at the initiation of the experiment (Table 4). The continuous use of N alone had the most acidifying effect with the pH value declining to 4.49 in the 42nd cropping cycle. Application of lime in combination with NPK brought the soil pH to near neutrality by raising the pH to 6.33 from the initial value of 5.8, which clearly indicated the ameliorative effect of lime on soil acidity. Due to the continuous application of FYM in acidic soil, the pH increased. Similar results were reported by Sharma, Subehia, and Sharma (2002). The effect of different treatments in the subsurface layer was almost similar as recorded in the surface layer.

Table 4. Effect of the long-term use of fertilizers and amendments on soil pH, soil organic carbon (g kg^{-1}), cation exchange capacity {c mol (p^+) kg^{-1}}, and available N, P and K (kg ha^{-1}).

	Soil pH	OC	CEC	N	P	K
Treatments	Soil depth (0–0.15 m)					
T_1: 50% NPK	5.28	10.0	9.87	324.1	47.5	142.7
T_2: 100% NPK	5.20	10.3	10.83	339.7	98.7	157.4
T_3: 150% NPK	4.81	10.2	10.60	365.9	182.0	187.4
T_4: 100% NPK+ Hand Weeding	5.23	11.1	11.33	345.0	100.8	150.2
T_5: 100% NPK+ Zn	5.13	9.8	10.27	350.2	106.6	154.2
T_6: 100% NP	5.08	9.4	9.47	334.5	120.6	125.1
T_7: 100% N	4.49	9.0	6.83	345.0	7.9	131.3
T_8: 100% NPK+ FYM	5.39	13.8	12.80	381.5	168.8	195.9
T_9: 100% NPK (-S)	5.10	9.7	9.97	355.4	119.8	173.8
T_{10}: 100% NPK+ lime	6.33	10.6	12.33	330.0	124.6	169.0
T_{11}: Control	5.72	7.9	8.37	261.3	7.3	111.6
Initial	5.8	7.9	12.1	736	12.0	194.2
CD	0.13	0.58	1.22	20	9.09	4.5
Soil depth (0.15–0.30 m)						
T_1: 50% NPK	5.15	6.7	8.97	236.6	35.1	131.4
T_2: 100% NPK	4.97	7.1	9.53	260.1	88.8	142.6
T_3: 150% NPK	4.88	7.2	9.07	286.0	160.1	173.1
T_4: 100% NPK+ HW	5.18	8.6	9.70	265.0	87.0	140.0
T_5: 100% NPK+ Zn	5.14	5.6	8.23	253.6	90.0	135.9
T_6: 100% NP	5.07	6.2	7.73	262.0	104.0	113.5
T_7: 100% N	4.48	5.6	5.67	261.7	6.0	105.2
T_8: 100% NPK+ FYM	5.30	9.4	11.07	309.2	147.3	173.2
T_9: 100% NPK (-S)	5.04	5.8	8.53	258.9	106.6	156.8
T_{10}: 100% NPK+ lime	6.21	6.4	10.67	262.5	108.5	150.8
T_{11}: Control	5.64	4.8	6.77	189.0	6.5	104.5
Initial	-	-	-	-	-	-
CD	0.21	1.02	1.04	4.8	4.75	11.9

The application of FYM had a moderating effect on soil reaction, which could be ascribed to the decrease in the activity of aluminum (Al^{3+}) ions in the soil solution due to chelation by organic molecules (Hue 1992). The substantial decline in the 100% N alone plot could be attributed to the acid-producing nature of urea because nitrification of urea releases hydrogen ions in the soil (Magdoff, Lanyon, and Liebhardt 1997). The moderating effect of lime on soil acidity has been reported earlier by Sharma, Subehia, and Sharma (2002); Subehia and Sharma (2005); Singh et al. (2009) and Verma et al. (2012).

Soil organic carbon

Application of FYM with the recommended rate of NPK increased the soil organic carbon (SOC) content to 13.8 g kg^{-1} from its initial content of 7.9 g kg^{-1} soil in 1972 (Table 4). The use of lime in combination with NPK increased the organic carbon content to 10.6 g kg^{-1}. The SOC content in 100% NPK + hand-weeding treatment was significantly higher than 100% NPK. The organic carbon content in the subsurface layer ranged from 4.8 under control to 9.4 g kg^{-1} under 100% NPK + FYM treatment. The surface soils contained a higher amount of organic carbon compared with the subsurface soils.

The low SOC content in the no-fertilization plots and the 100% N alone plots could be attributed to poor crop growth and hence low root biomass addition to the soil. Similar results have been reported by Sharma and Singh (1991). The SOC content improved in the fertilized plots compared with the unfertilized plots due to carbon addition through the roots, crop residues and rhizodeposition. These results corroborate the findings of Kundu et al. (2002). The substantial increase in SOC content due to the application of 100% NPK + FYM can be attributed to the direct addition of organic carbon through FYM and the addition of crop residues and root biomass during the last four decades. The SOC was considerably higher in soils receiving continuous FYM along with NPK fertilizer than in plots receiving NPK fertilizer alone (Masto et al. 2006). The higher SOC content in manually weeded plots compared with plots where chemical weed control was practiced might be due to the regular addition of weed biomass in these plots. In this study, the slow rate of organic matter decomposition in the wet temperate zone could be another reason for the build-up of SOC (Sharma, Subehia, and Sharma 2002; Verma et al. 2012).

