Hindawi
Applied and Environmental Soil Science
Volume 2022, Article ID 2607468, 11 pages
https://doi.org/10.1155/2022/2607468

Research Article

Soil Nutrient Balance and Soil Fertility Status under the Influence of Fertilization in Maize-Wheat Cropping System in Nepal

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Received 5 January 2022; Accepted 5 May 2022; Published 17 May 2022

Academic Editor: Balram Ambade

Soil nutrient balance is affected by nutrient management in crops. A poor nutrient management technique results in an imbalance in the soil nutrient status which could have a long-term negative impact on crop production. The current study was carried out to assess the effect of different rates of nitrogen (N), phosphorus (P), and potassium (K) on soil nutrient balance in a maize-wheat cropping system in Cambisols of Khumaltar, Lalitpur, Nepal during 2019/20 and 2020/21. The experiment included three-factor randomized complete block design with three doses of each N, P, and K which was replicated three times. There was a remarkable change in soil pH, soil organic carbon (SOC), and total N, P, and K contents of soil over a period of time with the application of different doses of NPK. Soil pH changed from 5.98 to 5.53, SOC increased from 11.7 to 16.8 $g\cdot kg^{-1}$, total N decreased from 1264 to 1177 $mg\cdot kg^{-1}$, available P_2O_5 declined from 214 to 63.6 $mg\cdot kg^{-1}$, and available K_2O decreased from 71.7 to 24.8 $mg\cdot kg^{-1}$ with varying rates of NPK after four cropping seasons. Furthermore, partial, apparent, and net N, P, K balance were predominantly negative in all the fertilizer treatments, but the magnitude was lower under higher nutrient rates and positive partial N balance was noticed in higher N levels. The depletion of native P and K pools even at higher application rates was attributed to higher crop removal over time as compared to inputs. Therefore, continuous application of balanced fertilizers is crucial in maintaining the fertility of soil and productivity of crops.

1. Introduction

Maize (*Zea mays*)-wheat (*Triticum aestivum*) is the second most important cropping system in Nepal after rice-wheat and the most prominent cropping system under the mid-hills of Nepal. Crop response to nutrients varies greatly from location to location, depending on soil fertility and environmental factors. If fertilizer management is not adequately addressed, a continuous maize-wheat cropping system can deplete soil fertility. Chemical fertilizers are necessary inputs in modern crop production to meet the crop's nutrient demand. These are important parts of modern crop production systems [1], with chemical fertilizer use contributing to almost half of the global crop production [2]. Chemical fertilizers are well known for their contribution to increased agricultural production in farming systems. Several studies have shown that commercial fertilizers can increase 30–50 percent crop production [3].

In Nepal, there is limited land, the proportion of cultivated land to population is low, and there is a lot of pressure to raise crop yields to fulfill the demands of a growing population; fertilizers are increasingly being applied to crops to improve their quality and yield. Changes in soil fertility owing to imbalanced fertilization may be identified as one of the key factors limiting crop yields under continuous and intensive cropping. In intensive cropping systems, the production of improved and hybrid varieties of crops increases fertilizer requirement [4]. Continuous cropping and long-term fertilization are likely to influence the properties of soil and crop yield depending on the type of crop and nutrient management techniques. This creates high nutrient demand and a negative nutrient balance if the mined nutrients are not substituted with the application of fertilizers. Chemical fertilizer inputs are essential to maintain a positive nutrient balance by replacing nutrients that are withdrawn and depleted during cropping [5].

Having a quantitative knowledge of soil nutrient depletion may aid in the application of optimal nutrient management measures. A negative balance in the soil can be minimized by applying the appropriate rate of fertilizer according to the crop's demand. Increasing the application of nutrients (NPK) using inorganic fertilizers increased the available nitrogen, phosphorus, and potassium contents in soil for wheat [6]. The use of NPK fertilizers is critical for restoring soil nutrients and closing the yield gap [7]. The drop in soil fertility in the hills is increased by a decrease in organic matter content, with nitrogen being the most important nutrient in Nepalese soils [8]. Similarly, applying an inadequate amount of K fertilizer over multiple years may lead to K deficit and reduction in crop yield [9].

In Nepal, current fertilizer recommendations for various crops are generalized and do not consider other aspects such as soil, climate, season, or geography, all of which needed revision. So far, there was little information about the effects of fertilizer application on nutrient balance in the maize-wheat cropping system in the mid-hills of Nepal. Multiple nutrient deficiencies caused by the overmining of nutrients from the soil and an imbalance in fertilizer application are causing diminishing yield trends in the maize-wheat system. Therefore, the current study was carried out to see how different rates of N, P, and K affected soil nutrient balance and to quantify changes in the status of soil nutrients, depletion, and accumulation in the soil after four successive cropping sequences.

2. Material and Methods

2.1. Location and Characteristics of the Experiment Site. Field experiments were conducted in Agronomy Farm, Khumaltar, while laboratory work was carried out at National Soil Science Research Centre, Khumaltar Lalitpur, for two years in 2019/20 and 2020/21. The location is situated at 27°39′ N Latitude and 85°19′E longitudes with an elevation of 1285 m from the mean sea level in the mid-hills valley of the Bagmati province of Nepal. The experimental site was located in the sub-tropical climatic belt of Nepal. In general, the site received ample rainfall during the rainy season, which started in May and continued up to September. The total annual rainfall received was 324.4 mm and 1304.1 mm in the experiment years 2019/20 and 2020/21, respectively. The area enjoyed weather conditions with cold winters, mild summers, and distinct rainy seasons. The minimum temperature was up to 0°C during the coldest month (December-March) and the range of minimum temperature was 3.5 to 21.3°C. The maximum winter temperature was 21.2°C in February 2021. In the hottest months of the year, the highest mean maximum temperature was 29.8°C in June 2019. Monthly average data on different weather parameters, i.e., maximum and minimum temperatures, and total rainfall, recorded during the maize and wheat growing seasons at National Agronomy Research Centre, Khumaltar, Lalitpur are presented in Figure 1.

