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Effects of Nitrogen and Phosphorus Fertilizer Rates on Maize (*Zea mays* L.) Growth and Yields in Terraced Lands of Medium and High Altitude Regions of Rwanda

A. Fashaho[1, 2], A.O. Musandu[2], J.J. Lelei[2], S.M. Mwonga[2], G.M. Ndegwa[3]

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ABSTRACT

Depletion of nitrogen and phosphorus in terraced hilly areas of Rwanda has lowered maize (*Zea mays* L.) production. Trials were carried out in 2017 and 2018 in four-year-old-terraced Lixisols and Acrisols of medium and high altitudes to determine effect of nitrogen and phosphorus fertilizer application rates on maize yields. A factorial arrangement of four levels of nitrogen (0, 60, 120 and 180 kg N ha^{-1}) and phosphorus (0, 40, 80 and 120 kg P_2O_5 ha^{-1}) in a randomized complete block design with 3 replications, was used. Results showed that combinations of 120 - 180 kg N ha^{-1} and 80 - 120 kg P_2O_5 ha^{-1} resulted in significantly ($P < 0.05$) higher increases in plant height (45 - 60% and 56 - 70% over the control), stem collar diameter (63 - 74% and 43% over the control) and grain yields (3 times over the control; i.e. 6.40 - 6.46 t ha^{-1} and 6.02 - 6.12 t ha^{-1}) in medium and high altitude sites. The optimum fertilizer rates are 176.6 kg N ha^{-1} and 96.2 kg P_2O_5 ha^{-1} in terraced Lixisols of medium altitude area. Land use needs to adjust fertilizer application to these optimum rates for enhanced maize yields in this area and other regions with similar agro-ecological characteristics. Further studies on integrated effects of N and P fertilizers are recommended.

Key words: Acrisols, Grain yield, Lixisols, Nitrogen, Phosphorus.

INTRODUCTION

Nitrogen (N) and phosphorus (P) are the most critical macronutrients that often limit crop growth and yield (Masood *et al.,* 2011; Belfield and Brown, 2008). Nitrogen increases vegetative growth and photosynthetic capacity of plants, determines number of leaves and number of seeds per cob (Roy *et al.,* 2006). Phosphorus is essential for growth, cell division, root lengthening, seed and fruit development and early ripening. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction (Masood *et al.*, 2011; Roy *et al.,* 2006).

Maize (*Zea mays* L.) is a major food security and income generating crop for small scale farmers in Rwanda. An average maize yield of 1.74 t ha^{-1} is obtained at farm level (NISR, 2016) which is low compared to a potential yield of 6 to 10 t ha^{-1} and average worldwide productivity of 5.52 t ha^{-1} (Yadav *et al.*, 2016). One of the causes of low yields is insufficient fertilizer application (NISR, 2016; Chianu *et al.*, 2012). In terraced lands, the fertilizer recommendations in use are based on results of studies done before terracing (MINAGRI, 2009; Kelly and Murekezi, 2000). Terrace construction causes mixing of soil layers and subsequent changes in the distribution of organic matter and chemical nutrients (Fashaho *et al.*, 2019; Ramos, 2007). Fertilizer application should consider new properties of terraced soils.

The objective of the study was to determine optimum nitrogen and phosphorus fertilizer application rates for the growth and yields of maize in terraced lands of Rwanda.

[1]Department of Crop Sciences, University of Rwanda, P.O. Box 210, Musanze, Rwanda.
[2]Department of Crops, Horticulture and Soils, Egerton University, P.O Box 536 - 20115, Egerton, Njoro, Kenya.
[3]Department of Soil Science, University of Rwanda, P.O. Box 210, Musanze, Rwanda.

