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Low Cost Technologies for Enhancing N and P Availability and Maize (*Zea mays* L.) Performance on Acid Soils

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Abstract: Soil degradation especially soil acidity and low fertility are the major constraints hampering maize production in Molo district, Kenya. The challenge therefore is to develop sustainable soil management strategies for enhancing maize production and concomitantly food security. A three-year field experiment were conducted on smallholder farms (SHF) of Molo to test the effectiveness of applying low cost technologies (LCT): lime, farm yard manure (FYM), minjingu rock phosphate (MRP), biological nitrogen fixation (BNF) and cowpea (CP) residue and crotalaria (CR) green manure, in enhancing nutrient availability and maize performance on acid soils. The performance of maize in three cropping systems; (a) pure maize (M) in rotation with CP with or without application of LCT ($M_{(lime,\ MRP)}$ – CP, M-CP), (b) maize intercropped with CP in rotation with CR with application of LCT ($M/CP_{(lime,\ MRP)}$-CR and $M/CP_{(lime,\ MRP,\ FYM)}$-CR) and (c) maize in rotation with fallow (F) with or without application of diamonium phosphate fertilizer (DAP) (M_{DAP}-F, M-F) as control, was evaluated during the long rain seasons (LRS) of 2004, 2005 and 2006. CP and CR were planted in the short rains season (SRS) of 2004 and 2006. The soil pH was significantly increased two months after liming and had appreciably increased by the end of the trial period to levels conducive to maize growth in the $M/CP_{(lime,\ MRP)}$-CR and $M/CP_{(lime,\ MRP,\ FYM)}$-CR and $M_{(lime,\ MRP)}$ – CP cropping systems. The cropping systems $M/CP_{(lime,\ MRP)}$-CR and $M/CP_{(lime,\ MRP,\ FYM)}$-CR showed superior performance in N_2 fixation and soil available N and P due to the application of LCT. Crotalaria fixed significantly higher amounts of N_2 (127-158 kg ha^{-1}) than cowpea (37-56 ha^{-1} in both years. Similarly, soil available N and P increased progressively with the planting seasons, except for the control, with P showing minor fluctuations. Maize grain yields were correspondingly higher under the imposed LCT and was notably higher in the $M/CP_{(lime,\ MRP,\ FYM)}$-CR and $M/CP_{(lime,\ MRP)}$-CR cropping systems. The utilization of the short rain season fallow by planting CR and CP and incorporating its residue and green manure, respectively during land preparation for the following maize/cowpea intercrop alongside application of LCT is thus a feasible strategy to manage soil acidity and boost maize performance on the SHF of Molo District, Kenya.

Key words: Cropping system · Lime · Minjingu rock phosphate · Farm yard manure · Legumes · Smallholder farms

INTRODUCTION

Maize (*Zea mays L.*) is a major staple food that is, to a large extent synonymous with food security, practically grown by every smallholder farmer in Kenya [1]. Its production in the smallholder farms (SHF) of Molo district is constrained by soil degradation especially soil acidity and low fertility [2] thus threatening food security. The active pH ($H_2$0) of the soils in Molo is below 5 [3, 4] and thus unsuitable for maize growth. Maximum maize yields are obtained in the pH range of 5.6 to 7.5 [5; http://maizedoctor.cimmyt.org/index.php].

In acid mineral soils, a variety of individual chemical constraints and interactions between them limit plant growth [6]. For instance, P adsorption and inhibition of nitrification process are responsible for the the

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unavailability of soil N and P, the main nutrients critical for maize production [7] and hence low maize yields. The maize yields obtained on acid soils, also true for Molo, are low (1.0-1.5 t ha^{-1}) compared to research potential yields of 3-5 t ha^{-1} [4, 8].

The farmers in Molo district plant maize as a monocrop, with a few intercropping with cowpea, during the long rain season (LRS) and the farms are left fallow in the short rain season (SRS). The problem of acidity is further exacerbated by the continuous use of the soluble but acid forming diammonium phosphate (DAP) fertilizer albeit in small amounts (20-30 kg ha^{-1}) against the recommended rate of 60 kg ha^{-1} [9]. High fertilizer costs following the liberalization of the economy and the low financial return from crops are the causes of the suboptimal or non use of fertilizers in the smallholder farms [10, 11].

For higher maize yields and consequently increased food security and improved farmer welfare to be realized, more efficient and sustainable practices such as use of low-cost technologies (LCT) with synergistic components that can be adopted by the resource-poor farmers must be sought. The objective of the current study was to determine the effectiveness of LCT in enhancing soil N and P availability and maize performance on acid soils.

MATERIALS AND METHODS

Site Description: The experiments were carried out on farmer's fields in Molo district (0°12´S, 35°41´E, 2500 m asl), Kenya during the SRS and LRS of 2004, 2005 and 2006 (LRS). The rainfall distribution, in Molo is bimodal in nature with the long rains occurring from March to July/August and short rains from September/October to December with peaks in April and November. The annual rainfall received in 2004, 2005 and 2006 was 1148.3, 1218 and 1344.3 mm, respectively with a mean temperature of 17.3°C for the three years. These amounts were oscillating around the long term mean of 1200 and 15.9°C [3]. The soils are acidic, well drained, deep, dark reddish brown with a mollic A horizon and are classified as mollic Andosols [12] with less than 1.56% organic carbon and pH(H_2O) of 4.95 [2].

