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Full Length Research Paper

Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a humic nitisol in the Central Highlands of Kenya

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Soybean (*Glycine max* (L.) Merrill) is one of the most important legume crops being introduced into the smallholder farming systems of the Central Highlands of Kenya (CHK) to improve income and household nutrition of farmers. However, phosphorus fixation, depletion of soil nutrients and soil acidity are major causes of low yields. The objective of this study is to evaluate effects of manure application, liming and phosphorus application on soil properties and soybean performance. The study consisted of 8 treatments: manure (0, 5 and 10 t ha^{-1}), lime (0 and 2 tha^{-1}) and P fertilizer (0, 30 and 60 kg P ha^{-1}). The experiment was laid out in a randomized complete block design (RCBD) with 4 replicates in plots of 4 m × 4.5 m. Manure and lime significantly reduced exchangeable acidity and increased soil pH. Application of manure alone or combined with lime or P fertilizer also increased Mg and K. Treatments that had sole lime, lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca. Soybean responded well and significantly to application of manure either alone or combined with lime, P or both. These results showed the potential role of lime, manure and P fertilizer in improving soil fertility and soybean yields.

Key words: Manure, lime, P fertilizer, soil pH, exchangeable acidity.

INTRODUCTION

Smallholder farmers in the Central Highlands of Kenya (CHK) are facing problems of declining soil fertility due to intensive cultivation, nutrient removal via crop harvest and soil erosion (Sanchez and Jama, 2002). Use of commercial fertilizers to address the declining soil fertility remains minimal due to farmer's low income which limits their ability to purchase fertilizers. High costs of fertilizer, lack of credit, delays in delivery of fertilizer due to poor transport and marketing infrastructure, and lack of know-how about their usage have individually or jointly constrained fertilizer optimal use (Heisey and Mwangi, 1996; Makokha et al., 2001). Several researchers have recommended Integrated Soil Fertility Management (ISFM) options for increasing soil fertility and agronomic efficiency of applied inputs (Sanginga and Woomer, 2009; Vanlauwe et al., 2010). The Integrated Soil Fertility Management (ISFM) practices comprise the use of organic and inorganic resources in an integrated manner in order to maximize their use efficiency and crop productivity. These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm, and must be adapted to the local conditions (Sanginga and Woomer, 2009; Vanlauwe et al., 2010; Fairhurst, 2012).

Legume integration into the farming systems is an important component of ISFM because of their potential to fix nitrogen and hence reduce farmers' costs for purchase of nitrogen fertilizers. Legumes have also been reported to improve the soil physical and chemical attributes as well as provide protein supplements for poor families (Latif et al., 1992). Soybean, a native of China, is one of the legumes being integrated into the smallholder farming systems of the CHK. The crop has a high commercial value and high concentration of protein, about 40%, calcium, phosphorus, fiber, and in addition it

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is cholesterol free (Hassan et al., 2010). It plays an important role in provision of food, cash and animal feeds (Mugendi et al., 2010). Soybean, like other leguminous crops has a positive impact on the soil; the canopies of soybean cover the soil and protect it from recurrent erosion (Latif et al., 1992). Soybean has potential to fix N from the atmosphere through biological fixation (Nieuwenhuis and Nieuwelink, 2002). This is important in farming systems where soils are continuously been exploited since the increasing population demands increased food production. Through research, it has been demonstrated that some varieties of this crop have the ability to fix nitrogen from 44 to 103 kg N ha^{-1} annually (Sanginga, 2003). In Kenya, this crop is relatively new and expected to increase production due to its importance in supply of food, income and improving household nutrition (Mugendi et al., 2010). However, its yields are still below the potential (3.0 - 3.6 t ha^{-1}), with average yields in central provinces ranging from 560 to 1100 kg ha^{-1} (Mahasi et al., 2010). Many factors are responsible for the low productivity, which include inherent poor soil fertility (Bationo et al., 2006), continuous decline of the soil fertility (Kimani et al., 2004), poor management practices and low agricultural input use (Njeru, 2009).

The predominant soils in the Central Highlands of Kenya are ‘humic nitisols’ that have moderate to high acidity with inherent high phosphorus fixing (Kanyanjua et al., 2002). The prevalence of acidity is associated with nitrogen (N), phosphorus (P) deficiency in the soil, aluminum (Al) toxicity, low extractable bases (Ca, Mg, K and Na), and reduced microbial activity which therefore results to low crop yield and land productivity (Crawford et al., 2008). These are some of the major factors that adversely affect performance of soybean.