Corresponding Author: A. Fashaho, Department of Crop Sciences, University of Rwanda, P.O. Box 210, Musanze, Rwanda.
Email: fashaho@yahoo.fr

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MATERIALS AND METHODS

Field experiments were carried out in lands belonging to farmer's Cooperatives HUGUKA in Gicumbi and GWIZA in Rwamagana Districts during the cropping seasons B 2017 (March to August 2017) and A 2018 (September 2017 to February 2018). Trials were set up in four-year-old terraced Lixisols of medium altitude [1565 m above sea level (a.s.l)] and Acrisols of high altitude (2061 m a.s.l) in eastern (1° 56' 42" S; 30° 19' 38" E) and north eastern (1° 37' 56" S; 30° 4' 31" E) Rwanda, respectively (Fashaho *et al.*, 2020; Verdoodt and Van Ranst, 2003). Mean annual rainfall received is 950 - 1000 mm in medium and 1200 - 1500 mm in high altitudes and average annual temperature range is 19 - 30°C in

medium altitude and 13.2 - 20.8°C in high altitude (Rwamagana District, 2013; Gicumbi District, 2013). In the previous cropping season, before the trial, common beans and garden peas had been grown in the medium and high altitudes, respectively and soils fertilized with Farm Yard Manure (FYM).

Trials were carried out concurrently in the two sites. A factorial experiment in a randomized complete block design (RCBD) with 3 replications was established. There were four levels of nitrogen (0, 60, 120 and 180 kg N ha^{-1}) and phosphorus (0, 40, 80 and 120 kg P_2O_5 ha^{-1}) resulting in a total of 16 treatment combinations. The land was divided into three blocks (replicates). Each block was set up on a separate terrace and each subdivided into 16 plots, with foot path of 30 cm between plots. Each plot or experimental unit size was 8.4 m^2 (2.8 m × 3 m). Sowing was done by dibbling method. Two seeds were planted manually per hole at 5 cm depth, with spacing of 70 cm between rows and 30 cm within rows (MINAGRI, 2009). Thinning to one seedling per hill was done two weeks after emergence to retain the recommended population of 47,619 plants per hectare (MINAGRI, 2009). Manual weeding was done twice during the vegetative cycle of maize to prevent competition between seedlings and weeds for light, space, water and minerals and also aerate soil. Rocket pesticide was applied at intervals of 5 days starting at 15 days after sowing to tasselling stage to control armyworm pest.

The assessment of treatments' effects on maize growth, phenology and yields was performed on 8 tagged plants from two central rows in each plot. Plant height (cm) was measured from ground surface to the top of plant using a measuring tape, at 30, 60 and 90 days after sowing (DAS). Collar diameter (cm) was measured at the first node from the ground surface using a vernier caliper on the same dates. Number of leaves per $plant^{-1}$ were counted on the same dates. Number of days to 50 percent tasselling was recorded.

Yield parameters were collected at maize physiological maturity from two central rows on a surface area of 1.68 m^2 (1.4 m long and 1.2 m wide). The above ground portion of the plant was harvested and separated into stover and cobs. Number of cobs $plant^{-1}$ was recorded. The stover (stalks and leaves) was chopped into small pieces and weighed. Sub-samples were weighed and oven-dried at 70°C in a ventilated oven to constant weight which was used to calculate total above-ground biomass yield. Oven drying of samples was done at the soil science laboratory of the University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine.

Grains on the cobs were shelled. Grain yield (at 13% moisture content) and total above-ground biomass yield (stover + cobs + grains) were determined using the formulae below (Tuyishime, 2012; Wasonga *et al.* 2008);

GY (kg ha^{-1}) =

(GW/PLS)*10000 * [(100 - GMH)/ (100 - GMD)]…….....(1)

Total dry matter yield (above-ground biomass) =

(GY + SY + CY)…….....(2)

Where

GY, GW, PLS, GMH and GMD are grain yield, grain weight at harvest, plot size harvested, grain moisture content at harvest and grain moisture content at 13%, respectively. SY and CY are stover and cob dry matter yields, respectively. Harvest index (H.I %) was calculated using the formula below:

H.I = (Grain yield / Total biomass yield) * 100 (Kaur, 2016) …(3)

Data collected were organized using Excel data sheet and subjected to Bartlett Chi-square test of homogeneity. Analysis of variance (ANOVA) was performed using statistical analysis system (SAS), version 9.2 (SAS, 2008). Duncan's Multiple Range Test (DMRT) was performed for means comparison. A 0.05 significance level was used for all statistical analyses (Gomez and Gomez, 1984). Regression analysis was performed to predict optimum N and P fertilizer rates for maximum maize yields (Meyers *et al.,* 2009; Cassman and Plant, 1992).