Treatments and Experimental Design: Treatments and Experimental design. The LCT: lime, farm yard manure (FYM), minjingu rock phosphate (MRP), cowpea (CP) residue and crotalaria (CR) green manure were applied to plots on which maize was grown under three cropping systems; (a) pure maize (M) in rotation with CP with or without application of LCT ($M_{(lime,\ MRP)}$-CP, M-CP), (b) maize intercropped with CP (M/CP) in rotation with CR with application of LCT (M/$CP_{(lime,\ MRP)}$-CR and M/$CP_{(lime,\ MRP,\ FYM)}$-CR) and (c) maize in rotation with fallow (NF) with or without application of diamonium phosphate fertilizer (DAP) (M_{DAP}-F, M-NF) as control (Table 1). CR green manure was removed and FYM (1.1-1.5 %N, 0.21-0.26% K and 0.9-1.1%K) added instead in the M/$CP_{(lime,\ MRP,\ FYM)}$-CR treatment. FYM is readily available but infrequently used and/or poorly managed, as a nutrient source [13]. This was done to compare direct application of CR green manure (GM) with its recycling as livestock feed and then applied as FYM. The treatments were laid out in a randomized complete block design, in plots measuring 3.75×4.8 m and replicated four times.

Table 1: Cropping systems and time of application of low cost technologies

	Year, cropping season and Inputs				
Cropping system/inputs	2004 LRS	2004, SRS	2005, LRS	2005, SRS	2006, LRS
A] Maize- Natural fallow					
1) M-F	Maize	Fallow (WI)	Maize	Fallow (WI)	Maize
2) $M_{(DAP)}$-F	Maize DAP	Fallow (WI)	Maize DAP	Fallow (WI)	Maize DAP
B] Maize-Cowpea					
1) M-CP	Maize	Cowpea (RI)	Maize	Cowpea (RI)	Maize
2) $M_{(lime+\ MRP)}$-CP	Maize lime + MRP	Cowpea (RI)	Maize	Cowpea (RI)	Maize
C] Maize /Cowpea – Crotalaria					
1) M/$CP_{(lime+MRP)}$-CR	Maize/CP (RI) +lime + MRP	Crotalaria (GMI)	Maize+Cowpea (RI)	Crotalaria (GMI)	Maize+Cowpea (RI)
2) M /$CP_{(lime+MRP+FYM)}$-CR	Maize/Cowpea(RI) +lime +MRP + FYM	Crotalaria (CC)	Maize/Cowpea (RI) +FYM	Crotalaria (CC)	Maize/Cowpea (RI) + FYM

Key: RI = Cowpea residue incorporated; WI = weed residue incorporated; CC = cut and carry fodder; GMI = green manure incorporated; FYM = farm yard manure; MRP = minjingu rock phosphate; LRS = long rain season; SRS = short rain season, - = Rotation, / = intercropping

Agronomic Practices: Land preparation and application of treatments. Land was ploughed manually using hand hoes followed by secondary, raking and levelling, cultivation. Lime (3 t ha^{-1}) and MRP (290 kg ha^{-1}) were broadcasted once during the experimental period. Lime was applied two months (February 9, 2004) prior to maize planting in the respective cropping system, to allow for sufficient time for reaction with soil. MRP was broadcasted a week to maize planting (April 3, 2004) while FYM (5 t ha^{-1}) was placed into planting holes and mixed well with soil, a week to planting of maize (April 3, 2004; March 30, 2005, April 10, 2006). DAP ha^{-1} (40 kg) was banded along the planting furrows in the control treatment at planting of maize and thoroughly mixed with soil before seed sowing.

Long Rain Seasons: Maize H614 was sown in all plots during the LRS of 2004, 2005 and 2006 (Table 1) at a spacing of 75×30 cm. Two seeds were sown into each planting hole and thinned to one plant 30 days after sowing (DAS). CP was sown as an intercrop between maize (one row of CP between two rows of maize) in the intercropping system. Three seeds were sown per hole and thinned to two 30 DAS.

Short Rain Seasons: CR and CP were planted as pure stands at the start of the SRS of 2004 and 2005 at a spacing of 75×30 cm in the respective cropping systems at the rate of three seeds per hole and later thinned to one plant 30 DAS (Table 1). CR was sown, as an improved fallow legume following M/CP intercrop system. Barley (a reference crop, for the determination of biological nitrogen fixation by the legumes using the extended difference method) was sown at rate of 100 kg ha^{-1} at the start of the short rains of 2004 and 2005 in furrows of about 3cm depth, dug out using strong sticks, at an inter-row distance of 20 cm. N_2 fixation by weeds was similarly determined. The extended difference method assumes that the uptake of soil derived N is the same in the legume and reference crop. Barley was chosen because it has similar N uptake characteristics as the legumes [14, 15].

Residue Management: CR green manure produced during the SRS was either completely removed (uprooted by hand) from plots shortly prior to planting maize and FYM applied instead ($M/CP_{(lime+MRP+FYM)}$-CR), or the biomass chopped into 5-20 cm small pieces spread across the plots and incorporated into soil by hand hoes to a depth of 15 cm during land preparation for maize planting in the LRS. The residues of CP and weeds were similarly handled and incorporated (Table 1).