Research has shown that application of manure significantly has an impact on the chemical, physical and biological properties of the soil. Most of these effects are due to an increase in soil organic matter (Shirani et al., 2002; Liang et al., 2011; Bakayoko et al., 2009) resulting from manure application. Therefore, manure is an excellent source of major plant nutrients such as N, P and potassium (K), and also provides many of the secondary nutrients that plants require. The actual nutrient value of manure from a particular operation will differ considerably due to the type of animal, its food ration, manure collection, storage and application procedures, and climate (Risse et al., 2008). Manure effect on soil physical properties include increased infiltration (Risse et al., 2008), water holding capacity (Liang et al., 2011; Salahin et al., 2011, Rasoulzadeh and Yaghoubi, 2010) and reduced compaction and erosion (Salahin et al., 2011). According to Kihanda et al. (2007), manure application is one of the most effective ways of improving fertility in tropical soils. Despite its low availability, manure is the most widely used organic fertilizer by approximately 80% of households in Central Highland of Kenya (Makokha et al., 2001). These manure have been used as fertilizer by smallholder farmers in order to increase crop production, and has been shown to be an alternative for improving crop yields in Central Highlands of Kenya (Mugwe et al., 2007). Moreover, application of lime tends to raise the soil pH by displacement of H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption site (Onwonga et al., 2010). More than increasing soil pH, it also supplies significant amounts of Ca and Mg, depending on the type. Indirect effects of lime include increased availability of P, Mo and B, and more favorable conditions for microbially mediated reactions such as nitrogen fixation and nitrification, and in some cases improved soil structure (Crawford et al., 2008).

Adoption of ISFM practice has been reported by researchers as a viable solution to restore and maintain soil fertility. Therefore, this study aimed at evaluating the effect of manure, lime, P mineral fertilizer and their combination on soil properties and soybean yields in an acidic soil in the Central Highlands of Kenya.

MATERIALS AND METHODS

Site description

The experiment was carried out at Embu Agricultural Training College (Embu-ATC), located in Embu West District (0°35’ 25.58’’S and 37° 25’ 31.84’’E), in Central Highlands of Kenya at an elevation of 1494 m above sea level. Embu West District is in Upper Midland 2 and 3 (UM 2 - UM 3) agro ecological zones having an altitude of about 1440 m above sea level, with average annual temperature of about 20°C and annual rainfall of 909 - 1230 mm (Jaetzold et al., 2006). The rainfall is bimodal with two seasons: Long Rains (LR) in March through June, and Short Rains (SR) from October through January. Over 65% of the rains occur in the LR season (Jaetzold et al., 2006). The soils are mainly ‘humic nitisols’ (Jaetzold et al., 2006), which are deep, well weathered with moderate to high inherent fertility but over time soil fertility has declined due to continuous mining of nutrients as a result of inadequate or no replenishment. Recent studies have reported that soils have generally low levels of organic carbon (<2.0%), nitrogen (<0.2 %), phosphorus (<10 ppm) and range from moderately to strongly acidic (pH ranges from 4.8 - 5.4), conditions that result in low crop production (Mugwe et al., 2007). The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 1.5 ha per household.

The area is characterized by rapid population growth, low agricultural productivity, increasing demands on agricultural resources and low soil fertility. The farming systems are complex consisting of an integration of crops trees and livestock, and smallholder farms that are intensively managed (Mairura et al., 2007). Land sizes are small ranging from 0.1 to 1.5 ha (mean=1 ha), and

Table 1. Treatments and their description.

Treatment	Description	Abbreviation
Manure	10 t ha^{-1} M	M
Lime	2 t ha^{-1}CaO	L
TSP	60 kg ha^{-1} P_2O_5	P
Manure+Lime	5 t ha^{-1} M + 2 t ha^{-1} CaO	ML
Manure+TSP	5 t ha^{-1} M + 30 kg ha^{-1} P_2O_5	MP
Manure+Lime+TSP	5 t ha^{-1} M + 2 t ha^{-1}CaO + 30 kg ha^{-1} P_2O_5	MLP
Lime+TSP	2 t ha^{-1} CaO + 30 kg ha^{-1} P_2O_5	LP
Control	No inputs	C

slope cultivation is widespread. The main cash crops are coffee (*Coffea arabica* L.) and tea (*Camelina sinensis* (L) O. Kuntze) while the main staple food crop is maize (*Zea mays* L.), which is cultivated from season to season mostly intercropped with beans (*Phaseolus vulgaris L*). Other food crops include sweet potatoes (*Ipomea batatas* (L.) Lam), bananas (*Musa* spp. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially improved dairy cattle breeds. Other livestock in the area include sheep, goats and poultry.