RESULTS AND DISCUSSION

Maize height, collar diameter and number of leaves

The maize height, stem collar diameter and number of leaves were enhanced by application of N and P fertilizers. In terraced Lixisols of medium altitude site, maize was significantly ($P<0.05$) taller in plots treated with combinations of 180:120, 180:80, 120:80 and 120:120 N: P_2O_5 kg ha^{-1}, with respective height increases of 56.8%, 57.2%, 59.5% and 45.4% over the control at 90 days after sowing (DAS). The respective values observed with these treatments were 259.6, 260.3, 264.1 and 270.0 cm (Table 1). In terraced Acrisols of high altitude site, significantly ($P<0.05$) taller plants of 229.2, 221.3, 214.7, 209.9 and 206.9 cm were attained in plots having the treatment combinations of 120:120, 180:120, 180:80, 180:40 and 120:80 N: P_2O_5 kg ha^{-1}, with height increases of 69.8%, 63.9%, 59.0%, 55.5% and 53.3% over the control, respectively, at 90 DAS (Table 2). Significantly ($P<0.05$) larger stem collar diameter of 3.1, 3.2 and 3.3 cm were observed with combinations of 120:80, 180:80 and 180:120 N: P_2O_5 kg ha^{-1}, with diameter increases of 63.2%, 68.4% and 73.7% over the control, respectively, in terraced Lixisols at 90 DAS (Table 1). Larger collar diameter of 3.0 cm was obtained with combination of 120:120 N: P_2O_5 kg ha^{-1}, with increase of 42.9% over the control, in terraced Acrisols at 90 DAS (Table 2). Interaction effect between nitrogen and phosphorus on number of leaves $plant^{-1}$ was non-significant in both study areas (Tables 1 and 2). However, main effects of N and P rates on number of leaves were significant ($P < 0.05$), where numbers were higher than the control but with non-significant differences observed among rates applied. The growth increases with fertilizer use is attributed to nitrogen and phosphorus assimilation by maize. Nitrogen increases plant photosynthetic capacity, rapidly converts the synthesized carbohydrates to proteins and protoplasm and this extra protein allows the plant to grow faster (Om *et al.,* 2014). Phosphorus improves

Table 1: Interaction effect between N and P fertilizers on plant growth, phenology and yields of maize in terraced Lixisols of medium altitude site, combined analysis of two cropping season's data B 2017 and A 2018.

