Changes in soil fertility status of maize-wheat system due to long-term use of chemical fertilizers and amendments in an alfisol

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ABSTRACT

The present study was undertaken to quantify changes in the status of soil nutrients, their depletion and build-up after continuous long intensive cropping for last 36 years in a permanent manorial trial which has been in progress since 1972 in an alfisol of western Himalayas. The rotation was maize-wheat which included various combinations of N, P, K, Zn and FYM (farmyard manure). Continuous cultivation influenced pH, OC (organic carbon), available N (nitrogen), P (phosphorus) and K (potassium). An increase in the status of organic carbon was observed in 100% NPK + FYM treatments for more than three decades from initial value of 7.9 to 12.0 g/kg. The use of either FYM or lime alongwith 100% NPK sustained crop productivity or improved nutrient status. However, imbalanced use of nutrients i.e. NP or N alone is adversely affecting the fertility of soil by aggravating the problem of soil acidity. Application of S free P fertilizer DAP (diammonium phosphate) drastically reduced the yield of both the crops. Thus, continuous use of balanced fertilizers is necessary for sustaining soil fertility and productivity of crops.

Keywords: sustainability; long-term fertilizer experiment; productivity; organic carbon; nutrient

Soil health is a key factor for increasing agricultural production. This called for long-term studies at fixed sites for monitoring changes in fertility status of soil. Long-term experiments in India suggested that under continuous cropping, changes in soil fertility due to imbalanced fertilization may be recognized as one of the important factor that limits crop yields. Contribution of chemical fertilizers towards an increase in agricultural production of farming system is well known. But their injudicious use exhibits a detrimental effect on soil health (Kanwar and Katyal 1997).

Rapidly increasing population, shrinking land resources for crop production are putting tremendous pressure on land resource due to intensive cultivation. Over exploitation of natural resources is resulting in total loss of soil health. Therefore, there is urgency for enhancing and sustaining productivity of land in India. Continuous cropping and long-term fertilization are liable to change soil properties and crop production, depending upon the type of management practices. Long-term fertilizer experiments provide best possible means to study changes in soil properties, dynamics of nutrient processes and future strategies for maintaining soil health. Therefore, the present study was undertaken.

MATERIAL AND METHODS

Experimental site. The present study was undertaken in an ongoing LTFE (long-term fertilizer experiment) started in 1972 in the experimental farm of the College of Agriculture, Palampur, India. The climate of the study area is wet temperate with June to September being the wettest months and the area receives a mean annual rainfall of 2213 ± 557 mm. The mean monthly temperature varies from 30°C (May–June) to 5°C (December–January). The soil of the experimental field is illitic, Typic Hapludalfs. The initial properties of the soil were:

silty clay loam texture with clay 24%, silt 47% and sand 29%, pH 5.8, organic carbon 7.9 g/kg, available N 736, available P 12 and available K 194 kg/ha, respectively. The DTPA extractable Fe, Mn, Zn and Cu were 26.0, 24.3, 0.4 and 1.9 mg/kg, respectively. Exchangeable cations Ca and Mg were 26.5 mmol/kg and 3.9 mmol/kg. Initially, experiment comprised of 10 treatments. The 11th treatment 100% NPK (-S) was introduced in Kharif 1981. The eleven treatments with four replications in a randomized block design were as follows:

Treatment details. T_1 – 50% NPK (sub-optimum); T_2 – 100% NPK (optimum); T_3 – 150% NPK (super-optimum); T_4 – 100% NPK + hand weeding; T_5 – 100% NPK + Zn; T_6 – 100% NP; T_7 – 100% N; T_8 – 100% NPK + farmyard manure; T_9 – 100% NPK (-S); T_{10} – 100% NPK + lime; T_{11} – control.