Experiment design and field management

The study was conducted during the 2012 Long Rain (LR) season which spans from October 2012 to February 2013. The experiment was a Randomized Complete Block Design (RCBD), with plots measuring 4.0 m × 4.5 m and replicated four times. The experiment had 8 treatments with the following factors: manure (M) (0, 5 and 10 t ha^{-1} as goat manure), lime (0, 2 t ha^{-1} as CaO) and P fertilizer (0, 30 and 60 kg P ha^{-1}) as Triple Super Phosphate (TSP). The treatments are presented in Table 1.

Land was ploughed manually using a hand hoe followed by leveling 2 weeks before planting. Manure and lime were broadcasted and then incorporated in the soil within 15 cm depth, using hand hoe 2 weeks before planting. TSP was the source of P and was applied per furrow and well mixed with the soil at planting. Soybean var. *Gazelle* was sown on 13th October, 2012 by placing 3 seeds per hole at 50 cm × 10 cm spacing. Two weeks after emergence, the seedlings were thinned to 2 plants per hill. All agronomic practices were undertaken during the growing season. The rainfall distribution during the study period is presented in Figure 1.

Soil sampling and analysis

Prior to the experiment set up, soil samples were collected from 0-15 cm depth for initial determination of soil fertility parameters. Thereafter, and to evaluate changes in soil as a result of applied treatments, soils were sampled at harvest. The soil samples were analyzed for pH, available P, exchangeable cations (Ca, Mg and K), mineral N, and exchangeable acidity. Soil pH was measured in a 1:2.5 ratio soil to water (pH_{H2O}) and to KCl (pH_{KCl}) using a pH meter model AD1000 (Okalebo et al., 2002). Soil exchangeable acidity was determined by titration (0.1M NaOH) method using 1M KCl for extraction (Okalebo et al., 2002). Soil mineral N was determined by flow injection method after extraction with 2M KCl. Exchangeable cations and available P were determined by Mehlich 1 method as described by Okalebo et al. (2002). The soils of the experimental site were moderately acidic (pH = 5.07) according to soil classification based on soil pH (Kanyanjua et al., 2002); and moderately low in available P (Tables 2). Goat manure was analyzed to assess its quality and the results are present in Table 3.

Harvest of soybean and yield determination

At physiologic maturity stage, four central rows out of nine were harvested by leaving 50 cm from the both edges of the rows, harvesting therefore a net area of 6 m^2. Plants were cut at ground level and fallen leaves were collected and weighed together in the field. Subsequently, the plants were threshed and the fresh weight of the grain was recorded. Thereafter, the grain samples were sun dried and yields were determined and adjusted to 12% of moisture content.

Data analysis

Data generated were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 8. Least Significance Difference (LSD) at 95% of significance level was used to separate means. The means were subjected to *t*-test at 95% of confidence to test means difference.

RESULTS

Soil chemical properties

Application of soil amendments significantly affected soil pH: water ($p < 0.0001$) and KCl ($p < 0.05$) (Table 4). The

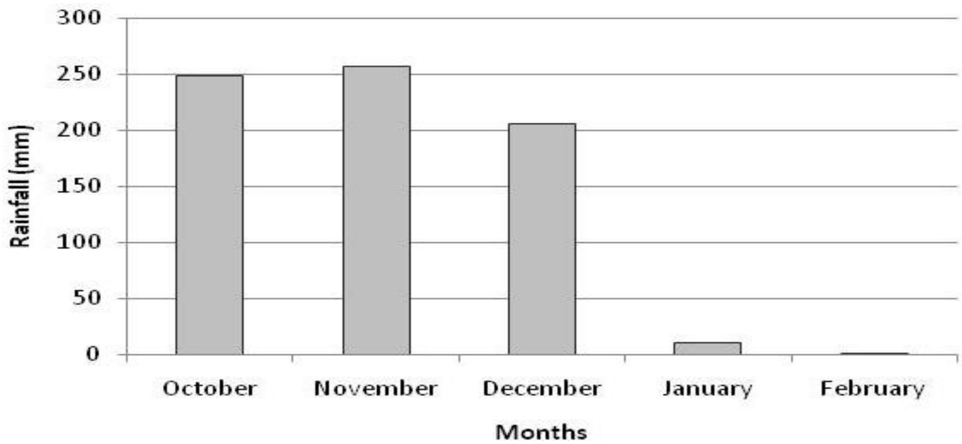

Figure 1. Rainfall distribution during the study period at Embu, Kenya.