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	Plant height 90 DAS (cm)	Stem collar diameter 90 DAS (cm)	Number of leaves plant^{-1} 90 DAS	Days to 50% tasselling	Number of cobs plant^{-1}	Grain yield (t ha^{-1})	100 grain weight (g)	Biomass yield above-ground (t ha^{-1})	Harvest index (%)
0	0	165.6 ± 15.4^{e}	1.9 ± 0.2^{g}	11.8 ± 0.5	65.0 ± 0.0^{a}	1.0 ± 0.0^{b}	2.2 ± 0.1^{e}	25.3 ± 0.6	7.3 ± 0.9^{d}	31.4 ± 2.9
	40	189.8 ± 15.8^{de}	2.3 ± 0.1^{efg}	12.4 ± 0.6	64.2 ± 0.3^{abc}	1.1 ± 0.1^{ab}	2.8 ± 0.2^{de}	27.0 ± 1.0	8.8 ± 0.3^{cd}	31.9 ± 1.7
	80	220.4 ± 18.9^{cd}	2.5 ± 0.2^{bcdef}	12.8 ± 0.5	63.3 ± 0.3^{cd}	1.1 ± 0.1^{ab}	3.0 ± 0.2^{d}	27.6 ± 0.6	9.7 ± 0.7^{c}	31.5 ± 2.6
	120	213.4 ± 17.9^{d}	2.4 ± 0.2^{defg}	12.3 ± 0.6	63.7 ± 0.2^{bcd}	1.2 ± 0.1^{ab}	3.3 ± 0.3^{d}	28.5 ± 0.7	9.7 ± 0.9^{c}	34.0 ± 3.0
60	0	166.3 ± 16.3^{e}	2.1 ± 0.2^{fg}	12.4 ± 0.7	64.3 ± 0.2^{abc}	1.0 ± 0.0^{b}	3.2 ± 0.3^{d}	26.8 ± 0.9	10.0 ± 0.7^{c}	31.6 ± 1.5
	40	215.2 ± 5.4^{d}	2.8 ± 0.2^{abcde}	13.1 ± 0.4	64.7 ± 0.2^{ab}	1.1 ± 0.0^{ab}	4.3 ± 0.3^{c}	28.8 ± 0.7	13.2 ± 0.7^{b}	32.9 ± 1.1
	80	252.6 ± 11.1^{abc}	2.9 ± 0.2^{abcd}	13.4 ± 0.5	63.7 ± 0.2^{bcd}	1.1 ± 0.0^{ab}	4.6 ± 0.2^{c}	30.8 ± 0.9	13.1 ± 1.0^{b}	35.8 ± 1.2
	120	257.7 ± 11.1^{ab}	3.0 ± 0.2^{ab}	13.4 ± 0.4	62.5 ± 0.6^{de}	1.2 ± 0.1^{ab}	4.3 ± 0.4c	30.3 ± 1.4	13.9 ± 0.9^{b}	31.1 ± 2.0
120	0	194.1 ± 4.7^{de}	2.0 ± 0.2^{fg}	12.7 ± 0.6	64.0 ± 0.5^{abc}	1.1 ± 0.0^{b}	4.1 ± 0.2^{c}	29.7 ± 0.5	13.5 ± 0.7^{b}	30.6 ± 1.4
	40	225.5 ± 5.6^{bcd}	2.8 ± 0.1^{abcde}	13.3 ± 0.3	62.67 ± 0.6^{de}	1.2 ± 0.1^{ab}	5.8 ± 0.1^{ab}	30.2 ± 0.9	18.1 ± 0.5^{a}	31.9 ± 1.1
	80	264.1 ± 9.1^{a}	3.1 ± 0.2^{a}	13.4 ± 0.6	64.0 ± 0.5^{abc}	1.3 ± 0.1^{a}	6.5 ± 0.2^{a}	32.5 ± 0.7	19.4 ± 0.2^{a}	33.4 ± 1.0
	120	270.0 ± 8.1^{a}	3.0 ± 0.1^{ab}	13.4 ± 0.4	62.0 ± 0.5^{e}	1.3 ± 0.1^{a}	6.4 ± 0.2^{a}	32.8 ± 0.5	19.7 ± 0.3^{a}	32.5 ± 0.9
180	0	192.8 ± 1.8^{de}	2.2 ± 0.2^{fg}	12.7 ± 0.4	63.3 ± 0.4^{cd}	1.2 ± 0.1^{ab}	4.1 ± 0.2^{c}	30.6 ± 1.1	12.9 ± 0.7^{b}	31.8 ± 1.3
	40	222.0 ± 4.2^{cd}	2.8 ± 0.2^{abcde}	13.3 ± 0.3	63.7 ± 0.3^{bcd}	1.2 ± 0.1^{ab}	5.5 ± 0.3^{b}	31.5 ± 0.3	17.7 ± 0.7^{a}	31.4 ± 1.8
	80	260.3 ± 6.0^{a}	3.2 ± 0.1^{a}	13.4 ± 0.3	63.3 ± 0.5^{cd}	1.3 ± 0.1^{a}	6.5 ± 0.2^{a}	33.0 ± 1.0	19.7 ± 0.4^{a}	32.7 ± 0.7
	120	259.6 ± 8.1^{a}	3.3 ± 0.1^{a}	13.4 ± 0.3	63.17 ± 0.4^{bce}	1.3 ± 0.1^{a}	6.4 ± 0.2^{a}	32.5 ± 1.0	19.7 ± 0.5^{a}	32.5 ± 1.1
Mean		**223.1**	**2.6**	**13.0**	**63.6**	**1.2**	**4.6**	**29.9**	**14.2**	**32.3**
n		**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**
CV (%)		**5.1**	**7.8**	**4.2**	**1.7**	**13.0**	**12.1**	**5.8**	**11.5**	**11.3**

B 2017 - March to August 2017; A 2018 - September 2017 to February 2018; N - Nitrogen; n - Number of observations; CV - Coefficient of variation; ± values after the means represent the means standard error; Different letters in the same column indicate significantly different values at $P < 0.05$.