Harvesting of Maize and Yield Determination: The above ground biomass of CP and CR were determined from two internal rows after harvest of grains and at cutting for green manure, respectively. Biomass determination of weeds was done using a $1m^2$ quadrant. Fresh weight was immediately determined in the field using a weighing balance. Sub samples were collected, placed in paper bags and taken to the laboratory for determination of dry weight. Maize grain (adjusted to 13% moisture content) and dry matter (70°C) yields, were determined from three centre rows at maize maturity. The CP grain yields (adjusted to 12% moisture content) were determined from two internal rows of each plot and expressed on hectare basis.

Soil, Plant Sampling and Analysis: Soil sampling for the initial soil pH, N and P determination were collected prior to crop sowing in February, 2004. Thereafter, changes in soil available N and P were monitored at seedling (15DAS), mid flowering (120 DAS) and post harvest (200 DAS) maize growth stages. Soil pH (measured in 1:2.5 water suspension) changes were monitored two months after liming and at the end of the trial period. At each sampling time four sub samples were obtained from the top soil (0-20 cm depth), between the plants within a row in every plot, using a 5 cm diameter soil auger. The samples were kept in polythene bags and taken to the laboratory for analysis. Soil and plant samples were analyzed for N and P contents using the methods described by Okalebo *et al*. [16].

N_2 Fixation Determination: The amounts of N_2 fixed by the legumes and weeds was estimated in the SRS of 2004 and 2005 at late pod fill stage of the CP and at flowering stage of CR. The extended difference method, the fourth extension [17], was used. The BNF by legumes was calculated using the formulae:

$$\begin{aligned} \text{BNF (kg ha}^{-1}) = {} & (\text{shoot } N_{leg} + \text{root } N_{leg}) \text{ kg ha}^{-1} \\ & - (\text{shoot } N_{ref} + \text{root } N_{ref}) \text{ kg ha}^{-1} \\ & + (N_{in} \text{ in soil}_{leg} - N_{in} \text{ in soil}_{ref}) \text{ kg ha}^{-1} \end{aligned}$$

where, leg = Legume, ref = Reference crop, in =Mineral N

Statistical Analysis: The soil and plant data obtained were subjected to analysis of variance (ANOVA) using SPSS [18] software. The analysis used was appropriate for a randomized complete block design. Turkey tests were used for comparison of means.

RESULTS AND DISCUSSION

Soil pH: At the end of the trial period (2006 LRS) the soil pH was significantly higher than at the beginning and two months after application of the LCT in the $M_{(lime,\ MRP)}$-CP, $M/CP_{(lime,\ MRP)}$-CR and $M/CP_{(lime,\ MRP,\ FYM)}$-CR as compared to the control (M-F and M_{DAP}-F) cropping system (Table 2).

The significant increases in soil pH in these cropping systems may be attributed to the application of lime, MRP and FYM. When lime is added to soil, it reacts with water leading to the production of OH^- ions which react with Al^{3+} and H^+ in the acid soil to form $Al(OH)_3$ and H_20. The precipitation of Al^{3+} and H^+ by lime causes the pH to increase.

Field experiments have demonstrated that lime application changes the soil pH over time and helps to remove negative effects of soil acidity [19]. Black [20] observed that soil pH continued to increase five years after lime application and began decreasing in the fifth year. MRP has a high content of carbonates [21] and had a liming effect. Besides, FYM, CP residue and CR green manure on decomposition produces organic acids (alkalinization effects) which may have suppressed the Al content of soil through chelation [22]. This may have further prevented lowering of pH as the possibility of deprotonation that occurs on hydrolysis of Al^{3+} may have been reduced.

N_2 Fixation by Cowpea and Crotalaria: CR fixed significantly higher amounts of N_2 than CP and weeds in both years (Table 3). The N fixed by CR and CP significantly increased with application of lime (Table 3). Significantly higher amounts of N were fixed in $M_{(lime,\ MRP)}$-CP than M-CP cropping system.

The highest amounts of N fixed by CR than CP may be attributed to its better genetic potential and adaptation to environmental conditions [23]. This is in addition to improved soil conditions with the application of the LCT that ameliorated the acidic conditions.

Acid-soil conditions pose problems for the plant, the bacteria and the symbiosis [24, 25]. The significantly higher amount of N_2 fixed in $M_{(lime,\ MRP)}$-CP than M-CP cropping system, with application of LCT, may be due to increased extractable P, Ca and Mg [26, 27] through liming and MRP application. In legumes, nodulation is adversely affected by a combination of high aluminium and/or manganese and low calcium and P concentrations in acid soils [6, 28]. With improving Ca and P supply and reducing Al due to application of LCT, the N fixation by the legumes was accordingly enhanced.

