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Soil acidifying effects of synthetically produced fertilizer application in high rainfall areas of Northwestern Ethiopia

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Abstract - Soil acidification is a natural process in high rainfall areas where leaching slowly acidifies the soil over time. Thus, a field experiment was conducted at Pawe Agricultural Research Center in 2018 to evaluate the effects of synthetically produced fertilizer on the fertility status of soil under Pawe conditions in Northwestern Ethiopia. The treatments consisted of factorial arrangements of four levels of Nitrogen (0, 50, 100, and 150 kg/ha) and four levels of phosphorus (0, 37.5, 75, and 112.5 kg/ha) that were laid out in a randomized complete block design with three replications in a factorial arrangement. Forty-eight soil samples were collected from the field for analysis. The results of this study revealed that soil acidification and P enrichment were the foremost problems identified. Soil acidification due to the use of phosphorus fertilizer is small compared to that attributed to nitrogen due to the lower amounts of this nutrient used and the lower acidification per kg of phosphorus. Application of synthetically produced fertilizer beyond 50 kg/ha N leads to potential environmental hazards of N and P pollution of nearby aquatic bodies, specifically in areas with high rainfall. Therefore, proposing different ameliorative measures and practicing area-specific recommendations are vital in areas that can receive higher annual rainfall.

Keywords: Soil acidity, soil pH, synthetically produced fertilizer

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1. Introduction

One of the biggest obstacles in tropical agriculture is sustainable soil productivity. Poor-resource farmers in the tropics often undertake continuous farming. As a result, the soil microbial population is unstable and soil nutrients are rapidly declining (Afe & Oluleye, 2017). As a result, there is an increase in poverty, a decrease in productivity, and low grower returns (FAO, 2017) the first SAU was established in 1960 at Pantnagar in Uttar Pradesh. The SAUs were given autonomous status and direct funding from the state governments. They were autonomous organizations with state-wide responsibility for agricultural research, education and training or extension education. The establishment of the SAUs, based on a pattern similar to that of the land-grant universities in the United States, was a landmark in reorganizing and strengthening the agricultural education system in India. These universities became the branches of research under the Indian Council of Agricultural Research (ICAR) and became the partners of the National Agricultural Research System (NARS). Ethiopia's prosperity and long-term food security are mostly fueled by agriculture. Consequently, to meet the increased demand for food from the growing population, agricultural land has expanded (Engda et al., 2008) agriculture is expanding at the expense of natural forests to feed the increasing population. Areas which were under natural forest are being converted to cropland, grazing land and eucalyptus plantations. However, the general ecological effects of these changes have not been well investigated and documented. Therefore, this study was undertaken to investigate the effects of these land use changes on the physical and chemical properties of soils and the possible consequences on land productivity and the environment as a whole. Laboratory analysis was done for soil samples collected from the upper 15-20 cm depth from land utilized for crop cultivation, grazing, eucalyptus plantation and natural forest growth in order to compare moisture content, particle size (texture). As a result, altered eating habits and rising food demand are likely to fuel intensive fertilizer use, which will eventually cause soil acidification (Piesse, 2020).