Table 2: Interaction effect between N and P fertilizers on plant growth, phenology and yields of maize in terraced Acrisols of high altitude area, combined analysis of two cropping season's data of B 2017 and A 2018.

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	Plant height 90 DAS (cm)	Stem collar diameter 90 DAS (cm)	Number of leaves plant^{-1} 90 DAS	Days to 50% tasselling	Number of cobs plant^{-1}	Grain yield (t ha^{-1})	Biomass yield above-ground (t ha^{-1})	Harvest index (%)	100 grain weight (g)
0	0	135.0 ± 5.8^{e}	2.1 ± 0.2^{cde}	12.0 ± 0.9	76.8 ± 0.5	1.0 ± 0.0	2.1 ± 0.1^{g}	6.5 ± 0.4^{h}	32.2 ± 2.0	26.8 ± 1.7
	40	139.1 ± 7.6^{e}	2.0 ± 0.1^{e}	12.6 ± 0.6	76.7 ± 0.4	1.1 ± 0.1	3.0 ± 0.3^{efg}	8.4 ± 0.9^{fgh}	36.3 ± 2.3	25.2 ± 0.8
	80	150.6 ± 6.0^{de}	2.2 ± 0.1^{cde}	12.7 ± 0.4	76.0 ± 0.5	1.1 ± 0.1	3.0 ± 0.3^{efg}	8.6 ± 0.9^{fgh}	35.3 ± 1.8	27.4 ± 1.4
	120	148.9 ± 3.5^{de}	2.2 ± 0.1^{cde}	12.8 ± 0.5	75.0 ± 0.5	1.1 ± 0.1	3.9 ± 0.4^{cde}	10.5 ± 1.0^{def}	37.2 ± 1.4	28.3 ± 0.9
60	0	150.7 ± 6.7^{de}	2.1 ± 0.1^{cde}	12.1 ± 0.6	78.0 ± 1.3	1.0 ± 0.0	2.5 ± 0.2^{fg}	7.2 ± 0.5^{gh}	34.3 ± 1.8	25.7 ± 0.6
	40	165.2 ± 5.3^{bcd}	2.2 ± 0.2^{cde}	13.2 ± 0.4	77.3 ± 1.0	1.2 ± 0.1	3.7 ± 0.2^{cde}	9.8 ± 0.4^{ef}	37.8 ± 1.4	25.4 ± 0.6
	80	178.7 ± 8.7^{bc}	2.3 ± 0.1^{bcde}	13.5 ± 0.4	75.7 ± 0.3	1.1 ± 0.1	3.7 ± 0.4^{cde}	10.6 ± 0.8^{def}	34.1 ± 1.9	28.2 ± 1.9
	120	184.9 ± 5.4^{b}	2.5 ± 0.1^{bcd}	13.5 ± 0.5	73.7 ± 0.9	1.2 ± 0.1	4.1 ± 0.2^{cd}	11.8 ± 0.8^{cde}	35.5 ± 1.8	26.5 ± 0.7
120	0	157.8 ± 9.7^{cde}	2.0 ± 0.2^{de}	12.1 ± 0.7	74.5 ± 0.8	1.0 ± 0.0	3.1 ± 0.2^{def}	8.7 ± 0.6^{fgh}	36.0 ± 1.4	26.2 ± 1.2
	40	184.9 ± 10.4^{b}	2.5 ± 0.2^{bcd}	13.4 ± 0.5	75.5 ± 1.2	1.2 ± 0.1	4.6 ± 0.4^{bc}	13.1 ± 0.8^{bc}	35.1 ± 1.7	26.3 ± 1.0
	80	206.9 ± 7.4^{a}	2.7 ± 0.1^{ab}	13.4 ± 0.5	72.8 ± 0.9	1.4 ± 0.1	5.3 ± 0.3^{ab}	13.9 ± 0.8^{abc}	37.8 ± 0.4	27.9 ± 1.0
	120	229.2 ± 8.3^{a}	3.0 ± 0.2^{a}	13.7 ± 0.5	74.0 ± 1.0	1.4 ± 0.1	6.1 ± 0.3^{a}	16.0 ± 0.8^{a}	38.2 ± 1.0	30.0 ± 1.1
180	0	166.6 ± 9.4^{bcd}	1.9 ± 0.2^{e}	11.9 ± 0.5	73.8 ± 1.1	1.1 ± 0.1	3.2 ± 0.4^{def}	9.1 ± 0.7^{fg}	34.6 ± 1.7	26.4 ± 1.8
	40	209.9 ± 6.4^{a}	2.5 ± 0.2^{bcd}	13.3 ± 0.4	73.3 ± 0.8	1.2 ± 0.1	4.6 ± 0.5^{bc}	12.8 ± 1.3^{bcd}	36.2 ± 1.3	27.7 ± 1.3
	80	214.7 ± 5.6^{a}	2.6 ± 0.1^{abc}	13.3 ± 0.6	74.5 ± 1.3	1.4 ± 0.1	6.0 ± 0.3^{a}	15.8 ± 0.7^{a}	38.2 ± 1.2	30.6 ± 0.9
	120	221.3 ± 5.8^{a}	2.8 ± 0.2^{ab}	13.9 ± 0.4	73.5 ± 0.9	1.4 ± 0.1	5.3 ± 0.4^{ab}	14.3 ± 0.9^{ab}	37.0 ± 1.3	30.5 ± 1.5
Mean	**177.8**	**177.8**	**2.3**	**75.1**	**75.1**	**1.2**	**4.0**	**11.1**	**36.0**	
n	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	**96.0**	
CV (%)	**9.4**	**9.4**	**12.4**	**3.1**	**3.1**	**11.5**	**17.5**	**14.6**	**9.8**	

