

*Full Length Research Paper*

# **Effects of lime, NPK fertilizer and intercropping on selected properties of an acid mollic andosol in potato (*solanum tuberosum*) production systems**

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This study investigated the effects of intercropping, liming, and NPK fertilizer application on soil pH, available soil phosphorus (P), and total soil nitrogen (N) in potato production system during a two season's field experiment in Molo sub-county, Kenya. A randomized complete block design with a split-split plot arrangement of treatments and three replicates was used. Main plot factors were NPK fertilizer levels (0 and 0.2 t ha<sup>-1</sup>). Lime rates (0 and 2 t ha<sup>-1</sup>) formed the sub-plots and cropping system (sole potato and Potato-Dolichos intercrop) the sub-sub plots. Application of lime increased the soil pH by 0.34 over the control. Sole NPK fertilizer application reduced the soil pH by 2% when compared to the control. Combined application of NPK fertilizer with lime increased soil available P by 6.5, 8 and 6 mg kg<sup>-1</sup>, and 20.41, 3.91 and 3.58 mg kg<sup>-1</sup> in the first and second season over the control, sole lime and sole fertilizer application, respectively. Application of NPK fertilizer under the Potato-Dolichos intercrop increased the total soil N by 0.08% over the control. The study concluded that intercropping, application of lime and NPK fertilizer to mollic Andosols of Molo Kenya is important in increasing soil pH, available P and total N.

**Key words:** Available P, dolichos, lime, NPK fertilizer, pH, total N.

## **INTRODUCTION**

Acid soils occupy 13% of Kenya's total land area. The soils in Molo, a major potato producing area, are acidic, with a pH of less than 5.2, and have low fertility (Gitari et al., 2015; Lelei and Onwonga, 2013; Komen et al., 2017). The main causes of acidity are leaching of basic cations by rainfall and acidic parent material. At pH below 5.5, the hydrolysis of Al-hydroxides on the clay mineral surface release the Al<sup>3+</sup> into soil solution which reacts with water molecules to form aluminium hydroxide and

hydrogen ions (McBride, 1994). Acid soils affect soil fertility through nutrient deficiencies, mainly through phosphorus (P) fixation, and presence of phytotoxic elements (Al<sup>3+</sup>, Fe<sup>2+</sup> and Mn<sup>2+</sup>) (Osundwa et al., 2013; Muindi et al., 2016; Nduwumuremyi, 2013). Under acidic conditions, phosphorus reacts with Fe<sup>2+</sup> and Al<sup>3+</sup> in soil solution to form insoluble phosphates making it unavailable for plant uptake (Opala, 2017). Low soil pH also affects soil microorganisms which results in reduced

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soil microbial activities. Acidic soil conditions affect the growth of nitrifiers (Mkhonza et al., 2020) and this slows the nitrification process hence low N levels in the soil available for plant growth. Reduction in microbial activities also results in a reduction in organic matter breakdown reducing release and uptake of plant nutrients. Low soil P levels and high  $Al^{3+}$  in the soil affects the growth of the symbiotic nitrogen fixing bacteria resulting in low nitrogen fixation (Bakari et al., 2020). Application of organic manure to farm lands to increase fertility levels of the soil is limited since crop residues are used as animal feeds while animal manure is used in small quantities and it is of low quality (Muindi et al., 2016). Fertilizer application is an effective means to increase plant nutrient uptake and improve yields (Girma et al., 2017). Small holder farmers in Molo practice continuous cultivation on their farms and they mostly use DAP or urea fertilizers to correct nutrient deficiencies and increase production. However, these farmers apply these fertilizers below the recommended rates due to their high costs (Gitari et al., 2015; Muthoni, 2016; Onwonga et al., 2014). Continuous cultivation with inadequate replenishment of mined nutrients results in soil infertility (Bidai et al., 2020).