The soil of the experimental field had slightly acidic pH, low organic matter, medium total N, high available P_2O_5, and medium available K_2O as rated using the soil value chart [10]. The soil texture was silty clay loam, with a bulk density of 1.39 gm·cm^{-3}. The detailed status of the macro and micronutrients of the soil before the field experiment is presented in Table 1.

2.2. Experimental Design and Treatments. The experiment was conducted for four consecutive cropping periods under the maize-wheat cropping system. There were 27 treatments consisting of N, P, and K levels that were laid out in a three-factorial randomized complete block design (RCBD) with three replications in a fixed plot of 10.5 m^2 (4.2 m × 2.5 m). The treatments' details for maize and wheat are presented in Table 2.

2.3. Crop Management. The hybrid maize variety Khumal Hybrid-2 was sown on 9 May 2019 and 15 May 2020 with a planting geometry of 60 cm × 25 cm as summer crop. Similarly, the wheat variety Surma was sown with continuous sowing in a row spacing of 25 cm at a recommended seed rate of 120 kg/ha on 14 November 2019 and 10 November 2020 in well-prepared plots as winter crop. The fertilizers applied to supply nitrogen, phosphorus, and potassium were urea (46% N), single superphosphate (16% P_2O_5), and muriate of potash (60% K_2O), respectively. A whole amount of phosphorous and potassium was applied as basal at the time of final land preparation while nitrogen was applied in three equal splits. For maize, nitrogen was applied at the planting, knee height, and tasseling stages while for wheat, it was applied at the planting, tillering, and spike initiation stages. Hoeing was done twice in the maize season at the knee height and tasseling stages. Furthermore, during different stages of maize and wheat growth, all essential agronomic practices were carried out equitably and properly. Irrigation, weed control, pest control, and other cultural operations were performed as needed. Maize was manually harvested on September 22, 2019, and September 28, 2020, while wheat was harvested on May 12, 2020, and May 17, 2021.

2.4. Plant Sampling and Analysis. Five soil samples were collected at a depth of 0–20 cm from each plot after the harvest of each crop and these samples were analyzed for pH, organic carbon, total nitrogen, and available P and K contents. The details of the methods applied are presented in Table 1. After crop maturity, plant samples (straw and grain) from each plot were collected and cleaned to remove the adherent soil and dust. The stem and leaf samples from each plot were combined to produce a composite straw sample, and the seeds sample from the net plot harvest was taken randomly. Both grain and straw samples were oven-dried at 70°C until constant weight and grinded and sieved through a

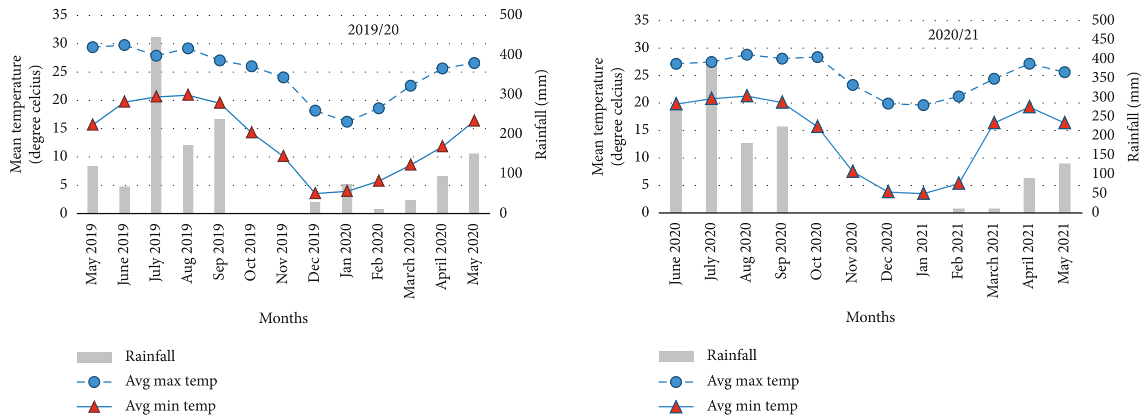

Figure 1: Monthly mean maximum, mean minimum, and total rainfall at Khumaltar, Lalitpur, Nepal, during 2019/20–2020/21.

Table 1: Physicochemical properties of the experimental plot before field experiment at Khumaltar, Lalitpur, Nepal, 2019.

Parameters	Soil test values	Method followed
Textural class	Silty clay loam	
Sand (%)	17.3	Hydrometer method [11] and texture classification (USDA texture triangle)
Silt (%)	57.1	
Clay (%)	25.6	
Bulk density (gm cm^{-3})	1.39	Core method [12]
Soil pH	5.98	1 : 2 soil water suspension [13]
Organic matter (g kg^{-1})	11.4	Walkely and Black [14]
Total N (kg ha^{-1})	2831.8	Micro-Kjeldahl [15]
Available P_2O_5 (kg ha^{-1})	478.7	Modified Olsen's [16]
Available K_2O (kg ha^{-1})	160.6	Ammonium acetate [13]
Available Ca (mg kg^{-1})	984	EDTA titration [17]
Available Mg (mg kg^{-1})	21.6	EDTA titration [17]
Available S (mg kg^{-1})	1.48	Turbidimetric [18]
Available B (mg kg^{-1})	0.81	Hot water method [19]
Available Fe (mg kg^{-1})	107.3	DTPA [20]
Available Zn (mg kg^{-1})	1.96	DTPA [20]
Available Cu (mg kg^{-1})	3.08	DTPA [20]
Available Mn (mg kg^{-1})	14.2	DTPA [20]

Table 2: Treatment details of the field experiment at Khumaltar, Lalitpur, Nepal, 2019/20–2020/21.