Table 2. Soil chemical properties of the soil (0-15 cm depth) prior to planting.

Parameter	Soil
pH water (1:2.5)	5.06
pH KCl (1:2.5)	4.21
Exchangeable acidity (cmol kg^{-1} soil)	3.72
Exchangeable cations (cmol kg^{-1} soil)	
Ca^{2+}	0.63
Mg^{2+}	0.51
K^{+}	0.12
Na^{+}	0.14
Extractable P (mg kg^{-1} soil)	7.54
Total N (%)	0.06

Table 3. Analysis of manure used in the study.

Parameter	pH_{water} (1:2.5)	Ca (%)	Mg (%)	K (%)	Na (%)	P (%)	N (%)	C (%)
Value	9.3	0.92	0.44	1.69	0.43	0.46	1.6	21.3

Table 4. Effects of manure, lime and P fertilizer on soil pH and exchangeable acidity at Embu.

Applied soil amendments	pH		Exchangeable acidity cmol kg^{-1} soil
	H_2O	KCl	
Manure	5.62	4.53	2.25
Lime	5.83	4.76	1.75
TSP	5.26	4.31	3.0
Manure+Lime	5.64	4.58	2.0
Manure+TSP	5.46	4.43	2.0
Manure+Lime+TSP	5.79	4.67	1.75
Lime+TSP	5.59	4.51	2.25
Control	5.05	4.19	4.0
p-value	<0.0001	<0.0001	0.0115
$LSD_{0.05}$	0.27	0.19	1.20

treatment with lime recorded the highest increase in soil pH. There was also significant difference ($p < 0.05$) in exchangeable acidity due to treatments. All treatments significantly reduced exchangeable acidity except the P treatment. The application of MLP and L treatments mostly reduced exchangeable acidity by 2.3 times followed by both application of MP and ML treatments by 2.0 times.

Application of MLP and M treatments significantly ($p < 0.05$) increased exchangeable Mg by 1.2 times. Contrary and consistently, application of P treatment recorded the lowest values in soil available Mg. Soil exchangeable Ca differed significantly ($p < 0.05$) among the treatments. Application of MLP treatment significantly increased soil exchangeable Ca by 2.97 times followed by application of M treatment by 2.14 times. Meanwhile, application of MP and P treatments recorded the lowest increase by 1.3 and 1.4 times, respectively. The application of M treatment recorded the highest significant ($p < 0.0001$) increase in soil K by 3.75 times which was followed by the application of MP treatment by 2.25 times. On the other hand, application of LP and L treatments recorded the lowest soil K of 0.07 and 0.08 cmol kg^{-1} soil, respectively.

All treatments did not significantly affect soil extractable P (Table 5). There was statistical difference in soil mineral N ($p < 0.05$) among the treatments (Table 5). Soil mineral N increased by 1.6 times as compared to the control with application of M treatment, followed by the ML and MLP treatments (1.3 times). However there was no significant difference between lime alone or lime combined with P fertilizer. On the other hand, application of L and LP treatments recorded the lowest soil mineral N increase.

Soybean growth and yields

Plant height was significantly ($p < 0.01$) affected by the treatments (Table 6). The highest plant height was obtained in the plots receiving the MP treatment (50.4 cm), while application of P treatment recorded the lowest plant height (40.2 cm) over the control. The number of pods per plant was affected statistically ($p < 0.01$) by application of soil amendments. The application of M treatment recorded the highest average number of pods per plant (34.95), while the lowest was recorded for P treatment (22.63). Treatments also significantly affected ($p < 0.05$) weight of 100 seed. Application of MP treatment mostly increased 100 seed weight by 1.08 times as compared to the control. Stover yield did not show significant differences due to treatments.