The continuous use of the acid forming fertilizers (DAP and urea) in the small holder farms without liming contribute to increased soil acidity (Opala et al., 2013; Muthoni, 2016). Liming acid soils is a long-term management practice that has been widely embraced as an acid amelioration strategy. Lime increases pH, reduces  $Al^{3+}$  and  $Mn^{+}$  toxicity, and increases P availability (Meriño-Gergichevich et al., 2010; Kisinyo et al., 2014; Nduwumuremyi, 2013). Lime also supplies basic cations (Ca and Mg), improves Molybdenum (Mo) availability and ensures optimal microbial activity (Bambara and Ndakidemi, 2010; Nekesa et al., 2011). Liming is rarely practiced in small holder farms in Molo due to lack of awareness on its benefits (Bakari et al., 2020). The traditional cultural practice of expanding farmlands to increase food production is no longer sustainable due to continued population increase and urbanization (Lambin et al., 2013). This has reduced the size of agricultural land even further. Due to small sizes of farm lands, intercropping can be used as a strategy to increase returns and guard against food insecurity in case of crop failure (Gitari et al., 2019). Intercropping potato with legumes enhances better nutrient utilization and thus improves productivity of the cropping system. Dolichos (*Lablab purpureus*) has a deep rooting system which enables it to acquire nutrients outside the rhizosphere of the potato crop thereby minimizing losses through leaching and fixation (Gitari et al., 2018). Dolichos also produces exudates which are important in availing nutrients in the rhizosphere of the main crop (Hinsinger et al., 2011). Identifying efficient and sustainable practices that reduce soil acidity enhance soil N and P fertility and increase potato production are of importance to small

holder farmers of Molo. The objective of this study was to determine the effects of lime, NPK fertilizer and intercropping on soil pH, available soil P and total soil N in potato systems.

## MATERIALS AND METHODS

### Experimental site

The experiment was conducted in Molo sub-County, Kenya, located at latitude  $0^{\circ} 12' S$ , longitude  $35^{\circ} 41' E$ , and altitude 2200 m asl, for two cropping seasons (2020 short rains and 2021 long rains). The area receives a mean annual rainfall of 1200 mm and mean temperature of  $13.75^{\circ}C$ . The main crops grown are pyrethrum (*Chrysanthemum cinerariifolium*), potatoes (*Solanum tuberosum*), barley (*Hordeum vulgare*) and maize (*Zea mays*). The soils are acidic, with pH of less than 5.2, well drained, deep, dark reddish brown with a mollic A horizon and are classified as mollic Andosols (Jaetzold et al., 2010).

### Determination of initial soil physicochemical properties

Soil was randomly sampled, using a soil auger, from six locations in the field in a zig zag pattern before land preparation, for characterization of initial physicochemical properties. The samples were collected from three soil depths (0-15, 15-30 and 30-45 cm) and thoroughly mixed to obtain one composite sample for each depth. The samples were put in well labelled khaki bags, sealed to avoid spilling and transported to the laboratory. The soils were air dried in shallow trays in well ventilated preparation room for one week. After drying, the soils were crushed to break large soil clods and then sieved using 2 mm sieve. Samples for analysis of total N were sieved through a 0.5 mm. The sieved samples were then taken to the main laboratory for analyses. Soil texture was determined by hydrometer method and bulk density by core ring method as described by Okalebo et al. (2002). Soil pH was measured (soil : distilled water ratio of 1:2.5) using a pH meter (Make: Jenway, UK; model: 3510 pH meter), available soil P was determined by Mehlich Double Acid Method (Mangale et al., 2016), soil CEC and exchangeable bases by the ammonium acetate method and soil organic carbon by the *Walkley-Black* procedure both as described by (Reeuwijk, 2002). Total soil N was determined by Kjeldahl method as described by Okalebo et al. (2002). The initial soil properties are presented in Table 1.

### Experimental design and treatments

Land, previously with canola (*Brassica napus*), was ploughed manually using hand hoes and crop residues present were removed by raking before application of treatments. The experiment was laid out as a split-split plot in a randomized complete block design (RCBD). Compound Fertilizer (NPK 17:17:17) at two levels (0 and  $0.2 t ha^{-1}$ ) formed the main plots, granulated lime at two rates (0 and  $2 t ha^{-1}$ ) the sub-plots and cropping system (sole potato and potato/dolichos intercrop) the sub-sub plots. The treatments were replicated 3 times. Granulated lime was applied 3 weeks before planting and incorporated at 30 cm depth. This was done only once, before the beginning of the first season. Potato sole crop was planted at a spacing of 75 cm x 30 cm. The dolichos intercrop was sown between the potato rows, at an intra-row spacing of 0.25 m. The sub sub-plots measured 5 x 4.5 m. The compound fertilizer, NPK (17:17:17) was applied at a rate of  $0.2 t ha^{-1}$  at planting to supply an equivalent of 34 kg N  $ha^{-1}$ , 34 kg P  $ha^{-1}$ , and 34 kg K  $ha^{-1}$  at the beginning of each season. Topdressing was carried out 28