The 100% NPK dose corresponds to the state level recommendations for the corresponding nutrients and is 120, 26 and 26; and 120, 26 and 18 kg/ha N, P and K for maize and wheat, respectively. The fertilizers used are urea, single super phosphate, diammonium phosphate (for T_9 only), muriate of potash, zinc sulphate (for T_5 only) and lime (for T_{10} only). The lime was applied at the rate of 900 kg/ha as marketable lime ($CaCO_3$) passed through 100 mesh sieve only to maize crop every year till the soil pH rose to about 6.5. Zinc was applied as $ZnSO_4$ at the rate of 25 kg/ha every year to both the crops. FYM (contained 60% moisture, 1.01%, 0.26% and 0.40% N, P and K, respectively on dry weight basis), application was made at the rate of 10 t/ha on fresh weight basis to the maize crop only, which corresponds to the practice being followed by the farmers of the region. The chemical weed control measures were followed in both the crops except in T_4 treatment, where weeds were removed manually. Generally sowing and harvesting time followed for maize is the first fortnight of June and the first week of October whereas wheat crop is sown in the second week of November and harvested in the first week of May.

After the harvest of the crops at maturity, grain and straw yields were recorded separately. Grain yield of maize was standardized at twelve per cent moisture content and stover yield on oven dry basis, whereas in wheat, yields of both grain and straw were recorded on air-dry basis. The available N was determined by alkaline permanganate method (Subbiah and Asija 1956), available P (Olsen et al. 1954) during 1983, 1993, 2003 (Bray and Kurtz 1945) during 2008, available K (Merwin and Peech 1951) and DTPA extractable Fe, Mn, Zn and Cu and exchangeable Ca and Mg by Atomic absorption spectrophotometer (Lindsay and Norvell 1978).

RESULTS AND DISCUSSION

Use of recommended levels of nitrogen alone through urea has a deleterious effect on crop productivity (Figure 1a). Super optimal dose of NPK though gave higher yield over 100% NPK in both the crops. Integrated use of optimal dose of NPK and FYM gave better and higher yields (Figure 1b). Application of lime along with 100% NPK increased crop productivity substantially over 100% NPK alone.

Soil pH. Application of lime in combination with NPK brought the soil pH to near neutrality by raising the pH to 6.2 from initial value of 5.5, which clearly indicated the ameliorative effect of lime on soil acidity (Table 1). The rest of the treatments resulted in reduction in soil pH with most pronounced decline under 100% N followed closely by 150% NPK. Ohi (1989) also reported a decline in soil pH due to acidifying effects of nitrogenous fertilizers. Due to continuous application of FYM in acidic soil, pH increased. Similar results were reported by Sharma et al. (2002).

Soil organic matter status. In 100% NPK + FYM treatment, organic carbon content increased to 12.8 g/kg from its initial status of 7.9 g/kg. The fertilizer treatments had significant changes in

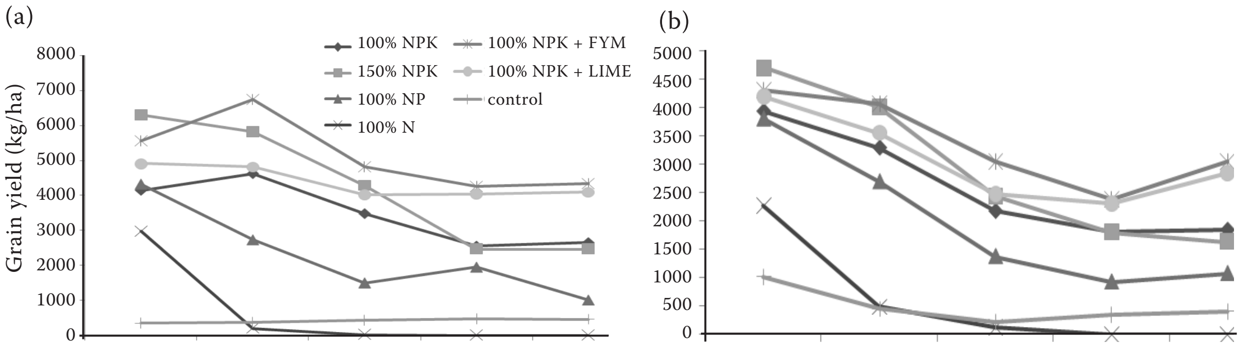

Figure 1. Effect of different long-term fertilizer treatments on the grain yield of (a) maize and (b) wheat