Soil acidity is common in all areas where precipitation is high enough to leach considerable amounts of exchangeable bases from the surface of soil (Oluwatoyinbo et al., 2005) or where hydrogen cations (H^+) build up; reducing soil pH. Intensive agriculture can enhance soil acidification through numerous processes - increasing leaching, addition of fertilizers, removal of crop residues and build-up of soil organic matter (Fertiliser Technology Research Centre, 1987). Soil acidification which is one of the key constraints for the global productivity and sustainability of agriculture, disturbs almost 40% of the world's farmlands (Tkaczyk et al., 2020). Soil acidity is now a tricky problem to crop production in most highland of Ethiopia (Haile & Boke, 2009). According to Zelleke et al., (2010) 41 percent of Ethiopia's land is likely to be affected by soil acidity and out of this 13 percent is strongly acidic (pH < 4.5) and 28 percent is moderately to weakly acidic (pH 4.5-5.5). This reduces the solubility of nutrients required for plant growth. Conditions also frequently lead to Al and Mn toxicity and deficiency in N, P, K, Mg, Ca, and various micronutrients (Zelleke et al., 2010) and affect soil C and N cycles by controlling the activities of microorganisms involved in the transformation of these two elements (Kunhikrishnan et al., 2016). This has several implications for plant growth and other soil fertility issues, which can lead to the absence of or reduced response to ammonium phosphate, ammonium, and urea fertilizers, stunted roots, and plant growth due to nutrient deficiency, increased incidence of disease, and toxicity. Fertilizer plays a major role among cultural practices for improved crop production. However, blanket application of inorganic fertilizers to production fields without adequate knowledge of the nutrient status often leads to increased soil acidity, particularly when nitrogen fertilizers are applied (Afe & Oluleye, 2017). Kunhikrishnan et al., (2016) also reported that fertilizer application in managed environments used for agricultural production is a major contributor to soil acidification. Many long-term trials have revealed that soil pH is significantly reduced by the long-term application of ammonium- or urea-based N fertilizers in croplands, particularly in soils with a low H+ buffer capacity (Hao et al., 2019) The contribution of this driver compared to other causes of soil acidification on intensive croplands has seldom been quantified under field conditions. Methods: we measured the fate of major nutrients, and calculated the related H^+ production, based on the difference between inputs and leaching losses of those nutrients for a wheat-maize rotation system on a moderate acid silty clay loam soil in a two-year field experiment. Results: topsoil pH decreased 0.3 units in the plots with conventional (current farmer practice. Agriculture requires the application of P fertilizer, but it must be handled carefully to avoid serious environmental harm like eutrophication of water bodies (Longley et al., 2019), trophic state analysis and relations between Chl-a and nutrients in Lake George, Florida, have been conducted. Three zones within Lake George was established to prepare a succinct analysis of the existing monthly and seasonal averages across the water body. Statistical analyses, including multiple regression analysis, were used in this study to establish the relationship between Chl-a and nutrients, total nitrogen (TN). Various organizations in Ethiopia have conducted numerous fertilizer experiments to date, primarily focusing on the nutritional benefits and increased crop yields resulting from their application. However, these experiments have not addressed the issue of soil acidity, which can occur due to improper fertilizer application, particularly in areas with high rainfall. Soil acidity is influenced by both biotic and abiotic factors, and thus, this study aimed to evaluate the impact of different nitrogen and phosphorus fertilization rates and their interactions on the chemical parameters related to soil acidity.

2. Materials and methods

2.1 Description of the study area

The experiment was conducted during the 2018 rainy season at the Pawe Agricultural Research Center, which is situated in the Metekel zone of the Benshangul Gumuz regional state, located at a latitude of $11^0$18`49.6``N and a longitude of $036^0$24`29.1``E (Aseffa et al., 2020). The research site is positioned 570 kilometers away from Ethiopia’s capital city, Addis Ababa, at an elevation of 1120 meters above sea level. The area receives an annual precipitation of 1507.7 mm, primarily between May and November (as shown in Figure 1), and has temperature ranges from 10.8 to 41.6 °C. The experimental site was characterized by a well-drained clay soil with a pH of 5.24, as indicated in **Table 1.** Agricultural activities, involving the cultivation of sorghum, maize, finger millet, groundnut, soybean, and sesame, as well as livestock rearing and forestry, play a significant role in shaping the land use system in the study area, as documented by Aseffa et al. (2020).