**Table 1.** Initial soil chemical and physical properties.

Variable	Soil depth (cm)		
	0 - 15	15 - 30	30 - 45
Parameters	value	value	value
Soil texture	SCL	SCL	SCL
Sand	56	56	56
Silt	16	14	12
Clay	28	30	32
Soil pH (H <sub>2</sub> O)	4.37	4.50	5.25
Exch. Acidity cmol kg <sup>-1</sup>	0.2	0.5	0.4
Potassium cmol kg <sup>-1</sup>	1.4	1.4	1.3
Calcium cmol kg <sup>-1</sup>	10.2	12.4	12.6
Magnesium cmol kg <sup>-1</sup>	1.6	1.9	2.0
Sodium cmol kg <sup>-1</sup>	0.2	0.1	0.02
Total Nitrogen %	0.20	0.17	0.15
Total Organic Carbon %	2.17	1.92	1.74
Available phosphorus (mg kg <sup>-1</sup> )	23	19	19
CEC (cmol kg <sup>-1</sup> )	32.4	32.6	28.3
Bulk density (g cm <sup>-3</sup> )	1.06	1.15	1.24

SCL denotes sand clay loam.

Source: Authors

**Table 2.** Treatment application, sowing and harvesting dates in Molo, Kenya.

Variable	Season 1	Season 2
Lime application	11/9/2020	-
NPK application	5/10/2020	11/03/2021
Potato/dolichos planting	5/10/2020	11/03/2021
Potato harvesting	26/01/2021	23/07/2021

Source: Authors

days after emergence (DAE) using Calcium Ammonium Nitrate (CAN 27%) at the rate of 0.2 t ha<sup>-1</sup> in order to supply an equivalent of 54 kg N ha<sup>-1</sup>. Weeding and earthing up was done manually 28 DAE to remove weeds and loosen up soil to allow tuber expansion and development. Fungal infections and insect pests were managed using appropriate fungicides and insecticides. Drenching was done immediately after planting and after germination to control cutworms. Pesticide was applied once every week to control bean aphids (*Aphis fabae*). After harvesting potatoes, there was continued pest management for the dolichos crop until harvest. Table 2 shows the treatment application, potato and dolichos sowing and potato harvesting dates for the two seasons in Molo, Kenya.

### Seeds

Potato variety *Shangi* used in the study is a semi-erect medium tall variety with moderately strong stems and light green broad leaves. It does well in altitudes of ≥1500 m.a.s.l. and the tubers are oval with white flesh containing medium to deep eyes with pink pigmentation. It has a very short dormancy and matures within 3-4 months, is moderately susceptible to late blight and its yield ranges between 30 – 40 tonnes ha<sup>-1</sup> (N.P.C.K, 2019). Certified seeds (pre-

sprouted tubers) size two were sourced from Agricultural Development Corporation (ADC) Molo. The potato seed rate used was 2 t ha<sup>-1</sup>. Dolichos (*Lablab purpureus*) used as an intercrop in the study, is a vigorously determinate herbaceous plant, resistant to disease and insect attack. Its leaves are large and trifoliate (Grotelüschen, 2014). Dolichos seeds were obtained from the local market and inspected for off types and damaged seeds. A germination test was conducted before planting. The seed rate used was 20 kg ha<sup>-1</sup>.

### Data collection

Soil samples were collected randomly from four locations in each experimental unit at 30 cm depth at the end of each cropping season (26/01/21 for first season and 23/07/21 for second season) from all the three replicates. The methods used for sample preparation and analyses are explained in section 1.2.2.

### Data analyses

Data were tested for normality using the Shapiro Wilk test at probability of ≤0.05 in SAS software using proc univariate plot.