Factor	Maize crop	Wheat crop	Symbol used
Factor A: nitrogen levels	150, 180, and 210 kg N/ha	100, 125, and 150 kg N/ha	N1, N2, N3
Factor B: phosphorus levels	40, 60, and 80 kg P_2O_5/ha	25, 50, 75 kg P_2O_5/ha	P1, P2, P3
Factor C: potassium levels	40, 60, and 80 kg K_2O/ha	25, 50, 75 kg K_2O/ha	K1, K2, K3

0.2 mm sieve for total N, P, and K concentrations' estimation. Total N was analyzed by Kjeldahl's digestion-distillation method [21], total P was determined by the Vanado-Molybdo-phosphoric acid yellow colour method [13], and total K content of the plant samples was estimated with the help of flame photometer from the digested extract prepared for P [22].

The total nutrient uptake was calculated using the formulae:

$$\begin{aligned}
\text{Nutrient}_{\text{Grainuptake}} &= \text{Yield}_{\text{grain}} \times \text{Nutrient content}_{\text{grain}},\\
\text{Nutrient}_{\text{strawuptake}} &= \text{Yield}_{\text{straw}} \times \text{Nutrient content}_{\text{straw}},\\
\text{Nutrient}_{\text{totaluptake}} &= \text{Nutrient}_{\text{Grainuptake}} + \text{Nutrient}_{\text{strawuptake}}.
\end{aligned} \tag{1}$$

2.5. Calculation of Soil Nutrient Balance. Nutrient balance was assessed using three ways: partial nutrient balance (PNB), apparent gain or loss of nutrients (ANB), and net gain or loss of nutrients (NNB). Partial nutrient balance is the total nutrient (NPK) profit or loss amount in the soil of each treatment every year.

$$\text{PNB (kg/ha)} = N_I - N_O. \tag{2}$$

Nutrient input (N_I) is the amount of nutrients applied from the fertilizer and nutrient output (N_O) is the total amount of nutrients harvested from the maize and wheat crops [23].

Similarly, ANB and NNB were calculated using the following formulae [24]:

$$\begin{aligned} \text{ANB}\,(\text{kg/ha}) &= F_N - (I_N + N_I - N_O), \\ \text{NNB}\,(\text{kg/ha}) &= F_N - I_N, \end{aligned} \tag{3}$$

where F_N = final status of nutrients in soil, I_N = initial status of nutrients in soil, N_I = Nutrient input through fertilizers, and N_O = Nutrient output through above-ground plant uptake.

2.6. Data Analysis. All the data were subjected to statistical analysis of variance using GenStat. Various parameters were analyzed at $p < 0.05$ level using the LSD (least significant difference) test as described for factorial randomized block design [25]. For mean separation, data were analyzed using Duncan's Multiple Range Test (DMRT).

3. Results

3.1. Crop Yield and Nutrient Uptake by Crops. Maize and wheat grain yields were significantly affected by the N and K rates, whereas P rates had no significant effect in all four seasons (Figure 2). Yields were high at higher rates compared to the lower fertilizer rates. The two-year data revealed that N@210 kg·ha^{-1} and K_2O@80 kg·ha^{-1} were significant for grain yield of maize, whereas N@125 kg·ha^{-1} and K_2O@ 50 kg·ha^{-1} were found considerable for grain yield of wheat, which was at par when the levels increased further. However, there was no considerable effect of P beyond 40 and 25 kg·ha^{-1} in maize and wheat, respectively, in both the years. In the second year, mean grain yield was very low, especially for maize.

The uptake of nutrients by crops was also affected by different nutrient doses (Tables 3, 4, and 5). With an increase in nutritional supply, the uptake of nutrients was increased. Significantly higher uptake of N, P, and K was obtained with the higher rates of N, P, and K applied. The total uptake of N, P, and K from the application of their higher rates was 31.9, 13.8, and 19.0 percent higher than the lower rates.

3.2. Nutrient Balance in the Soil

3.2.1. Nitrogen Balance. The annual partial nitrogen balance (PNB), apparent nitrogen loss or gain (ANB), and net gain or loss (NNB) for all soil treatments in the maize-wheat cropping system are shown (Table 3). The results showed that partial nitrogen balance was significantly affected by the NPK rates, whereas ANB and NNB were found to be nonsignificantly affected by different fertilizer rates. With the increase in N levels, PNB was increased, whereas higher P and K inputs indicate N deficit to the soil. Crops remove a considerable portion of the nitrogen from the soil as a result of the large volume of grain and straw removed for consumption. PNB showed that 16.3 kg·N/ha/year was added to the soil with the application of 210 kg·N for maize and 150 kg·N for wheat per hectare which was higher as compared to other lower N rates. The partial N deficit was higher (19.5 kg·N/ha/year) with the application of higher levels of K and vice-versa. Similarly, the results showed that ANB and NNB in the soil remained negative for all the treatments, though ANB and NNB in the soil were higher with higher levels of nitrogen and lower levels of P and K.

3.2.2. Phosphorus Balance. The annual partial P balance (PPB), apparent P loss or gain (APB), and net gain or loss (NPB) for all soil treatments in the maize-wheat cropping system are shown (Table 4). The data revealed that PPB and APB were considerably affected by the NPK rates, while NPB was significantly influenced by P rates but N and K rates did not vary significantly. Furthermore, the results showed that PPB, APB, and NNB in the soil remained negative for all the treatments. With the increase in P levels, PNB and NPB increased and APB decreased, whereas higher N and K inputs indicate more P deficit to the soil. The APB, APB, and NPB ranged from −19.4 to −88.2 kg P_2O_5/ha/year, −97.9 to −159.2 kg P_2O_5/ha/year, and −177.6 to −186.2 kg P_2O_5/ha/year, respectively. The partial and net P deficit were higher with the application of lower rates of P and were lower with higher rates of P.