Cation exchange capacity (CEC)

Compared to the initial value, the values of CEC decreased in almost all the treatments except that of 100% NPK + FYM and 100% NPK + lime, wherein the initial status of 12.1 cmol (p^+) kg^{-1} was almost maintained (Table 4). The decline in CEC was 30.8, 43.5 and 21.7% in the control, 100% N and 100% NP-treated plots, respectively, compared with the initial value of the experiment. The subsurface layer of soil had lesser values of CEC compared with the surface layer.

The slight decrease in the CEC value of soil in the present study, therefore, may be attributed to the acidifying effect of fertilizers resulting in reduced pH values under almost all the treatments and prominently in the 100% N-treated plots. The CEC value of soils was comparatively high in the 100% NPK + FYM-treated plots, which might be due to the higher organic colloids in these plots. The increase in CEC due to the application of lime may be ascribed to the increase in pH. Moreover, the increase in CEC with the addition of FYM or lime can be attributed to the increase in root biomass and crop residues production and their incorporation in the soil. Similar findings were reported by Prasad, Srivastava, and Mathur (1996) and Sharma (2004).

Available nitrogen

Continuous manuring and cropping for 42 years decreased the available N content in all the treatments compared with the initial status (Table 4). The initial available N content in the soil was 736 kg ha^{-1}, which declined to 261.3 kg ha^{-1} in the plots receiving zero fertilization after the forty-second cropping cycle. Application of 100% NPK + FYM and 150% NPK recorded about 12.3 and 7.7% higher available N content compared with the 100% NPK alone. The lowest value of

available N in the control was significantly inferior to the rest of the treatments whereas the highest value of available N in 100% NPK + FYM was at par with 150% NPK. The available N content declined with increase in depth.

The overall decline in the available N content may be due to the leaching losses of N under very high rainfall conditions and its application schedule not synchronizing with the crop requirement. The 100% NPK + FYM-treated plots showed the highest contents of available nitrogen, which might be due to the direct addition of N through FYM to the available pool of soil. This higher N might be attributed to the greater multiplication of soil microbes, which convert organically bound N to the inorganic form (Bhandari et al. 2002; Gami et al. 2001; Katkar, Turkhede, and Wankhade 2006; Yadav et al. 2000). The lower value of available N in the control (T_{11}) is a result of N mining. Higher values of available N were observed in the surface layer of the soil compared with the subsurface layer. This might be due to the higher organic carbon content in the surface layer. Similar observations were recorded by Sammy Reddy et al. (2003) and Tabassum et al. (2010).

Available phosphorus

The available P content decreased in the control and 100% N-treated plots over the initial status (12.0 kg ha^{-1}), whereas in the rest of the treatments, it increased from its initial levels (Table 4). Application of FYM and lime along with NPK increased the available P content by 156.8 and 112.6 kg ha^{-1} over its initial status, respectively. The available P contents were less in the subsurface layer compared with the surface soils.

The substantial build-up of available phosphorus with its continuous use in these soils is attributed to the low crop recovery of applied P and its high stability in the form of residual phosphorus (Sharma and Gupta 1997; Zhang, Mackenzie, and Liang 1995). The low pH in 100% N alone leading to high P fixing capacity and the non-application of P resulted in very low available P content (Sharma, Subehia, and Sharma 2002). The increase in available P in the 150% NPK-treated plots might be attributed to the addition of P at super-optimal rates. In the case of FYM (T_8), the inactivation of iron, aluminum and hydroxyl aluminum ions by organic molecules might be responsible for the reduction in P fixation and increase in its availability (Gupta, Antil, and Narwal 1988; Verma 2002). The increase in available P content with the application of lime might be due to the decrease in exchangeable acidity and increase in mineralization of organic phosphorus (Kumar and Verma 1997). Considerable build-up of available P with the application of phosphatic fertilizer has also been reported by Biswas and Benbi (1997).

Available potassium

The available K declined in almost all the treatments except 100% NPK + FYM with its initial status of 194.2 kg ha^{-1} (Table 4). The continuous application of 100% NPK along with FYM, however, maintained the initial K status of the soil. Compared with 100% NPK, the application of FYM along with 100% NPK and 150% NPK increased the available K content by 1.24 and 1.19 times, respectively. The available K content in the subsurface soils was less compared with the surface layer in all the treatments. However, the treatment-wise effect was similar to the surface soil layer.

The exclusion of K in crop nutrition (control, 100% N and 100% NP) led to the maximum mining of its native pools over the years. The depletion in native K pools even at the recommended rates of its application is due to its increased crop removal compared with the additions over a period of 42 years. Combining FYM with 100% NPK resulted in higher available K content, which might be ascribed to the additional supply of potassium through FYM. Moreover, the decomposition of FYM in the soils leads to the release of organic colloids, which results in an increase in CEC. Higher CEC reduces the leaching losses of potassium. Similar findings have been reported by Sudhir, Srikanth, and Jayaprakash (2002).

Conclusion

It is evident from the results that the continuous use of NPK along with amendments (FYM/lime) for 42 years brought out a marked increase in the productivity and NPK uptake by wheat and maize. Imbalanced use of fertilizers (100% N alone) had the most deleterious effect on soil properties and crop productivity. Application of 150% NPK could not increase the productivity over 100% NPK. Omission of potassium and sulfur resulted in a significant decrease in the productivity of maize and wheat compared with the recommended dose of NPK. The integrated use of the optimal dose of NPK along with amendments (FYM/lime) influenced the organic carbon, CEC and available N, P and K significantly. 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.

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ORCID

Hari Mohan Meena http://orcid.org/0000-0002-3253-5187

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