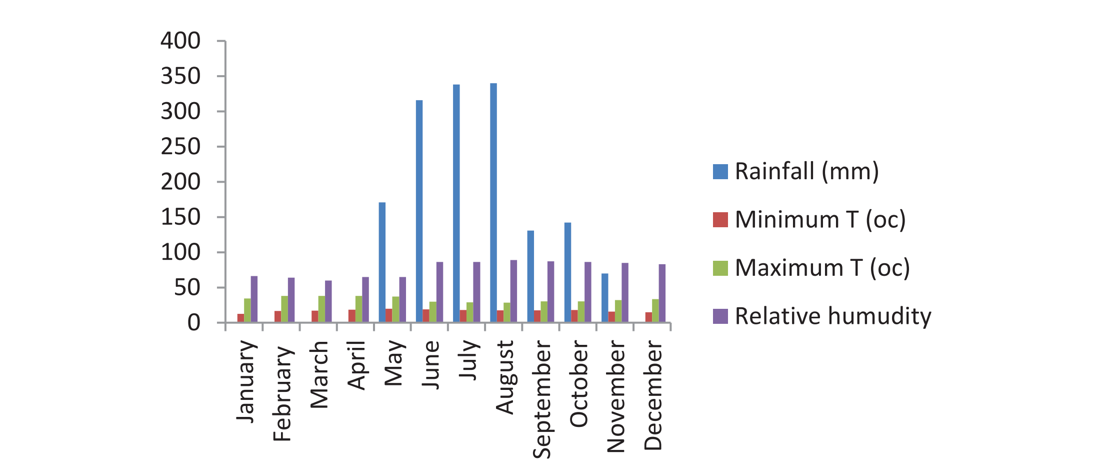

Figure 1. Meteorological information in the study area (January - December 2018) (Aseffa et al., 2020)

2.2 Experimental material, treatments and design

Four nitrogen (0, 50, 100, and 150 kg/ha) and four phosphorus (37.5, 75, and 112.5 kg/ha) levels were used for fertilizer treatments. The fertilizer sources for nitrogen and phosphorus were urea (46 percent N) and triple super phosphate TSP (46 percent P_2O_5), respectively (Figure 2). When the final land preparation was performed, all TSP used in the studies was applied. Split applications of urea were used as a top dressing (Aseffa et al., 2020). Around the plant, the first and second rounds of urea treatments were applied as top dressings and mixed into the soil during the third- and fifth-weeks following seedling emergence. Three replicates of the treatments were ordered in a factorial fashion, using a randomized complete block design (RCBD). Analysis of variance was performed on the obtained data, and the LSD test was used to compare the differences in treatment means (Gomez, 1984).

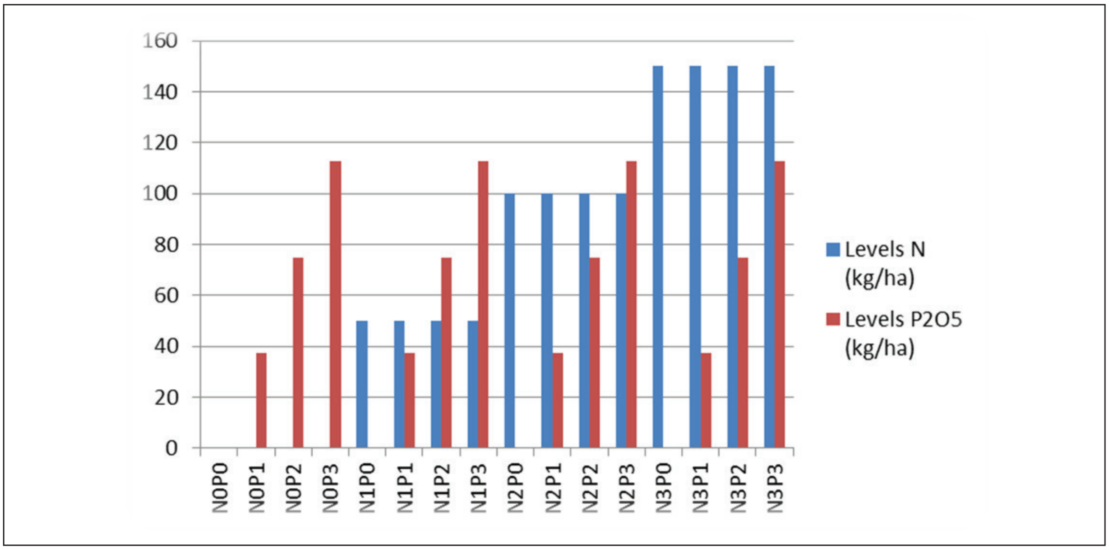

Figure 2. Nitrogen and phosphorus treatment combination (Aseffa et al., 2020)