3.2.3. Potassium Balance. The annual partial K balance (PKB), apparent K loss or gain (AKB), and net gain or loss (NKB) for NPK rates in the maize-wheat cropping system are shown in Table 5. The data showed that PKB was significantly influenced by the NPK rates, while AKB was remarkably affected by NK rates but it was not considerably influenced by P rates. Similarly, the effect of NPK rates on NKB was not notable. Furthermore, the results revealed that PPB and NNB in the soil remained negative for all the treatments. With higher use of N and P levels, K deficit to the soil increased, whereas higher K inputs indicate decrement in K deficit to the soil. Likewise, after four seasons of successive cropping, annual PKB in the soil ranged from −157.7 kg·K_2O/ha in lower K rates to −110.0 kg·K_2O/ha in higher K rates. A positive balance in apparent K was obtained in the soil under all the fertilizer application rates with the maximum gain in higher N and K rates, whereas a negative balance in net K was obtained in the soil for the applied treatments.

3.3. Status of the Soil after Harvesting

3.3.1. Soil pH. Although there was a slight decrement in soil pH in the first year (Table 6), there was no significant variation due to the different levels of fertilizers. However, in the second year, after maize cropping, there was a considerable effect on phosphorus application rates, whereas there was a significant effect of different rates of nitrogen on soil pH after the second-year experiment. Application of chemical fertilizer resulted in a reduction in soil pH with more decline seen under urea application. Despite some variations in all treatments, the pH values indicated a clear downward trend over time. On average, the soil pH decreased from 5.98 to 5.53 after four successive chemical fertilizer applications in the soil.

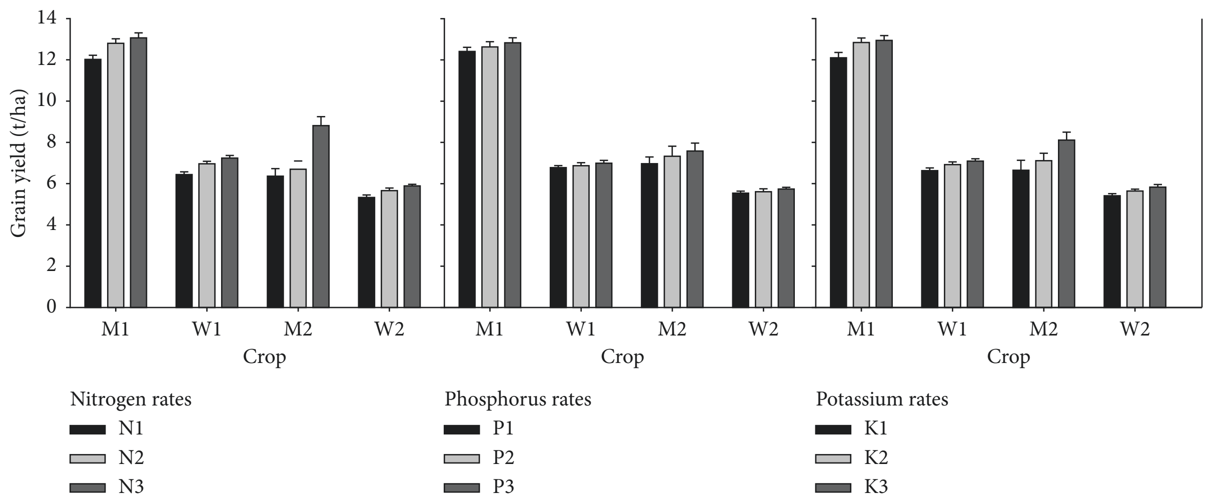

Figure 2: Mean grain yields of maize and wheat in different fertilization treatments during four successive crop seasons at Khumaltar, Lalitpur, Nepal (2019/20–2020/21). $M1$ = maize crop in 1st year, $W1$ = wheat crop in 1st year, $M2$ = maize crop in 2nd year, and $M1$ = wheat crop in 2nd year.

Table 3: Partial balance, apparent gain or loss, and net gain or loss of nitrogen (kg/ha) per year as affected by fertilization in the maize-wheat experiment, Khumaltar, Lalitpur, 2019/20–2020/21.

Treatments	Input	Nitrogen uptake by crop (kg/ha)					PNB (kg/ha/yr)	ANB (kg/ha/yr)	NNB (kg/ha/yr)
	Fa	M1	W1	M2	W2	Total			
Nitrogen levels (N)									
N1	500	189.0 c	109.3 c	103.6 b	119.3 c	521.3 c	−10.6 c	−242 a	−252 a
N2	610	217.1 b	128.9 b	117.2 b	137.4 b	600.7 b	4.6 b	−245 a	−240 a
N3	720	241.5 a	139.0 a	159.2 a	147.8 a	687.4 a	16.3 a	−228 a	−211 a
LSD 0.05		11.09	7.97	14.08	8.30	22.33	11.2	NS	NS
Phosphorus levels (P)									
P1	610	206.3 b	122.4 a	116.9 b	131.0 a	576.6 c	16.7 a	−244 a	−228 a
P2	610	217.3 ab	123.9 a	126.6 ab	134.9 a	602.7 b	3.6 b	−242 a	−239 a
P3	610	224.0 a	130.9 a	136.6 a	138.6 a	630.1 a	−10.1 c	−227 a	−237 a
LSD 0.05		11.09	NS	14.08	NS	22.33	11.2	NS	NS
Potassium levels (K)									
K1	610	199.3 b	116.9 c	110.2 c	125.3 b	551.7 c	29.2 a	−244 a	−214 a
K2	610	221.4 a	125.4 b	126.2 b	135.7 a	608.7 b	0.6 b	−233 a	−232 a
K3	610	226.9 a	134.9 a	143.6 a	143.6 a	649.0 a	−19.5 c	−237 a	−257 a
LSD 0.05		11.09	7.97	14.08	8.30	22.33	11.2	NS	NS
F test prob (P > F)									
N		***	***	***	***	***	***	NS	NS
P		*	NS	*	NS	***	***	NS	NS
K		***	**	***	**	***	***	NS	NS
NP		NS	NS	**	NS	**	**	NS	NS
NK		NS	NS	NS	NS	NS	NS	NS	*
PK		NS	NS	NS	NS	NS	NS	NS	*
NPK		*	NS	NS	NS	**	**	NS	NS
CV (%)		9.4	11.6	20.3	11.3	6.8	25.2	20.2	19.9
GM		215.9	125.7	126.7	134.8	603.1	3.4	−238	−235