**Table 3.** Main effects of lime and NPK fertilizer on soil pH in potato cropping system in Molo, Kenya.

Lime rates (t ha <sup>-1</sup> )	Soil pH
0	4.32 <sup>b</sup>
2	4.539 <sup>a</sup>
NPK fertilizer rates (t ha <sup>-1</sup> )	
0	4.46 <sup>a</sup>
0.2	4.38 <sup>b</sup>
Mean	4.42
CV	1.76
MSD	0.05

Means within a column followed by the same letter are not significantly different at P≤0.05.  
Source: Authors

$$W = \frac{(\sum_{i=1}^n a_i x_{(i)})^2}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

Data were then subjected to analysis of variance (ANOVA) using SAS software for windows 9.4 (SAS Institute, Cary, NC). Where the Fisher's protected F-test was significant, means of the main effects were separated using Tukey's honest significance test (P<0.05). Pearson correlation coefficient was carried out to test the significance of the relationship between soil pH and available soil P.

## RESULTS AND DISCUSSION

### Effects of lime and NPK fertilizer on soil pH

The main effects of NPK fertilizer and lime on pH were significant at P<0.05 (Table 3). Lime application resulted in an increase in soil pH by 5% when compared to the control (Table 3). Application of NPK fertilizer resulted in a significant (P<0.05) decrease in soil pH by 2% when compared to the control (Table 3).

Application of lime tends to raise the soil pH and reduce acidity by displacement of H<sup>+</sup>, Fe<sup>2+</sup>, Al<sup>3+</sup>, and Mn<sup>4+</sup> ions from soil adsorption site (Osundwa et al., 2013; Calba et al., 2006). Similarly, the anions CO<sub>3</sub><sup>2-</sup> and OH<sup>-</sup> present in lime neutralize the H<sup>+</sup> released from the exchange sites and hydrolyze Al in the soil solution (Fageria and Baligar, 2008). The observed liming effect on pH in the study concurs with the findings of other workers (Herrera and Pérez, 2020; Dinkecha and Leku (2017); Omollo et al., 2016; Otieno et al., 2018)

The NPK (17:17:17) fertilizer contains 5% N in ammoniacal form and 12% N in Urea form. Inorganic ammonium based fertilizers are not acidic but their application to soil result in increased acidification through the oxidation of NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> during the process of nitrification which generates H<sup>+</sup> resulting in low soil pH

(Schroder et al., 2011). Additionally, plants release excess H<sup>+</sup> when cation uptake exceeds anion uptake (Tang et al., 2011). The decrease in pH with NPK application was also observed by Ogundijo et al. (2015) and Beukes et al. (2012).

### Effects of lime and NPK fertilizer on available soil P

The interaction effects of lime, fertilizer, and season were significant at P<0.05 for available soil P (Table 4). Application of fertilizer and lime resulted in a significant increase in available soil P content (31.08 mg kg<sup>-1</sup>) at the end of the second season, compared to other treatments. The combined application of NPK fertilizer and lime resulted in an increase in soil available P by 20.41, 3.91 and 3.58 mg kg<sup>-1</sup> in the second season over the control, sole lime and sole fertilizer application, respectively (Table 4).

The release of P from NPK caused the increase in available soil P. Increase in soil available P due to liming is attributed to the decrease in soil acidity. Lime increased the soil pH leading to reduction in P sorption. Therefore, both the inherent phosphorous and fertilizer supplied phosphorus increased available soil P (Kisinyo et al., 2013). At low soil pH values, phosphorus is fixed by aluminium and iron oxides and hydroxides (Ameyu, 2019). Liming of acidic soils to increase the pH results in the release of phosphate ions fixed by Al and Fe ions into the soil solution (Kisinyo, 2016). Additionally, liming stimulates mineralization of soil organic P. Increasing the pH of acidic soils provides favourable environment for microorganisms which are important in the mineralization of soil organic phosphorus (Ameyu, 2019). In a four-year study carried out on immediate and residual effects of lime and P fertilizer on soil acidity and maize productivity by Kisinyo et al. (2014), sole application of 4t ha<sup>-1</sup> lime

**Table 4.** Season, Fertilizer and lime interaction effects on soil available P in potato cropping system in Molo, Kenya.

Seasons	Fertilizer levels (t ha <sup>-1</sup> )	Lime levels (t ha <sup>-1</sup> )	Available P (mg kg <sup>-1</sup> )
1	0	0	9.67±0.82 <sup>de</sup>
		2	9.17±0.75 <sup>e</sup>
	0.2	0	11.17±0.98 <sup>d</sup>
		2	17.17±1.34 <sup>c</sup>
2	0	0	10.33±1.03 <sup>de</sup>
		2	27.17±1.34 <sup>b</sup>
	0.2	0	27.50±1.82 <sup>b</sup>
		2	31.08±2.84 <sup>a</sup>
Mean	-	-	19.95
CV	-	-	4.35

Means within a column followed by the same letter are not significantly different at P≤0.05.