1.1.1 Soil analysis

Before planting, a soil sample was collected in a zigzag walking pattern to capture the heterogeneity of the soil and minimize errors from 0 to 30 cm of the cultivable soil profile. The Pawe Agricultural Research Center Soil Laboratory was used to analyze the samples. To analyze the pH and texture, the composite soil sample was air-dried and pulverized before being passed through a 2 mm size sieve. The hydrometer method was used to determine the soil texture (Bouyoucos, 1962). The soil samples were passed through a sieve with a pore size of 1 mm to determine the amounts of total nitrogen and organic carbon. An electrode pH meter was used to measure the pH of the soil in a suspension with a soil-water ratio of 1:2.5 A volumetric approach was used to determine the organic carbon content of the total nitrogen was calculated using sulfuric acid and the micro-Kjeldahl technique Bray II extraction technique was used to assess the amount of available phosphorus. Similarly, soil samples were collected from each plot to calculate the crop nutrient efficiency and residue from a composite across the various treatment levels. Physical characteristics including soil texture (sand, silt, and clay) and chemical qualities (available N, available P, pH, OC, and organic matter) were examined. The values of various components and the techniques used to determine them were provided. Table 1 lists the physical and chemical characteristics of the soil prior to planting.

Table 1. Soil physico-chemical properties before fertilizer application

Soil parameters	Values
pH	5.24
Organic matter (%)	4.10
Organic carbon (%)	2.38
Total nitrogen (%)	0.186
Available P (mg/kg)	1.81
Sand (%)	2
Silt (%)	20
Clay (%)	78
Class	Clay

(Aseffa et al., 2020)

3. Results and discussions

3.1 Soil pH

The pH of the soil is thought to play a significant role in the microbiological activity of various types of soil Kunhikrishnan et al., (2016). The pH level of the soil was dramatically ($P<0.001$) decreased after applying urea, a type of N fertilizer (Table 2). The pH value of the treatment plot, which was fertilized with 50 kg of nitrogen per hectare, was 5.09, while the maximum pH value of the control plot, which was statistically equivalent, was 5.25. The treatment plots that received nitrogen treatment at the maximum rate (150 kg/ha) had the lowest pH values (4.59) (Table 3). When N fertilizer was applied in different amounts, starting at zero, the pH values of the soil decreased and its acidity rose (Figure 3). The obtained result was in line with research done by Tkaczyk et al., (2020), who discovered that over the course of three years, soil pH was dramatically reduced by 0.5 and 0.2 units on average when nitrogen levels were tripled (360 kg N/ha) and doubled (240 kg N/ha), respectively. No appreciable changes in top soil pH were seen in the N-free plots, validating the idea that excessive nitrogen (N) fertilization is the main cause of agricultural soil acidification (Hao et al., 2019). The contribution of this driver compared to other causes of soil acidification on intensive croplands has seldom been quantified under field conditions. Methods: we measured the fate of major nutrients, and calculated the related H^+ production, based on the difference between inputs and leaching losses of those nutrients for a wheat-maize rotation system on a moderate acid silty clay loam soil in a two-year field experiment. Results: topsoil pH decreased 0.3 units in the plots with conventional (current farmer practice). Nitrogen's impact on soil acidity vary based on the kind of fertilizer used, how much was applied, the state of the soil, and external influences (Tian & Niu, 2015). NH_4NO_3 form fertilizer and urea applications significantly decreased the pH of the soil (Tian & Niu, 2015). A notable decrease was seen when the applied-N level above 5 $g/m_2/yr$. Furthermore, it was reported that when the initial pH of the soil was between 3 and 4, the addition of N had no effect on pH. Above this range, N addition dramatically reduced the pH of the soil (Tian & Niu, 2015). The conversion of ammonium (NH_4^+) to nitrates (NO^-_3) occurs when deposited nitrogen (N) is taken by plants. Meanwhile, the released hydrogen (H^+) mostly acidifies the soil through nitrification and NO^-_3 leaching (Kunhikrishnan et al., 2016). Thus, the addition of N results in the release of more acidic cations (such as Fe^+_3 and Al^+_3) and a decrease in the concentration of non-acidic cations (such as K^+, Ca^+_2, Mg^+_2, and the pH of the soil) (Huang et al., 2021). Soil acidity also has a negative effect on plant development (particularly fine root biomass), plant diversity, and microbial activity (Huang et al., 2021). Similarly, as figure 3 shows, the pH of the soil decreased linearly with an increase in the rate of N application. Figure 4 demonstrates that the addition of phosphorus fertilizer had no effect on the pH of the soil. The use of phosphorus and nitrogen fertilizer in the form of TSP and urea had no effect on organic carbon and organic matter of the soil (Table 2). The result was inline with the finding of Adekiya et al., (2020) chemical and biological properties. Hence, field experiments were carried out in 2017 and 2018 to compare the impact of different organic manures and NPK fertilizer on soil properties, growth, yield, proximate and mineral contents of okra (*Abelmoschus esculentus* L. reported that NPK fertilizer application did not increase OM contents of the soil relative to the control.