Fa = fertilizer applied in 2 years, $M1$ = maize crop N uptake in 1st year, $W1$ = wheat crop N uptake in 1st year, $M2$ = maize crop N uptake in 2nd year, $M1$ = wheat crop N uptake in 2nd year, PNB = partial nitrogen balance, ANB = apparent nitrogen loss or gain, NNB = net nitrogen loss or gain, NS = nonsignificant ($p > -0.05$); *** = significant at 0.1%; ** = significant at 1%; and * = significant at 5%, GM = grand mean.

3.3.2. Soil Organic Carbon. The fertilizer application rates had no significant effects on the soil organic carbon content (Table 6). However, the result showed that the organic carbon content of the soil was slightly increased as a result of continuous cropping and fertilizer use over years. The OC content was more after harvesting the wheat crop than after

Table 4: Partial balance, apparent gain or loss, and net gain or loss of phosphorus per year as affected by fertilization in the maize-wheat experiment, Khumaltar, Lalitpur, 2019/20–2020/21.

Treatments	Input	Phosphorus uptake by crop (kg/ha)					PPB (kg/ha/yr)	APB (kg/ha/yr)	NPB (kg/ha/yr)
	Fa	M1	W1	M2	W2	Total			
Nitrogen levels (N)									
N1	220	105.9 b	54.5 c	72.1 b	50.9 c	283.4 c	−31.7 a	−148.5 c	−180.2 a
N2	220	114.9 a	69.3 b	82.2 b	59.6 b	326.1 b	−53.0 b	−127.4 b	180.4 a
N3	220	121.9 a	75.5 a	113.2 a	65.0 a	375.3 a	−77.6 c	−104.2 a	−181.8 a
LSD 0.05		7.91	4.51	11.21	3.642	16.37	8.2	10.20	NS
Phosphorus levels (P)									
P1	130	108.9 b	62.3 b	80.4 b	54.9 b	306.5 c	−88.2 c	−97.9 a	−186.2 b
P2	220	115.0 ab	66.6 ab	89.6 ab	58.6 a	329.5 b	−54.8 b	−122.8 b	−177.6 a
P3	310	118.7 a	70.4 a	97.5 a	62.1 a	348.7 a	−19.3 a	−159.2 c	−178.6 a
LSD 0.05		7.91	4.51	11.21	3.64	16.37	8.2	10.20	6.75
Potassium levels (K)									
K1	220	108.5 b	63.5 b	77.2 b	55.3 b	304.5 c	−42.3 a	−136.8 b	−179.0 a
K2	220	116.3 ab	67.1 ab	86.1 b	58.4 ab	327.9 b	−53.9 b	−129.1 b	−183.0 a
K3	220	117.9 a	68.7 a	104.3 a	61.7 a	352.3 a	−66.1 c	−114.2 a	−180.3 a
LSD 0.05		7.91	NS	11.21	3.64	16.37	8.2	10.20	NS
F test prob (P > F)									
N		***	***	***	***	***	***	***	NS
P		*	**	*	**	***	***	***	*
K		*	NS	**	*	***	***	***	NS
NP		NS	NS	*	NS	NS	NS	NS	NS
NK		NS	NS	NS	NS	NS	NS	NS	NS
PK		NS	NS	NS	NS	NS	NS	NS	*
NPK		NS	NS	NS	NS	NS	NS	NS	NS
CV (%)		12.7	12.4	23.0	11.4	9.1	27.7	14.7	6.8
GM		114.2	66.42	89.2	58.50	328.2	−54.1	−126.7	−180.8

Fa = fertilizer applied in 2 years, *M*1 = maize crop P uptake in 1st year, *W*1 = wheat crop P uptake in 1st year, *M*2 = maize crop P uptake in 2nd year, *M*1 = wheat crop P uptake in 2nd year, PPB = partial phosphorus balance, APB = apparent phosphorus loss or gain, NPB = net phosphorus loss or gain, NS = nonsignificant ($p > -0.05$); *** = significant at 0.1%; ** = significant at 1%; and * = significant at 5%, GM = grand mean.

harvesting maize. Organic carbon content varied from 11.2 g/kg after the first maize crop to 16.8 g/kg after harvesting the final wheat crop.