Table 1. Effects of different long-term fertilizer treatments on pH, organic carbon (OC), N, P and K over the years

Treatments	pH				OC (g/kg)				N (kg/ha)				P (kg/ha)				K (kg/ha)			
	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008
Initial	5.8				7.9				736				12				194			
50% NPK	5.6	5.3	5.5	5.3	8.5	5.7	9.0	9.5	742	467	267	272	47.3	26.8	34.6	46.6	227	104	130	142
100% NPK	5.6	5.2	5.2	5.2	8.9	5.5	8.2	9.7	808	483	281	293	94.7	65.4	126.7	89.3	252	117	155	146
150% NPK	5.4	5.1	5.0	4.7	9.6	6.1	8.1	9.9	793	511	303	282	119.8	76.7	169.5	216.2	243	147	172	175
100% NPK + HW	5.5	5.3	5.2	5.2	9.9	6.1	11.1	10.9	755	495	302	298	95.8	77.9	82.5	121.4	221	121	162	144
100% NPK + Zn	5.5	5.4	5.0	5.0	9.2	5.2	8.0	9.5	777	503	289	309	99.0	57.6	105.5	149.8	256	101	151	146
100% NP	5.6	5.3	5.0	5.1	9.0	4.6	7.7	9.5	764	480	298	282	107.7	55.6	117.3	138.9	152	102	111	102
100% N	5.2	5.0	4.5	4.5	8.1	4.7	7.1	9.4	821	479	266	293	12.7	9.1	6.69	15.7	142	108	148	156
100% NPK + FYM	5.4	5.2	5.2	5.2	11.8	4.3	12.0	12.8	802	530	308	314	110.0	50.4	155.4	166.9	299	125	171	202
100% NPK-S	5.6	5.2	5.1	5.1	9.4	5.3	7.8	9.6	755	466	282	298	106.7	50.6	104.6	132.4	230	116	160	156
100% NPK + LIME	6.5	6.6	6.6	6.2	9.5	5.5	8.2	10.3	796	540	295	277	73.5	64.4	121.6	93.3	327	116	143	132
Control	5.7	5.6	5.5	5.5	7.6	4.0	7.2	8.6	695	416	256	245	11.3	7.9	5.93	13.0	224	99	129	121
$LSD_{0.05}$	0.15	0.18	0.13	0.16	0.71	1.20	0.59	0.40	50.2	32.2	20.4	6.6	7.9	12.9	9.0	3.8	26.6	33	16.5	9.3

Long-term fertilizer experiment at experimental farm of College of Agriculture, Palampur (India); HW – hand weeding; OC – organic carbon; FYM – farm yard manure application was made at the rate of 10 t/ha on fresh weight basis to the maize crop only. Lime was applied at the rate of 900 kg/ha only to maize crop every year till the soil pH rose to about 6.5; zinc was applied as $ZnSO_4$ at the rate of 25 kg/ha every year to both the crops; *LSD* – least significant difference

soil organic matter status (Table 1). It varied from 9.4 g/kg in 100% N to 12.8 g/kg in NPK + FYM treatment. This shows that the use of fertilizers alone also helps in increasing the organic carbon content of the soil. The findings are in conformity with Sharma et al. (2007) and Thakur et al. (2009). Treatments receiving inorganic fertilizer also observed an increase in organic carbon content due to the use of fertilizers, which is attributed to higher contribution of biomass to the soil in the form of crop stubbles and residues over the years. Moreover, it was also observed that with increasing levels of fertilizer, organic carbon content increased over the years (Gathala et al. 2007).