Source: Authors

**Table 5.** Effects of NPK fertilizer on total soil N under Potato cropping systems for two seasons (mean ± SD).

Season	Fertilizer level (t ha <sup>-1</sup> )	Cropping system	Total soil N (%)
1	0	P	0.20±0.02 <sup>b</sup>
		PD	0.23±0.03 <sup>b</sup>
	0.2	P	0.27±0.03 <sup>a</sup>
		PD	0.26±0.03 <sup>a</sup>
2	0	P	0.21±0.02 <sup>b</sup>
		PD	0.22±0.03 <sup>b</sup>
	0.2	P	0.27±0.02 <sup>a</sup>
		PD	0.28±0.01 <sup>a</sup>
Mean	-	-	0.24
CV	-	-	5.78
R <sup>2</sup>	-	-	95.56

Means within a column followed by the same letter are not significantly different at P≤0.05.

Source: Authors

resulted in increase in available soil P. Kisinyo (2016) in a four year study on maize productivity in an acid soil, reported increased available soil P when 6 t ha<sup>-1</sup> lime was applied. Bidai et al. (2020) in his study on effects of soil amendments on selected soil properties reported an increase in available soil P above the control when 2 t ha<sup>-1</sup> lime was applied. Therefore, both lime and P fertilizer should be used for long term management of acid soils

deficient of P.

#### Effects of lime and NPK fertilizer on total soil N

The interaction of season, fertilizer and cropping system had a significant (P < 0.05) effect on total soil N (Table 5). Application of NPK fertilizer resulted in higher total soil N

in both the sole potato and potato/dolichos intercrop, in both cropping seasons, compared to where the fertilizer was not applied. Higher total soil N contents of 0.27 and 0.26% were observed during the first season and were not significantly ( $P < 0.05$ ) different from 0.27 and 0.28% observed in the second season under the potato sole crop and the potato/dolichos intercrop with fertilization, respectively (Table 5).

Dolichos has the ability to fix atmospheric N. Gitari (2018) and Sitienei et al. (2017) reported a significant increase in total soil N under potato legume intercrop. High total soil N was also partly due to fertilization. Nitrogen increases plant growth and organic N inputs in the form of plant residues. Ge et al. (2018) also reported increase in total N where NPK fertilizer was applied when compared to the control. High total soil N due to fertilization was also reported by Aula et al. (2016). Dolichos has a high canopy cover hence creates a cool microclimate that reduces the rate of N mineralisation (Gitari et al., 2018).

### Correlation between soil pH and available soil P

Soil pH and available soil P had a positive correlation ( $r = 0.4^{**}$ ). This implies that an increase in soil pH resulted in increase in soil available P. Kisinyo (2016) and Bidai et al. (2020) reported increases in soil available P as a result of liming. The slow change in soil pH (4.65), however, upon liming is attributed to the slow reactivity of lime to release  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . This explains the weak correlation between soil pH and available soil P. Kisinyo et al. (2014a) reported that the changes in soil pH upon application of lime are more evident during the second year after lime application. Kisinyo (2016) reported that lime took 425 days to increase soil pH to maximum peak of 7.0. The current study took place for only two seasons. The applied P in form of NPK fertilizer also could have been fixed by the  $\text{Al}^{3+}$  and  $\text{Fe}^{2+}$ .

### Conclusion

Lime application resulted in a slight increase in soil pH in two growing seasons. Sole application of NPK fertilizer resulted in an increase in soil acidity. The availability of P in soil was influenced by pH. The correlation showed an increase in soil available P with an increase in soil pH. Combined application of NPK fertilizer and lime in potato production systems resulted in an increase in soil available P, with greater evidence in the second growing season. Sole NPK fertilizer application resulted in an increase in total soil N across the two growing seasons and cropping systems. Lime application is recommended to raise soil pH to optimum for crop production at a suitable rate depending on the lime requirement of the specific soil and the crops to be grown. Combined

application of lime, inorganic fertilizers at suitable rates and integration of legumes is also recommended to improve available soil P and soil N in acidic soils. This study also recommends long term research on other soil amendments that can result in increased soil pH and avail soil nutrients in acidic mollic Andosols of Molo, Kenya.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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