B 2017 - March to August 2017; A 2018 - September 2017 to February 2018; N - Nitrogen; n - Number of observations; CV - Coefficient of variation; ± values after the means represent the means standard error; Different letters in the same column indicate significantly different values at $P < 0.05$.

photosynthesis, utilization of sugar and starch, nucleus formation and cell division (Masood *et al.,* 2011) and protein synthesis (Reddy *et al.,* 2018). Getnet and Dugasa, 2019; Reddy *et al.*, 2018; Sapkota *et al.*, 2017 and Khan *et al.*, 2014 reported similar findings.

Days to 50 percent tasselling

The phenology of maize was influenced by N and P supply. Plants took fewer days to 50% tasselling (62.0) in plots having the combinations of 120:120 N: P_2O_5 kg ha^{-1}, which was lower than control by 3 days, in medium altitude (Table 1). In high altitude, interaction effect between nitrogen and phosphorus on number of days to 50 percent tasselling was non-significant, while their main effects were significant ($P < 0.05$). For nitrogen, plants with less number of days to 50 percent tasselling; 74.2 and 73.8 days, were observed in plots having 120 and 180 kg N ha^{-1}, respectively. The rates of 120 and 180 kg N ha^{-1} decreased the number of days to 50 percent tasselling by 2 and 4 days over the control, respectively. For phosphorus, plants with less number of days to 50 percent tasselling; 74.0 days, were observed in plots with 120 kg P_2O_5 ha^{-1} which was lower than control by 2 days. These observations might be attributed to the adequate nitrogen levels which contributed to higher leaf area index (LAI) and dry matter accumulation resulting in increased health and energy levels in plants. This subsequently enhanced tasselling and decreased number of days to 50% tasselling. The results are in line with findings of Jassal *et al.* (2017) and Kaur (2016).