Available nitrogen. A reduction in available nitrogen in control plot was due to continuous cropping without fertilization. Such losses of added fertilizer N over the years might be due to leaching conditions under high rainfall conditions or the schedule of N application perhaps not coinciding with the crop demands (Kumar and Yadav 2005). Application of 100% NPK + FYM recorded significantly higher available nitrogen over 100% NPK alone during all the years. The increase in FYM treated plots was due to mineralization of FYM. Singh et al. (2009) also observed that available nitrogen content in soil increased significantly with the use of recommended doses of fertilizer in combination with organic manures. Further by increasing the application rate of nutrients, the amount of nutrients also increased significantly. Addition of P in 100% NP improved available nutrient status of soil in comparison to application of nitrogen alone under 100% N (Thakur et al. 2009). Application of N alone was significantly inferior to the unfertilized control. A similar effect was also recorded by Singh et al. (2009).

Available phosphorus. There was a substantial build-up of available P content over the years. The maximum available P content of 216.2 kg/ha was recorded in T_3 (150% NPK) treatment, the second highest was 166.9 kg/ha under T_8 (100% NPK + FYM) treatment compared to its initial status of 12 kg/ha. Compared to 50% NPK, application of 100% NPK, 150% NPK, 100% NPK + HW, 100% NPK + Zn, 100% NP, 100% NPK + FYM and 100% NPK + lime recorded significantly higher available P contents. Build-up of available P with continuous

Table 2. Effects of different long-term fertilizer treatments on DTPA (diethyltriamine pentacetic acid) extractable micronutrients and Ca, Mg over the years

Treatments	Fe (mg/kg)				Mn (mg/kg)				Cu (mg/kg)				Zn (mg/kg)				Ca (mmol/kg)				Mg (mmol/kg)			
	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008	1983	1993	2003	2008
Initial	26.0				24.3				0.4				1.9				26.5				3.9			
50% NPK	28.5	30.9	22.3	24.4	18.0	12.3	17.25	22.7	0.3	1.0	1.9	1.5	1.0	2.1	0.6	1.0	20	13.0	15.0	16.0	2.7	1.8	1.5	0.9
100% NPK	30.0	26.2	25.3	24.3	19.3	11.2	21.75	22.9	0.4	1.2	1.5	1.5	1.0	1.9	0.6	1.3	20	13.0	14.0	15.0	3.9	1.8	1.2	1.2
150% NPK	33.0	32	31.4	32.7	21.0	11.7	22.25	25.0	0.4	1.0	1.5	2.0	1.1	1.9	0.7	1.5	21	10.0	13.0	15.0	5.1	1.5	0.9	0.9
100% NPK + HW	27.0	32.9	20.4	24.6	17.5	16.1	28.25	28.8	0.4	1.2	2.0	1.9	1.1	2.3	0.8	0.9	17	13.0	20.0	18.0	3.9	1.8	0.9	0.9
100% NPK + Zn	26.0	31.1	25.4	24.5	20.2	12.7	27.0	31.8	0.4	1.0	1.6	1.9	1.8	4.9	8.8	5.6	19	12.0	17.0	17.0	3.9	1.8	0.9	0.9
100% NP	19.0	33.8	35.8	24.7	18.0	12.7	30.0	32.6	0.4	1.1	2.0	1.9	1.6	2.2	0.7	1.0	20	11.0	16.0	16.0	3.6	1.5	0.9	0.6
100% N	18.0	25.6	26.5	32.6	18.0	15.9	22.75	25.2	0.4	0.9	1.0	1.9	1.2	1.8	0.5	1.5	14	6.0	6.0	8.0	2.4	0.6	1.2	0.3
100% NPK + FYM	25.0	35.6	39.6	39.8	24.4	14.9	33.0	35.1	0.4	1.3	2.2	2.2	1.7	2.3	1.8	2.0	23	17.0	23.0	22.0	3.9	3.6	1.8	1.5
100% NPK-S	25.0	28.5	23.8	24.9	21.0	13.5	19.75	23.2	0.3	1.2	1.6	1.6	1.3	2.0	0.8	1.1	19	8.0	13.0	13.0	3.3	1.5	1.5	0.9
100% NPK + LIME	18.0	21.5	24.2	24.7	17.0	8.1	21.0	24.5	0.3	1.5	1.7	2.0	1.4	1.6	0.8	1.4	25	19.0	31.0	29.0	7.5	3.6	1.8	0.9
Control	18.0	26.2	19.6	19.7	17.0	14.5	19.0	21.7	0.3	1.2	1.3	1.7	1.0	1.4	0.6	1.3	14	14.0	20.0	17.0	3.3	3.3	1.5	1.2
$LSD_{0.05}$	3.5	6.5	2.1	0.4	3.5	3.8	1.2	0.5	0.1	0.4	0.1	0.2	0.2	0.1	0.1	0.2	6	3.0	1.0	2.0	2.4	0.001	0.01	0.03