Table 2: Soil pH changes (0-20 cm depth) at two weeks after liming and end of experiment

Time of measurement			
LCT/ Cropping system	Initial (Before liming)	2 months (After liming)	End of trial (After 5 seasons)
M-F	4.95 ^{a} (0.30)	4.95 ^{a} (0.02)	4.80 ^{b} (0.08)
$M_{(DAP)}$-F	4.93 ^{a} (0.02)	4.94 ^{a} (0.02)	4.40 ^{a} (0.05)
M-CP	4.94 ^{a} (0.02)	4.95 ^{a} (0.03)	5.12 ^{c} (0.11)
$M_{(lime,\ MRP)}$-CP	4.97 ^{a} (0.01)	5.40 ^{b} (0.16)	6.00 ^{d} (0.05)
$M/CP_{(lime,\ MRP)}$-CR	5.02 ^{a} (0.12)	5.46 ^{b} (0.04)	6.16 ^{d} (0.06)
$M/CP_{(lime,\ MRP,\ FYM)}$-CR	4.94 ^{a} (0.03)	5.01 ^{a} (0.13)	6.10 ^{d} (0.14)

Means in a column followed by the same letter are not significantly different at $P < 0.05$ using the Tukey means separation procedure. Standard deviations in parenthesis

Table 3: Nitrogen fixed (kg ha) by weeds, cowpea and crotalaria in 2004 and 2005 SRS

		N fixed	
Cropping system/LCT	Plant	2004	2005
M-F	weeds	4^a (1.4)	5^a (1.5)
$M_{(DAP)}$-F	weeds	3^a (1.6)	4^a (1.5)
M-CP	cowpea	37^b (1.41)	42^b (1.52)
$M_{(lime,\ MRP)}$-CP	cowpea	51^c (1.60)	56^c (1.50)
$M/CP_{(lime,\ MRP)}$-CR	crotalaria	127^d (2.15)	158^e (1.92)
$M/CP_{(lime,\ MRP,\ FYM)}$-CR	crotalaria	132^e (1.75)	147^d (2.25)

Means in a column followed by the same letter are not significantly different at $P<0.05$, using the Tukey mean separation procedure. Standard deviations in parenthesis

The amount of N_2 fixed by CR in this study (Table 3), upon the application of the LCT was in the range of the BNF values reported in literature [28], a clear indication that soil acidity is the major hindrance to enhanced N_2 fixation and legume performance.

Biomass of Cowpea, Crotalaria and Weeds and Their N and P Contents: The above ground biomass of weeds, CP and CR was significantly higher in the second year (SRS of 2005) with the weeds, consisting mainly of herbs, having the highest biomass, followed by CR and CP in that order (Table 4). The highest biomass yields of weeds may be attributed to their rapid growth and establishment in comparison to the legume species. Higher biomass production in the second year is attributable to improved soil productivity due to amelioration of the soil pH through application of the LCT. The N and P content (kg ha^{-1}) were higher in CR and weed biomass in both years with a marked increase in the second year (Table 4).

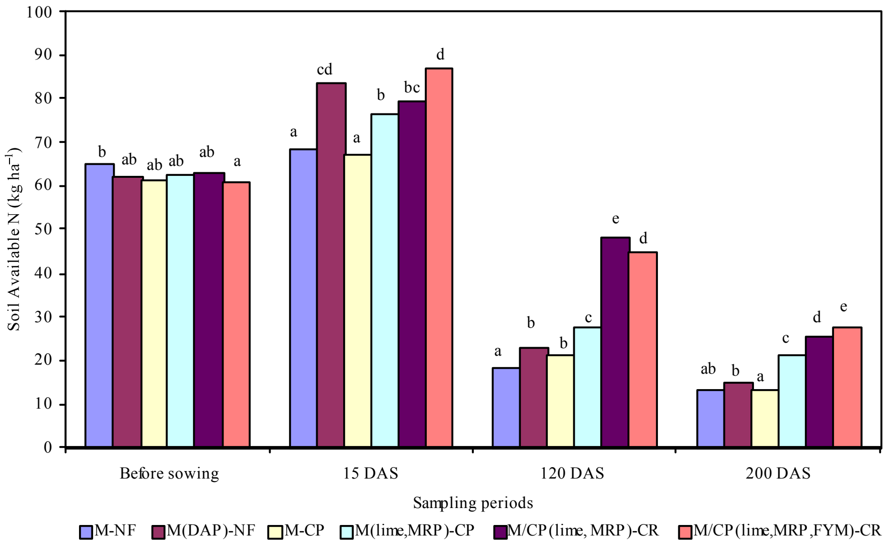

Fig. 1: Soil available N (kg ha^{-1}) in 2004 LRS
Means of soil available N for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, $P < 0.05$