Table 2. Mean square values for soil parameters

Source of variation	DF	pH	Available P	Organic carbon	Organic matter	Total nitrogen
Block	2	1.07***	22.66^{ns}	0.53***	1.59***	0.018***
Nitrogen	3	1.01***	22.96*	0.055^{ns}	0.16^{ns}	0.00006^{ns}
Phosphorus	3	0.06^{ns}	37.86*	0.07^{ns}	0.21^{ns}	0.00024^{ns}
N*P	9	0.047^{ns}	3.97^{ns}	0.029^{ns}	0.087^{ns}	0.00026^{ns}
Error	30	0.052	8.5	0.057	0.17	0.00029
CV		4.6	71.4	9.27	9.26	8.27

***= significant at 0.01%, **= significant at 1%, *= significant at 5% level of significance, ns= not significance, DF= degrees of freedom, pH =power of hydrogen ion, Available P=available phosphorus, N*P= nitrogen and phosphorus interaction

Table 3. Effects of N and P fertilizer rates on soil chemical properties

Treatments N (kg/ha)	pH	Available P	Organic carbon	Organic Matter	Total Nitrogen
0	5.25^{a}	6.13^{a}	2.58	4.44	0.205
50	5.09^{a}	3.42^{b}	2.68	4.62	0.209
100	4.8^{b}	3.106^{b}	2.57	4.43	0.206
150	4.59^{c}	3.68^{b}	2.52	4.34	0.21

Table 3. Effects of N and P fertilizer rates on soil chemical properties (cont.)

Treatments N (kg/ha)	pH	Available P	Organic carbon	Organic Matter	Total Nitrogen
Phosphorus					
0	4.86	1.584[b]	2.63	4.54	0.203
37.5	4.98	4.265[a]	2.65	4.57	0.208
75	5.01	4.751[a]	2.58	4.45	0.213
112.5	4.89	5.739[a]	2.48	4.27	0.205
LSD at 5%	0.189	2.43	0.2	0.34	0.0143
CV	4.6	71.4	9.27	9.26	8.27

* Means followed by the same letter (s) in the same column are not significantly different at 5% level of significance, pH= power of hydrogen ion, Available P= available phosphorus