use of phosphatic fertilizers (Table 1) is in agreement with the findings of Zhang et al. (1995) and Subehia et al. (2005). Use of 100% NP over 100% N significantly increased the available P status of soil. A similar trend was observed by Parmar and Sharma (2002).

Available potassium. Available soil K declined in all the treatments except T_8 treatment over the years (Table 1). In control, 100% N and 100% NP treatment, due to exclusion of K, there is maximum mining of the native reserves due to nutrient imbalance in soil.

DTPA extractable micronutrients. A general reduction in DTPA extractable Fe, Mn and Zn in comparison to its initial status was noticed in almost all the treatments. Addition of zinc along with 100% NPK significantly raised the level of available Zn content in the soil. Application of 100% NPK + FYM showed significantly higher DTPA Fe, Mn and Zn content than other treatments over the years. Similar results were also reported by Singh et al. (2009). On the other hand, DTPA extractable Cu showed a marked increase in its content over the years. DTPA extractable Zn increased to 5.55 from its initial status of 1.9 mg/kg where 100% NPK + Zn was applied, while the balanced use of organics and inorganics (100% NPK + FYM) maintained its content to its initial status whereas rest of the treatments resulted in reduced levels in the soil (Table 2). The levels of DTPA extractable Fe, Mn and Cu were much higher than their critical levels even after 36 years of continuous cropping.

Exchangeable calcium and magnesium. Over the years a declining trend of both secondary nutrients (Ca and Mg) was observed in almost all the treatments in comparison to its initial status. However, 100% NPK + lime maintained a higher Ca status in comparison to its initial status, which was recorded before the start of the experiment (Table 2). Application of lime resulted in a significant increase in exchangeable Ca over 100% N and control during all the years. The increase in exchangeable Ca due to application of lime may be attributed to its supply from $CaCO_3$.

Although there was a build-up in the content of organic carbon and available N, P, and K, the use of nitrogenous fertilizer alone continuously aggravated the problem of soil acidity over the years. A general reduction in DTPA extractable Fe, Mn, Zn and exchangeable Ca and Mg in comparison to its initial status was noticed in almost all the treatments. On the other hand, DTPA extractable Cu showed a marked increase in its content over the years. Therefore, it is concluded that the balanced use of fertilizers alone or conjoint use of inorganics with organics resulted in a significant build-up of organic carbon and available N, P and K over three long decades leading to sustained soil fertility and productivity. However, a steady supply of micronutrients in the soils is due to their solubilization under acidic soil environment.

Acknowledgement

Financial and technical help to carry out this work by way of sponsoring the 'All India Coordinated Research Project on Long Term Fertilizer Experiment' at CSK Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh (India) by Indian Council of Agricultural Research is duly acknowledged.

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Received on May 2, 2012

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