Yield and yield components

The maize yield traits were improved by the application of N and P fertilizers. In terraced Lixisols of medium altitude, significantly ($P < 0.05$) higher number of cobs $plant^{-1}$ (1.3) was obtained in plots having combinations of 120:120, 180:120, 180:80 and 120:80 N: P_2O_5 kg ha^{-1}. These rates equally increased the number of cobs by 23.1% over the control (Table 1). Higher grain yield of 6.4, 6.4, 6.5 and 6.5 t ha^{-1} were attained in plots applied with combinations of 120:120, 180:120, 180:80 and 120:80 N: P_2O_5 kg ha^{-1}, respectively. They increased grain yield by 2.9 - 3.0 times over the control (Table 1). Higher above-ground biomass yields of 17.6, 18.1, 19.4, 19.7, 19.7 and 19.7 t ha^{-1} were given by combinations of 180:40, 120:40, 120:80, 120:120, 180:80 and 180:120 N: P_2O_5 kg ha^{-1}, respectively. These increased above-ground biomass yields by 2.4 - 2.7 times over the control, with non-significant differences in harvest index (Table 1). In regards to hundred grain weight, there was no significant interaction effect of N and P rates, but their main effects were significant ($P < 0.05$). Significantly ($P < 0.05$) higher hundred grain weights were obtained with application of 120 and 180 kg N ha^{-1}, which increased hundred grain weights by 15.5% and 18.2% over the control, respectively and 80 and 120 kg P_2O_5 ha^{-1} with equal weight increase of 10.3% over the control. In terraced Acrisols of high altitude, higher grain yields of 6.1 and 6.0 t ha^{-1} were given by combinations of 120:120 and 180:80 N: P_2O_5 kg ha^{-1}, respectively, with equal grain yield increase of 2.9 times over the control (Table 2). Higher above-ground biomass yield of 16.0 and 15.8 t ha^{-1} were given by the combinations of 120:120 and 180:80 N: P_2O_5 kg ha^{-1}, respectively. The rates increased biomass yield by 2.5 and 2.4 times over the control, with non-significant differences in harvest index (Table 2). Interaction effect between nitrogen and phosphorus on number of cobs $plant^{-1}$ and hundred grain weight was non-significant, but their main effects were significant ($P < 0.05$). For nitrogen, higher number of cobs $plant^{-1}$ (1.2) was given by 120 and 180 kg N ha^{-1} with increase of 9.1% over the control and higher hundred grain weight (28.8 g) was given by 180 kg N ha^{-1} with weight increase of 9.5% over the control. For phosphorus, higher number of 1.3 cobs $plant^{-1}$ was attained with 120 kg P_2O_5 ha^{-1} and higher hundred grain weights (28.5; 28.8 g) were obtained with 80 and 120 kg P_2O_5 ha^{-1}, with respective increases of 11.3% and 14.5% over the control. The increases in grain yields,

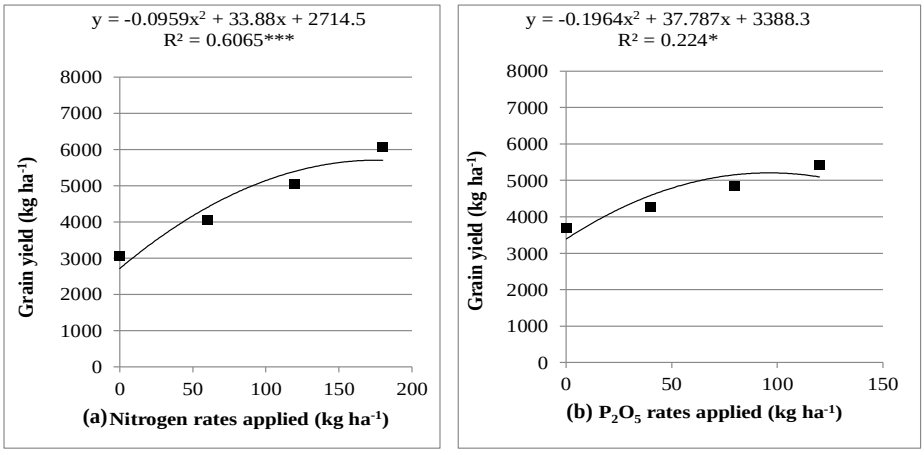

Fig 1: Effect of increasing applied rates of (a) nitrogen and (b) phosphorus fertilizers on grain yield in terraced Lixisols of medium altitude.
* Coefficient of determination (R^2) significant at P= 0.05; *** R^2 significant at P = 0.001.