3.3.3. Total Nitrogen. The application of fertilizer rates had a nonsignificant effect on the total nitrogen content of the soil in the first maize experiment (Table 6). In the second crop, the total N content was considerably affected by the N levels but the influence of P and K was found to be nonremarkable. Significantly higher content of N was found from the application of higher nitrogen rates (N_3). Likewise, there was a nonsignificant effect of different rates of N, P, and K in soil nitrogen content in the third and fourth seasons, though there was slight increment in the soil's total nitrogen with increased nitrogen levels. The total nitrogen content varied from 1145 mg/kg after the first maize crop harvest to 1261 mg/kg after harvesting the second maize crop. At the end of the experiment, the total nitrogen content in the soil declined to 1177 mg/kg. The data revealed that higher the rates of P and K, the lower the nitrogen content in the soil. The interaction of N, P, and K is shown in Table 6.

3.3.4. Available Phosphorus. The effect of application of N, P, and K at different rates was nonsignificant on the available phosphorus at harvest of the first maize crop (Table 6). However, P rates had a considerable effect on the available P at the end of the first-year experiment in which higher available P content was observed from the application of 75 kg P_2O_5 per ha. Similar to the second crop, after the harvest of the third (maize) and fourth (wheat) crops, the available P content was significantly higher from the application of 75 kg P_2O_5 per ha, but the effect of N and K application rates was nonsignificant. The data revealed that higher the rates of N and K, lower the P content in the soil. Over the years, a declining trend of P was observed in almost all the treatments in comparison to its initial status. There was a heavy reduction in the P content of soil during four successive cropping seasons even after fertilization through SSP.

3.3.5. Available Potassium. Different levels of nitrogen did not significantly affect the available potassium content in the first years of experiment, whereas the residual soil K was considerably affected by the N levels in the second year of the experiment (Table 6). The data revealed that higher the rates of N, lower the available K content in the soil. However, the application of P rates at different rates had a nonsignificant effect on the available K at harvest of each crop during the two years. Likewise, K application rates had a nonremarkable effect on the K content of soil after the harvest of each maize crop, whereas K rates had a considerable effect on the available K after the harvest of each wheat crop during

Table 5: Partial balance, apparent gain or loss, and net gain or loss of potassium (kg/ha) per year as affected by fertilization in the maize-wheat experiment, Khumaltar, Lalitpur, 2019/20–2020/21.

Treatments	Input Fa	Potassium uptake by crop (kg/ha) M1	W1	M2	W2	Total	PKB (kg/ha/yr)	AKB (kg/ha/yr)	NKB (kg/ha/yr)
Nitrogen levels (N)									
N1	220	111.4 b	129.0 c	51.8 c	131.1 b	423.2 c	−101.6 a	55.7 c	−45.9 a
N2	220	127.0 a	155.0 b	61.6 b	152.2 a	495.7 b	−137.9 b	84.3 b	−53.6 a
N3	220	135.7 a	171.3 a	79.3 a	161.5 a	547.7 a	−163.9 c	110.5 a	−53.3 a
LSD 0.05		12.0	11.13	9.72	9.8	25.03	12.5	14.61	NS
Phosphorus levels (P)									
P1	220	115.6 b	146.3 a	58.1 b	143.0 a	463.0 b	−121.5 a	73.6 a	47.9 a
P2	220	131.0 a	151.1 a	63.9 ab	148.4 a	494.5 a	−137.2 b	85.9 a	−51.3 a
P3	220	127.4 ab	157.8 a	70.7 a	153.3 a	509.2 a	−144.6 b	91.0 a	−53.5 a
LSD 0.05		12.0	NS	9.72	NS	25.03	12.5	NS	NS
Potassium levels (K)									
K1	130	114.5 b	141.6 b	53.4 c	135.8 c	445.3 c	−157.7 c	109.1 a	−48.6 a
K2	220	128.7 a	150.6 b	64.2 b	147.8 b	491.3 b	−135.7 b	88.2 b	−47.4 a
K3	310	130.7 a	163.1 a	75.1 a	161.2 a	530.1 a	−110.0 a	53.2 c	−56.8 a
LSD 0.05		12.0	11.13	9.72	9.8	25.03	12.5	14.61	NS
F test prob (P > F)									
N		**	***	***	***	***	***	***	NS
P		*	NS	*	NS	**	**	NS	NS
K		*	**	***	**	***	***	***	NS
NP		NS	NS	*	NS	NS	NS	NS	NS
NK		NS	NS	NS	NS	NS	NS	NS	NS
PK		NS	NS	NS	NS	NS	NS	NS	NS
NPK		NS	NS	NS	NS	NS	NS	NS	NS
CV (%)		17.6	13.4	23.7	12.1	9.4	17.0	23.0	21.6
GM		124.7	151.7	64.2	148.3	488.9	−134.5	83.5	−50.9

Fa = fertilizer applied in 2 years, *M*1 = maize crop K uptake in 1st year, *W*1 = wheat crop K uptake in 1st year, *M*2 = maize crop K uptake in 2nd year, *M*1 = wheat crop K uptake in 2nd year, PKB = partial potassium balance, AKB = apparent potassium loss or gain, NKB = net potassium loss or gain, and NS = non-significant ($p > -0.05$); *** = significant at 0.1%; ** = significant at 1%; and * = significant at 5%, GM = Grand Mean.

Table 6: Effects of different NPK rates on pH, organic carbon (g/kg), total nitrogen (mg/kg), available phosphorus (P_2O_5, mg/kg), and available potassium (K_2O, mg/kg) over different seasons at Khumaltar, Lalitpur.