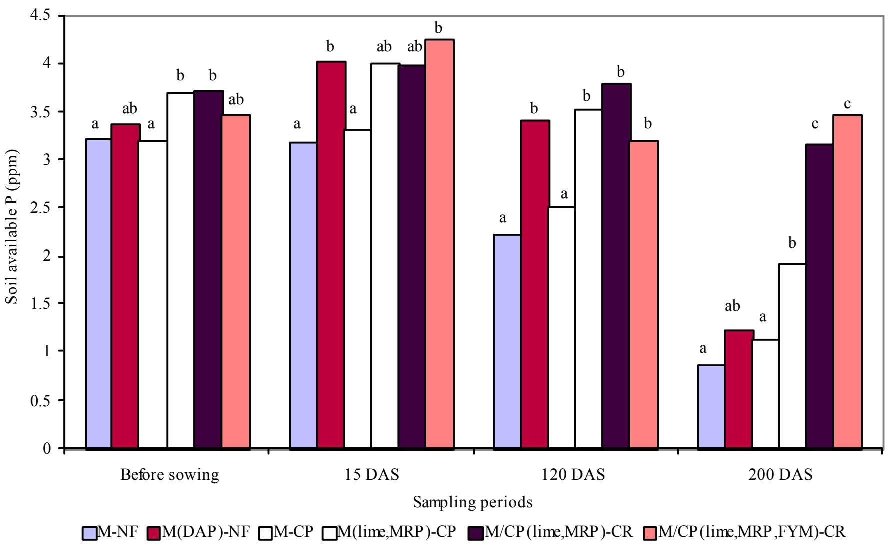

Fig. 2: Soil available P (ppm) in 2004 LRS
Means of soil available P for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, $p < 0.05$

This is due to the highest biomass produced by CR relative to CP (Table 4). Gathumbi *et al*. [29] studying short term fallows recorded the greatest total N yield in the improved crotalaria fallows and attributed the same to their fast establishment and higher total biomass production.

Soil Available N and P in 2004, 2005 and 2006 LRS: Soil available N and P in 2004 LRS. Soil available N was higher at 15 DAS following application of the LCT and significantly decreased thereafter towards maize maturity (Fig. 1). Significantly higher amounts of soil available N and P at 15 DAS were found in $M_{(DAP)}$-F, $M_{(lime,\ MRP)}$-CP, $M/CP_{(lime,\ MRP)}$-CR and $M\ /CP_{(lime,\ MRP,\ FYM)}$-CR cropping systems (Fig. 2 and 3). At 120 and 200 DAS the cropping systems $M\ /CP_{(lime,\ MRP,\ FYM)}$-CR and $M/CP_{(lime,\ MRP)}$-CR had significantly higher amounts of soil available N than in the other cropping systems. At 120 DAS higher

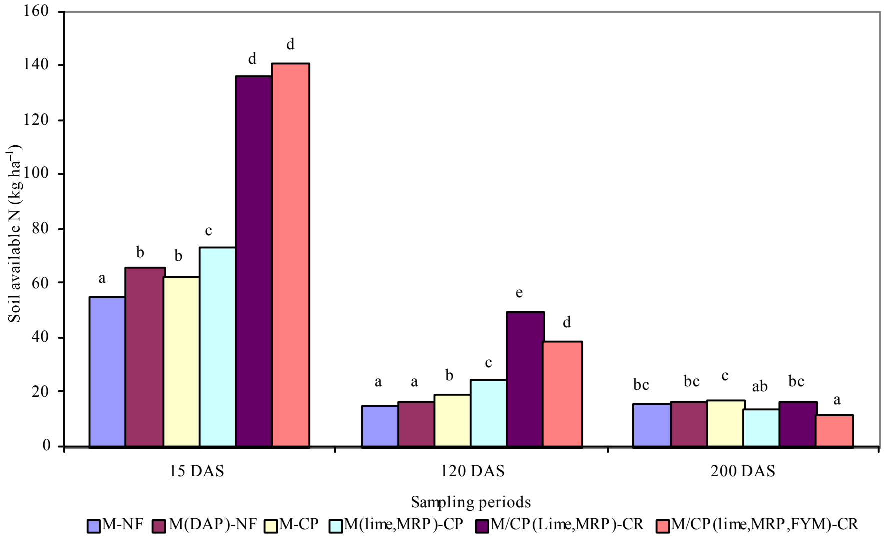

Fig. 3: Soil available N (kg ha^{-1}) in 2005 LRS
Means of soil available N for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, $P < 0.05$

concentrations of soil available P were found in $M_{(DAP)}$-F, $M_{(lime, MRP)}$-CP, $M/CP_{(lime, MRP)}$-CR and $M/CP_{(lime, MRP, FYM)}$-CR cropping system. At maturity (200 DAS) significantly higher concentrations of P were found in $M/CP_{(lime, MRP, FYM)}$-CR and $M/CP_{(lime, MRP)}$-CR than in $M_{(lime, MRP)}$-CP, M-CP, $M_{(DAP)}$-F and M-F cropping system (Fig. 2 and 3).

The highest N and P contents at 15 DAS, in the respective cropping systems, was due to the supply of N and P from the added DAP fertilizer, FYM and MRP, release of fixed P and enhanced mineralization of native organic matter due to liming effects. This is because of the increased population of nitrifyers as a result of liming and MRP application. Mineralization of organic matter is a key process regulating microbial activity and the cycling of nutrients [30, 31] and is affected by low pH [32].

The significantly higher N contents in the ($M/CP_{(lime, MRP, FYM)}$-CR and $M/CP_{(lime, MRP)}$-CR) cropping system at 120 DAS is because of the fixed N_2 by the intercropped cowpea and mineralization of the incorporated cowpea residues. Cereals can compete for N in the rhizosphere of cereal /legume mixtures, leading to N depletion in the rhizosphere of the legumes and this stimulates increased N fixation by the legumes [33]. When fixing N, legume plants take up more cations than anions and release H ions from the roots [34]. The H ions released are particularly important in dissolving P [35]. Vanlauwe *et al*. [36] reported enhanced release of P from phosphate rock due to the increased soil P content in a Mucuna cropping system.