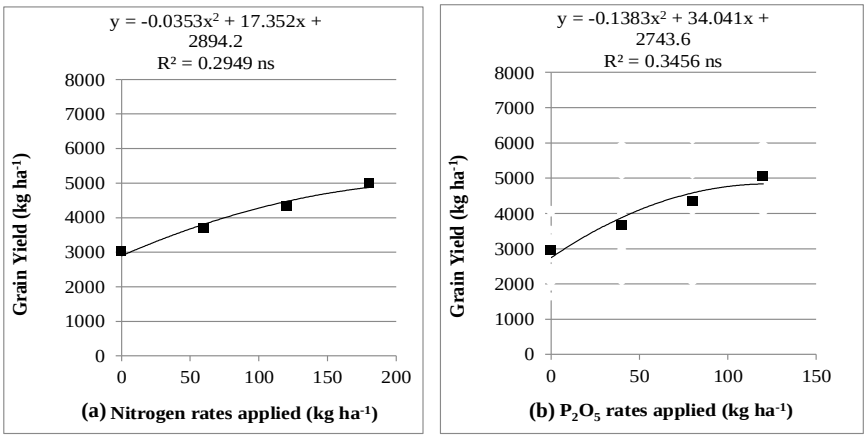

Fig 2: Effect of increasing applied rates of (a) nitrogen and (b) phosphorus fertilizers on grain yield in terraced Acrisols of high altitude ns - Coefficient of determination (R^2) not significant.

above-ground biomass and other yield components can be attributed to the adequate and balanced N and P levels, which are important macronutrients for maize. The results are similar to the findings of Getnet and Dugasa (2019) who reported highest grain yield with combination of N (120 kg ha^{-1}) and P (60 kg ha^{-1}); Reddy *et al.* (2018) who reported that grain yield is directly related to complex phenomenon of phosphorus utilization in plant metabolism; Khan *et al.* (2014) who reported maximum grain yield with combination of 150 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} and Om *et al.* (2014) who reported an increase of stover yield resulting from increase of N supply.

A quadratic polynomial regression analysis was performed between experimental factors (N, P fertilizer rates) and grain yield. By projecting grain yield as a function of increasing rates of N and P fertilizers, the best/optimum rates were estimated by the zero-solutions of the derivatives of the projection equations (Fig 1 and 2). In terraced Lixisols of medium altitude site, the zero-solutions of the equations were located at the rates of 176.6 kg N ha^{-1} and 96.2 kg P_2O_5 ha^{-1}. In terraced Acrisols of high altitude site, the coefficient of determination (R^2) was not significant at P = 0.05 for both N and P_2O_5 (Fig 2). Therefore, optimum fertilizer rates were not estimated. This indicated that the applied rates of nitrogen and phosphorus were low and did not reach the optimum.

CONCLUSION

The objective of this study was to determine N and P requirements for enhanced growth and yields of maize in terraced Lixisols of medium and Acrisols of high altitudes. Results show that the rates of 120-180 kg N ha^{-1} and 80-120 kg P_2O_5 ha^{-1} gave higher plant height, collar diameter, number of cobs $plant^{-1}$, hundred grain weight, above-ground biomass and grain yields. The optimum rates are 176.6 kg N ha^{-1} and 96.2 kg P_2O_5 ha^{-1} in terraced Lixisols of medium altitude area. Therefore, land use needs to adjust fertilizer application to these optimum rates for enhanced maize yields in this area and other regions having similar agro-ecological characteristics. The applied rates of nitrogen and phosphorus were low in terraced Acrisols of high altitude. Further studies on integrated effects of N and P fertilizers on maize performance are recommended.

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