3.2 Total nitrogen

The total N in the soil following harvest is shown in Table 3 data. This result demonstrated that as applied N levels rose, the total N content of the soil increased as well, rising from 0.205 percent in control plots to 0.21 percent at 150 kg/ha. Nevertheless, there was no statistically significant variation in the nitrogen content among these mean values across all N rates (Table 2). The outcome was consistent with the research done by Biñas and Cagasan, (2021), which found that the treatments had no effect on soil nutrients other than pH and available P after the crop was harvested. The pre-sowing level of N (0.186 %) (Table 1) of the soil increased to 0.205 % in the control plot and it was in the range of 0.205 to 0.21% in plots fertilized with N. More okra leaves were likely added to the soil as biproducts after harvest, which was the main cause of the increase in total N and the likely explanation for this rise. In line with this result, Zhang et al. (2019) an aerobic incubation experiment (105 days reported that N and NP fertilization increased top soil organic N content). The application of fertilizers including nitrogen, phosphorus and their interaction had little influence on soil organic matter, carbon, and total N (Table 2) even in cases where the return of plat residues was extremely high. Similar results were found by Zhang et al. (2019) who showed that after an aerobic incubation for 105 day. N and/or P fertilization had no discernible effect on the concentration of soil organic C.

3.3 Available phosphorus

When phosphorus fertilizer rates were applied, the soil's available P content increased. Phosphorus application resulted in a considerable ($P<0.01$) increase in the available P concentration in the soil following harvest (Table 2). The treatment plots with the highest mean values (5.739 ppm) received P at a rate of 112.5 kg/ha, while the control plot had the lowest mean values (1.584 ppm) (Table 3). However, there was no statistically significant difference in the available P concentration at these P fertilization rates. The outcome showed that as P fertilizer rates were raised, the amount of available P in the soil gradually rose. In contrast, the control plot's initial amount of available P in the soil dropped to 1.584 ppm, suggesting that some P was lost to plant uptake or soil fixation. Bulluck et al. (2002) demonstrated in agreement with this, that the primary loss of available soil phosphorus is fixation. The P fertilization that raised the available P concentration in the soil in this study may have been caused by replacing fixed P with more P in the soil, largely in labile forms that can release phosphorus into the soil solution. An increase in applied P from 0 to 112.5 kg/ha highly significantly increased the level of soil available P from 1.584 to 5.739 mg/kg soil (Table 3). The observed increment in soil available P in response to the increase in applied P could be explained by the fact that some of the applied P in the soil has not been utilized by the plant and hence remained in the soil.

A substantial ($P<0.05$) impact of nitrogen fertilizer application was seen on the soil's available phosphorus concentration (Table 2). Soil available P fell from 6.13 to 3.106 mg/kg soil when N application was increased from 0 to 150 kg N/ha (Table 3). The reason for this could be that the Okra plants' P nutrition was enhanced by the increased application of N, since both nutrients have linked metabolic processes. Liu et al. (2021), in keeping with this finding, availability of phosphorus can be improved by reducing the amount of nitrogen fertilizer rate applied in soils. According to Liu et al. (2021), co-fertilization with N is often a successful strategy for increasing P use efficiency. It is possible to distinguish between the chemical and biological effects of N on P availability (Grunes, 1959). Chemical effects changed the solubility of soil P, which affected plant uptake of P, whereas biological effects resulted from N's indirect effects on plant shape and functions. Nitrogen molecules, such ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3N), have the capacity to alter soil pH, which might affect plants' availability of P (Ruan et al., 2000).