The CP residue incorporated at harvest in the respective cropping systems further contributed to the high P levels measured at maize maturity (200 DAS) in the M/CP cropping system. The incorporated CP residues upon mineralization released organic acids that bound Al, the key fixer of P in acid soils and enhanced solubilization of the MRP in addition to P release by residues [37]. The higher P content in $M_{(lime, MRP)}$-CP than M-CP cropping system is attributable to counteraction of the negative soil pH effects and consequently enhanced P desorption with the application of lime and MRP. Liming reduces Al toxicity and increases extractable P [26].

The observed decline in soil available N and P with crop growth is attributable to continued crop uptake. Maize draws most nutrients from the soil from about 10 days before tasselling to about 25 to 30 days after tasselling [38-40].

Soil available N and P in the 2005 LRS: At 15 DAS, soil available N levels were higher in $M/CP_{(lime, MRP)}$-CR and $M/CP_{(lime, MRP, FYM)}$-CR than in $M_{(lime, MRP)}$-CP, M-CP, $M_{(DAP)}$-F and M-F cropping system (Fig. 3).

At 120DAS, significantly higher amounts of N were found in $M/CP_{(lime, MRP)}$-CR than and $M/CP_{(lime, MRP, FYM)}$-CR cropping systems with higher amounts in $M/CP_{(lime, MRP, FYM)}$-CR than M-CP and $M_{(DAP)}$-F and M-F cropping systems. At maturity (200 DAS) soil available N was relatively low in all cropping systems (Fig. 3).

The higher available soil N in the respective cropping system following CR green manure or FYM

Table 4: Weeds, cowpea and crotalaria biomass (t ha^{-1}) and N and P contents (kg ha^{-1}) in 2004 and 2005 SRS

		Year					
				2005	2006	2005	2006
		2005	2006	N and P contents			
Cropping system	Plant	Biomass yield		N	P	N	P
M-F	weeds	4.73^a(0.05)	5.23^a(0.04)	56.72^b(2.96)	72.76^c(2.23)	5.21^c(0.28)	5.44^{bc}(0.17)
$M_{(DAP)}$-F	weeds	5.20^b(0.06)	6.39^b(0.05)	92.58^d(4.05)	126.18^d(9.23)	19.24^e(0.64)	22.69^d(2.69)
M-CP	cowpea	1.10^c(0.10)	2.37^c(0.10)	20.79^a(1.64)	30.55^a(1.98)	1.85^a(0.15)	2.85^a(0.22)
$M_{(lime,\ MRP)}$-CP	cowpea	1.68^d(0.04)	2.79^c(0.05)	27.99^a(1.73)	47.42^b(1.58)	3.49^b(0.21)	3.33^a(1.01)
$M/CP_{(lime,\ MRP)}$-CR	crotalaria	2.49^e(0.03)	3.40^e(0.05)	91.71^d(3.76)	108.90^d(3.62)	7.74^d(0.07)	6.81^c(0.22)
M $/CP_{(lime,\ MRP,\ FYM)}$-CR	crotalaria	2.30^f(0.04)	3.88^f(0.36)	72.18^c(4.36)	132.44^d(11.21)	6.22^c(0.79)	7.85^c(0.64)

Means in a column followed by the same letter are not significantly different using the Tukey mean separation procedure at $P<0.05$. Standard deviations in parenthesis

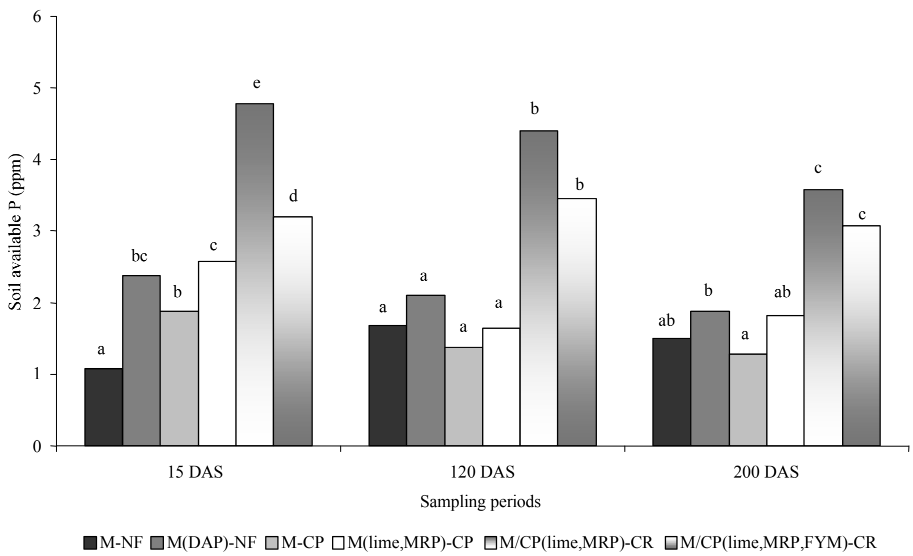

Fig. 4: Soil available P (ppm) in 2005 LRS

Means of soil available P for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, P < 0.05

application observed at 15 and 120 DAS resulted from the mineralization of FYM and CR green manure in addition to biological N fixation by the legumes (Table 3). Dalal *et al*. [41] and Badaruddin and Meyer [42], reported that mineral N in the root zone of soil following legumes is often 30-60 kg N ha^{-1} higher than after cereal crops in the same environment. The higher N in $M/CP_{(lime,\ MRP)}$-CR than $M_{(lime,\ MRP)}$-CP, M-CP or $M_{(DAP)}$-F and M-F cropping system is because of the higher N content in the CR green manure (Table 3) coupled with the N_2 fixed by the CR and the intercropped cowpea (Table 3 and 4) which boosted the soil N levels(Table 4). A significant amount of N can be added to soils through atmospheric N fixation by N legumes which is then made available for the same crop or the following crops [43, 44].