Trt	pH				SOC				N				P				K			
	M1	W1	M2	W2	M1	W1	M2	W2	M1	W1	M2	W2	M1	W1	M2	W2	M1	W1	M2	W2
Nitrogen levels (N)																				
N1	5.80	5.65	5.85	5.60	11.2	15.4	14.8	16.6	1152	1171	1268	1161	169	161	136	65.1	28.1	30.4	41.9	29.0
N2	5.81	5.63	5.84	5.55	11.2	16.0	15.1	16.8	1152	1176	1264	1172	166	157	133	63.5	27.1	30.2	34.4	23.7
N3	5.79	5.63	5.81	5.45	11.1	16.3	15.1	16.9	1131	1209	1250	1198	164	155	132	62.1	27.1	27.5	33.1	21.8
LSD	NS	NS	NS	0.11*	NS	NS	NS	NS	NS	32.2*	NS	NS	NS	NS	NS	NS	NS	NS	5.7**	5.3*
Phosphorus levels (P)																				
P1	5.85	5.66	5.88	5.55	10.9	15.7	14.8	16.7	1161	1187	1267	1183	164	155	127	57.6	27.9	28.1	36.0	26.8
P2	5.81	5.65	5.84	5.52	11.2	16.0	15.0	16.7	1141	1186	1261	1174	167	155	134	66.4	27.6	28.8	35.3	24.7
P3	5.80	5.61	5.78	5.51	11.3	16.1	15.2	16.9	1134	1183	1255	1175	169	164	140	66.7	26.9	31.3	38.1	23.0
LSD	NS	NS	0.08*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.0*	9.1*	6.9*	NS	NS	NS	NS
Potassium levels (K)																				
K1	5.87	5.65	5.86	5.54	11.0	15.5	14.9	16.7	1161	1192	1270	1195	166	156	132	65.0	27.9	26.0	36.7	26.5
K2	5.80	5.64	5.83	5.53	11.2	16.0	15.0	16.8	1130	1190	1264	1179	167	160	132	62.2	27.1	29.1	35.8	27.0
K3	5.79	5.62	5.81	5.51	11.4	16.2	15.1	16.9	1144	1174	1249	1157	166	158	137	63.6	27.4	33.1	36.8	21.0
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4.45**	NS	5.3*
F test Prob (P > F)																				
NP	NS	NS	**	*	NS	NS	NS	NS	*	NS	**	NS	NS	NS	NS	NS	NS	NS	*	NS
NK	NS	*	*	NS	NS	NS	NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS	NS	NS
PK	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	**	*	NS	NS	NS	*	NS	NS	NS	NS
NPK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.1	2.9	2.4	3.7	21.4	11.1	9.6	10.0	4.5	5.0	3.0	5.3	17.0	8.2	12.5	20.1	23.7	21.7	22.6	21.4
GM	5.82	5.64	5.83	5.53	11.2	15.9	15.1	16.8	1145	1185	1261	1177	166	158	134	63.6	27.5	29.4	36.4	24.8

Trt = Treatments, *M*1 = maize crop in 1st year, *W*1 = wheat crop in 1st year, *M*2 = maize crop in 2nd year, *M*1 = wheat crop in 2nd year, NS = nonsignificant ($p > -0.05$); *** = significant at 0.1%; ** = significant at 1%; and * = significant at 5%, GM = Grand Mean.

the two years. The data showed that in the first year higher available K content was observed from the application of 75 kg P_2O_5 per ha, whereas the K content was higher from 25 kg P_2O_5 per ha. Even after fertilizing with potassic fertilizers, the P content of the soil decreased dramatically during four subsequent cropping seasons.

4. Discussion

4.1. Crop Yield and Nutrient Uptake. Low indigenous supply of N and K from the soil may be the cause of the significant response of N and K rates. Similarly, the uptake of N and K by high nutrients demanding crops: hybrid maize and improved wheat, were comparatively higher with respect to supply through fertilization, which may be another factor for the response. The results are in agreement with [26] who obtained significant increase in grain yield of wheat with increased N levels and [27] who observed an increase in grain yield of maize with increased N rates. Likewise, increased grain yield of maize was reported with higher K levels [28] and enhanced yield of wheat was found with K fertilization rates [29]. With the progress of time, there was successive decrement in the yield of both maize and wheat crops. Similar to our findings, fertilization and fertilization years had a considerable effect on crop yield [30]. The main reason for the reduced yield in maize in the second year was water stress conditions that occurred due to waterlogging in the maize crop, which reduced its capacity to absorb and uptake nutrients. The other factor for reduced yield and uptake with the progress of time was the mining of nutrients, especially N and K in the soil. There was high uptake of nutrients with an increase in fertilization rate which may be due to the increased availability of applied fertilizers in addition to the nutrients present. The initial vigorous growth with high photosynthetic rate enhanced the uptake of nutrients in higher fertilization. The findings are in line with [31, 32].

4.2. Nutrient Balance in the Soil

4.2.1. Nitrogen Balance. An increased nitrogen rate from N_1 to N_3 increased the balance of nitrogen. More N under higher doses of N increased the total nitrogen content in the soil which ultimately helped increase the N balance of the soil. Similar findings were obtained by [24, 33] who confirmed that more N at higher N levels enhanced the available N in the soil, which worked to enhance the net N balance in the soil. Increased cropping intensity and the introduction of high-yielding improved variety of wheat and hybrid maize have resulted in significant N depletion and positive crop response to additional N in the soil which is in line with [34]. Higher uptake of N in biomass of maize and wheat with higher levels of P and K resulted in lower PNB, ANB, and NNB in the soil.

4.2.2. Phosphorus Balance. With higher use of N and K levels, P deficit to the soil increased, whereas higher P inputs indicate decrement in the P deficit to the soil. More P under higher doses of P increased the available P content in the soil which ultimately helped increase the P balance of the soil. More uptake of P by high-yielding improved wheat and hybrid maize varieties has resulted in significant P depletion and negative P balance in the soil after two years of the maize-wheat cropping system. The negative P balance is obviously due to low P fertilization as compared to the excess uptake by the crops [35].