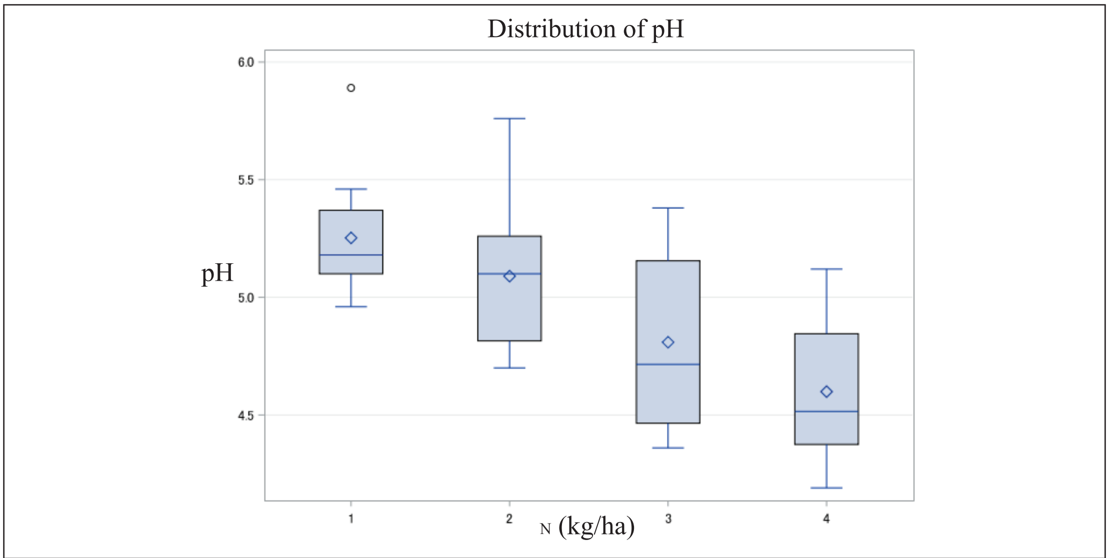

Figure 3. Effects of nitrogen on pH value and 1 =control which is 0, 2= 50kg N/ha, 3 =100 kg/ha, 4 = 150 kg/ha

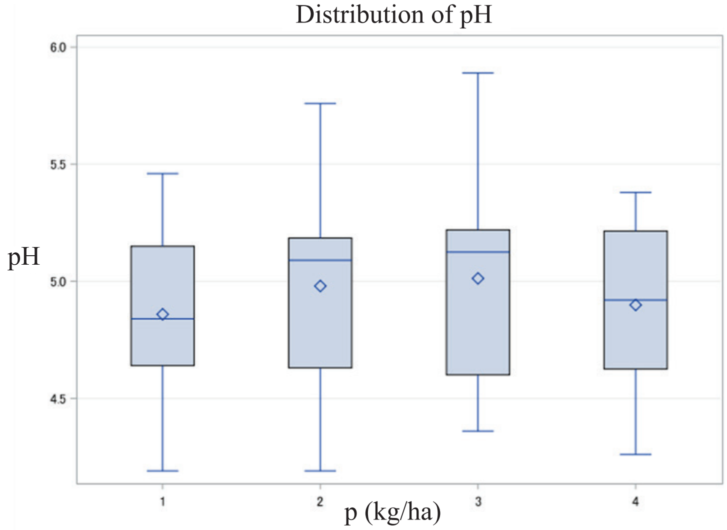

Figure 4. Effects of P_2O_5 on soil pH value and 1 =0, 2 =37.5 kg P_2O_5/ha, 3 =75 kg P_2O_5/ha, and 4 = 112.5 kg P_2O_5/ha

4. Conclusion

This study revealed the effects of synthetically produced fertilizer application mainly focusing on N and P in okra production fields in northwestern Ethiopia. A trend of increasing soil acidification after growing okra in this particular area was identified, and an excess of N application greater than 50 kg per ha in the form of urea might be the main reason. The application of large amounts of inorganic P fertilizers causes the accumulation of P in soil after harvest, which poses a potential threat to aquatic environments. Even if the response of soil to N and P fertilizer application depends on environmental factors such as initial soil pH, soil carbon and nitrogen content, precipitation, and temperature, designing a nationwide experiment is very important for developing sustainable recommendations. Soil acidification problems can be coupled by reducing NO^-_3 leaching by avoiding the use of acidifying fertilizers such as ammonium sulfate and urea, by preventing erosion of the surface soil, and by lime application such as calcite ($CaCO_3$), burnt lime (CaO), and dolomite ($CaMg(CO_3)_2$), which are added to the soil to neutralize acidic soils and overcome the problems associated with soil acidification.

Conflicts of interest

The authors declare that there is no conflict of interest.

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