Higher soil available N in $M/CP_{(lime,\ MRP)}$-CR and M $/CP_{(lime,\ MRP,\ FYM)}$-CR than $M_{(lime,\ MRP)}$-CP, M-CP, $M_{(DAP)}$-F and M-F (Fig. 6) cropping systems at 120DAS may be attributable partly to the N fixed by intercropped cowpea (Table 3). The higher N in $M/CP_{(lime,\ MRP)}$-CR than $M/CP_{(lime,\ MRP,\ FYM)}$-CR cropping system at 120 DAS was probably due to highest N fixed in the former. The application of FYM may have reduced N_2 fixation due to additional N supply. When soil N levels are high, nodule

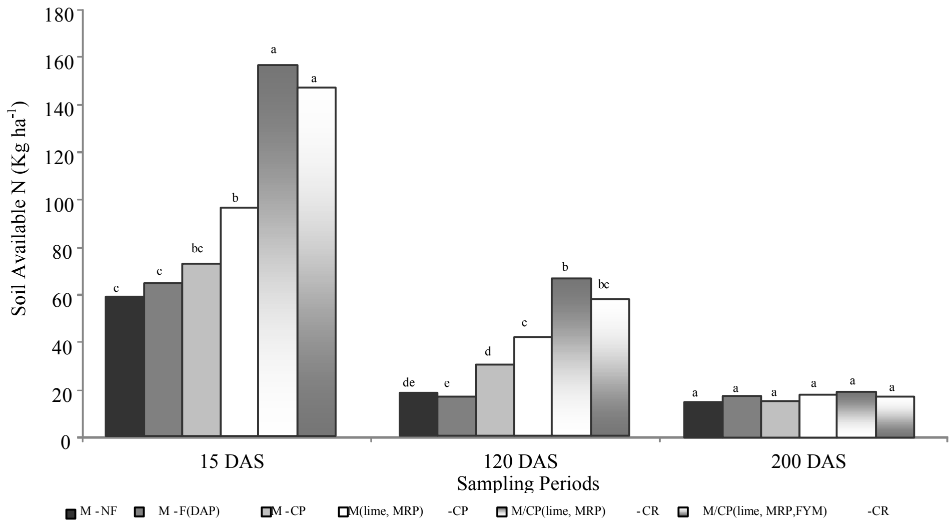

Fig. 5: Soil available N (kg ha^{-1}) in 2006 LRS
Means of soil available N for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, P < 0.05

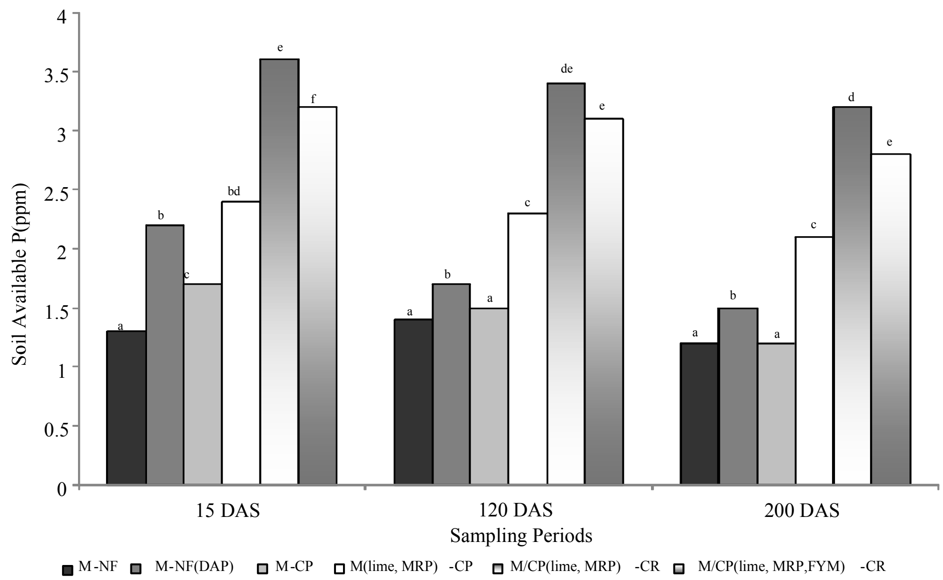

Fig. 6: Soil available P (ppm) in 2006 LRS
Means of soil available P for each cropping system at each sampling period followed by the same letter are not significantly different according to Tukey mean separation procedure, P < 0.05

number and activity decreases. Roots do not attract bacteria or allow infection hence N fixation is limited or non existent [45].