4.2.3. Potassium Balance. The partial K deficit was higher with the application of lower rates of K and the deficit was lower with higher rates of P, suggesting less fertility exhaustion under high P rates. Crop K removal considerably exceeds the K applied through fertilizer, resulting in a negative K balance in the soil. Furthermore, intensification of the cropping systems, as well as the adoption of high-yielding varieties, has led to soil mining, resulting in K deficit. This findings is in support of the findings of [36] who concluded that crop residues remove around five times the amount of potassium that fertilizers applied to the soil. Similarly, there was a negative K balance in today's intensive and high yield-oriented agriculture, and soils were being mined for this vital element [37].

4.3. Status of the Soil after Harvesting

4.3.1. Soil pH. At the completion of the experiment, there was a 7.5% decrement in soil pH, with the application of chemical fertilizers which is in line with [38] who observed a decrease in soil pH due to the acidifying effects of nitrogen fertilizers. There were no noticeable changes in pH between any treatments in the beginning years after fertilization, but gradually the soil pH declined sharply to 5.53 from its initial pH value of 5.98. Similarly, the pH of the soil gradually decreased as a result of continuous cropping and fertilizer use over the years [39]. During the hydrolysis of NH_4-based N fertilizers, H^+ ions are released, which may enhance soil acidity [40]. Infertile soils that do not respond well to additional N fertilizer application result from increased soil acidity caused by N fertilizer application [41, 42], which may cause the inefficient utilization of fertilizer [43].

4.3.2. Soil Organic Carbon. The finding showed that using fertilizers can assist in increasing the soil organic carbon content. It was revealed that as fertilizer levels increased, organic carbon content increased over time [44]. Similarly, the application of fertilizers had a remarkable increment in soil organic carbon as compared to the control [45]. This could be due to the fact that the use of higher rates of fertilizers enhanced the increase in crop biomass supporting additional root residues in the soil which consequently increased soil organic matter [46]. Furthermore, the results are in line with the findings of [47, 48]. An increase in organic carbon content in treatments receiving inorganic fertilizer can be attributed to a higher contribution of biomass to the soil in the form of crop stubbles and residues over years. A similar conclusion was drawn by [49] who indicated that the use of nitrogenous fertilizer improved organic carbon content in the soil as a result of increased crop biomass and residue returned to the soil.

4.3.3. Total Nitrogen. The nitrogen content decreased from 1264.2 mg/kg at initial to 1177 mg/kg at the final harvest after two years. The huge drop in nitrogen content even after the application of higher amounts of nitrogen might be due to higher uptake of nitrogen during the harvest of maize and wheat crops. The overall drop in the available nitrogen content could be attributable to leaching losses of nitrogen under extremely high rainfall conditions, as well as its application schedule not matching crop requirements [38, 50]. At harvest, the higher the rates of nitrogen, the higher the nitrogen content in the soil which is in line with [51] who found that adding nitrogen to the wheat crop improved soil N status. In the same way, a considerable impact of nitrogen fertilizer was observed on soil fertility [52]. With increased nitrogen rates, there was a slight increment in soil nitrogen after the harvest of wheat which is in agreement with [53] who found that the soil total nitrogen at 10–20 cm depth increased with an increase in N rates.

4.3.4. Available Phosphorus. Phosphorus content in soil increased as P levels increased, most likely due to the mobilization of native soil phosphorus, resulting in enhanced P availability. This result is in line with [54] who observed that the amount of available P in the soil samples after harvest increased significantly as the rate of P increased. Similarly, when the amount of P application in the soil increased, so did the amount of available P [55] and the highest residual soil P value of 10.95 mg $P \cdot kg^{-1}$ was noticed with higher P levels applied [56]. After two years of continuous cropping, the available P value dropped from 213.7 mg/kg at the start of the experiment to 63.6 mg/kg at the end of the experiment. The large decline (70.2%) in P content even after applying P fertilizer in each crop could be associated with greater P uptake during maize and wheat crop harvest.

4.3.5. Available Potassium. The lower available K content in the soil was seen with higher N rates, which could be attributable to greater K uptake by maize and wheat crops from the soil with higher grain yield and biomass from higher N application. K content in the soil increased as K levels increased in the first year, most likely due to the mobilization of native soil K, resulting in enhanced K availability. However, at the end of the experiment, due to heavy mining of K by continuous cropping resulting in higher K uptake by crops, the K content was lower. The average available K value declined from 71.7 mg/kg at the start of the experiment to 24.8 mg/kg at the end of the experiment after two years of continuous cropping. The heavy drop (65.4%) in K content even after the application of higher amounts of K might be due to higher uptake of K through the harvest of huge amount of biomass of hybrid maize and improved wheat crops. This finding is in accordance with [57] who conclude that increased cropping intensity, biomass removal from the field, and introduction of higher yielding hybrid varieties have all resulted in significant soil K exhaustion. Likewise, low K application rates in crops have resulted in an over-dependance on the native K reserve in the soil [58] which caused heavy mining of K. Similarly, a declining trend in the available K from its initial status was observed, indicating significant mining of the available K as a result of continuous cropping [59–61].

5. Conclusions

In conclusion, there was a decline in soil pH and an increase in soil organic carbon over the period with the application of fertilizers. Similarly, even after the application of fertilizers, there was a substantial decrease in the total N, P, and K contents in the soil over time. There was heavy mining of nutrients, especially P and K after intensive cropping and heavy feeding of hybrid maize and improved wheat. In this study, we reported that the nutrient balance for all the treatments was negative which indicated that removable nutrients exceeded the quantity added to the soil. This means chemical fertilizer replenishment was insufficient to compensate for crop P and K removal.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors are grateful to the staff of National Soil Science Research Centre and National Agronomy Research Centre for technical assistance and support in carrying out the laboratory and field experiments. The authors express gratitude to the Nepal Agricultural Research Council (NARC) for funding this study through the Nepal Seed and Fertilizer Project (NSAF).

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