The trends in soil available P (Fig. 1 and 4) with respect to cropping systems were similar to the preceding 2004 LRS (Fig. 2). Soil available P was however higher in 2005 than 2004 and this is attributable to the residual effects of the LCT

Soil Available N and P in the 2006 LRS: The trends in soil available N and P, with the application of the LCT, in the respective cropping system were similar to the preceding 2005 LRS and similar reasons as earlier advanced apply. The concentration of the soil available N was however significantly higher in the 2006 LRS than in the previous cropping seasons. This is attributable to favourable soil conditions that had resulted due to

Table 5: Maize grain and DM yields (kg ha^{-1}) in 2004 and 2005 and 2006 LRS

	Grain yield			DM yield		
Cropping system	2004	2005	2006	2004	2005	2006
M-F	1.80^{a} (0.24)	1.48^{a} (0.22)	1.67^{a}(0.21)	3.08^{a}(0.25)	3.16^{a}(0.05)	3.22 (0.21)
$M_{(DAP)}$-F	2.48^{b}(0.36)	2.88^{b}(0,34)	2.73^{b} (0.27)	4.20^{b}(0.43)	4.65^{b}(0.42)	4.81 (0.38)
M-CP	1.70^{a} (0.27)	3.13^{bc}(0.10)	3.26^{bc} (0.21)	3.25^{a}(0.17)	5.25^{b}(0.19)	5.54 (0.26)
$M_{(lime, MRP)}$-CP	3.08^{bc} (0.17)	3.45^{cd} (0.13)	3.52^{cd}(0.19)	5.23^{c}(0.23)	5.95^{c}(0.24)	5.82 (0.32)
$M/CP_{(lime, MRP)}$-CR	3.28^{cd} (0.19)	3.85^{d} (0.17)	3.91^{d} (0.21)	5.68^{cd}(0.43)	6.68^{cd}(0.40)	6.16 (0.28)
M $/CP_{(lime, MRP, FYM)}$-CR	3.70^{d} (0.29)	3.80^{d} (0.28)	3.86^{d} (0.32)	6.18^{d}(0.29)	6.60^{d}(0.29)	6.61(0.23)

Means in a column followed by the same letter are not significantly different at $P<0.05$, using the Tukey mean separation procedure. Values in parenthesis are standard deviations.

application of LCT, for microbial decomposition of FYM, CR green manure and CP residue. This is further confirmed by the enhanced pH realized at the end of the trial period (Table 2). Soil available P in 2006 LRS was lower than in the 2005 LRS but higher than 2004. Although organic matter and crop residues increase the availability of native and fixed P, Vanlauwe *et al.* [46] pointed out that factors such as P uptake and release by roots, soil microbes and mycorrhizal hyphae can mask the real effects of organic inputs on P availability.

Maize Grain and DM Yields: Maize grain yield was significantly increased by the LCT in $M/CP_{(lime, MRP)}$-CR and M $/CP_{(lime, MRP, FYM)}$-CR cropping systems and steadily improved with the progression of the cropping seasons (Table 5). LCT and cropping system effects with respect to maize DM yields (Table 5) followed a similar trend.

The highest yields obtained in $M/CP_{(lime, MRP)}$-CR and M $/CP_{(lime, MRP, FYM)}$-CR cropping systems is due to enhanced nutrient supply to maize through BNF by CP. Skovgard and Pats [47] and Li *et al*. [48] reported that if a legume is grown in association with another crop, commonly a cereal, the N nutrition of the associated crop may be improved by the direct N transfer from the legume to the cereal. The legume uses fixed atmospheric N which can be exploited by the companion crop [49].

Increase in maize yields with progression of the cropping seasons may have resulted from the improved soil conditions due to enhanced nutrient availability, maintenance of soil organic matter (SOM) levels through continuous input of legume residue, green manure and FYM to soil. SOM is crucial because of its role in maintaining soil fertility and soil structure [50]. The amelioration of soil acidity by the lime and MRP and the supply of P by the latter and the rotational effects of the legumes may have further increased maize yields.

The integration of legumes into the cropping system potentially enhanced the yields of the following maize crop, an effect which can largely be attributed to the increase in plant available nitrogen in the soil for uptake by the same crop and/or the following crops [44, 51].

CONCLUSION

Liming of the acid soils of Molo, in addition to application of the other LCT, significantly increased soil pH at the end of the experimental period to levels (6.0-6.2) conducive for maize growth.

Application of the LCT further enhanced N_2 fixation by the legumes with superior biological N fixation realized in CR in the second year. This was due to the enhanced soil pH for the rhizobia through liming and enhanced P supply by MRP and residue/green manure incorporation. The incorporation of CR green manure, or its recycling as livestock feed and applying as FYM before maize planting enhanced soil available N and P proportionately and hence use of either approach is recommended to the farmer. Maize grain and DM yields increased with progression of the cropping seasons with higher yields realized in the intercropping system across seasons.

The utilization of the SRS by planting CP and incorporating its residue during land preparation for the following maize crop alongside the application of LCT in a maize/cowpea intercropping system is a feasible strategy to combat soil acidity, enhance soil nutrient availability and boost maize performance in the SHF of Molo.

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