Grain yield and harvest index were significantly affected by treatment application (Table 6). Application of M treatment most significantly ($p < 0.01$) increased grain yield 2.5 times more than the control. This was also significantly different from L and LP treatments. The lowest grain yield was recorded in the plots receiving P treatment (1.2 t ha^{-1}). Harvest Index (HI) which relates the grain yield to the total dry matter yield showed significant ($p < 0.05$) differences. The highest HI was recorded for MP and MLP treatments (0.35), while the lowest was recorded in plots under P treatment (0.24).

DISCUSSION

The increase in soil pH and reduction of soil exchangeable acidity following application of manure and lime either sole or combined can be attributed to the release of organic acids (during mineralization of manure), which in turn may have suppressed Al content in the soil through chelation (Onwonga et al., 2008; Okwuagwu et al., 2003). Moreover, lime when applied in the soil reacts with water leading to the production of OH^- ions and Ca^{2+} ions which displace H^+ and Al^{3+} ions from soil adsorption sites resulting in an increase in soil pH (Kisinyo et al., 2012). These findings are similar to those of Adeniyan et al. (2011) who found increased soil pH with application of manure in Nigeria.

Increased Mg availability in the soil as a result of manure application was also observed elsewhere by Adeleye et al. (2010) who suggested that this was due to the release of nutrients through manure decomposition. Rahman et al. (2002) also found increased available Mg in the soil as a result of applied manure either alone or combined with lime and attributed the increase to improved Mg availability as a result of improved soil pH, as was observed in this study. The increase can be attributed to the release of Ca^{2+} ions in lime through its dissociation (Chimdi et al., 2012) and to mineralization of manure with released nutrients (Shen and Shen, 2001). It was observed that application of manure either solely or combined with P fertilizer and both P fertilizer and lime had a positive effect on soil exchangeable K, and may be attributed to release of K from the manure. Similar findings were reported by Chimdi et al. (2012).

Manure alone or combined with lime increased mostly the soil available P, depicting that the increase was not significant. Abera et al. (2005) also found higher soil extractable P with higher application of manure. The soils tested low P (7.54 $mg.kg^{-1}$) before the experiment set. It was observed that the levels of P before planting were higher than after harvest under all treatments except sole manure. The same trend was also observed by Abera et al. (2005) in Ethiopia and attributed it to the higher phosphorus fixation capacity of acid soils and to the uptake by plants. This was also in agreement with Jibrin et al. (2002) who also reported extremely low concentration of P even with application of 60 kg P ha^{-1}. The soils where this study was undertaken were moderately acidic ($pH_{H2O} = 5.06$; $pH_{KCl} = 4.21$), therefore high P fixation was expected. Also the little changes in soil available P even with application of P fertilizer may be due to the method of application of the fertilizer (Kamara et al., 2008), which was point placed rather than

Table 5. Effects of manure, lime and P fertilizer on soil exchangeable cations and available P.

Applied soil amendments	Mg^{+2} cmol kg^{-1}	Ca^{+2} cmol kg^{-1}	K^{+} cmol kg^{-1}	Available P mg kg^{-1}	Mineral N mg kg^{-1}
Manure	0.61	0.73	0.30	8.02	22.35
Lime	0.57	0.61	0.08	7.51	14.95
TSP	0.51	0.48	0.09	7.35	17.08
Manure+Lime	0.57	0.68	0.13	7.79	17.30
Manure+TSP	0.56	0.43	0.18	6.87	17.25
Manure+Lime+TSP	0.62	1.01	0.15	7.32	16.13
Lime+TSP	0.56	0.7	0.07	7.24	15.78
Control	0.51	0.34	0.08	7.45	13.76
p-value	**0.0229**	**0.0477**	**< 0.0001**	**0.8575**	**0.0238**
$LSD_{0.05}$	**0.07**	**0.39**	**0.08**	**1.53**	**3.79**

Table 6. Effects of manure, lime and P fertilizer on soybean growth, yield components, grain yield and harvest index.

Applied soil amendments	Plant height (cm)	No. pods (pod.plant^{-1})	100seed (g.)	Stover yield (t.ha^{-1})	Grain yield (t.ha^{-1})	Grain yield Relative increase (%)	HI
Manure	49.9	34.95	18.43	5.52	2.8	145.6%	0.34
Lime	42.4	23.03	18.35	4.42	1.66	45.6%	0.27
TSP	40.2	22.63	18.1	3.78	1.2	5.3%	0.24
Manure+Lime	45.0	26.18	18.13	4.7	2.45	114.9%	0.34
Manure+TSP	50.4	25.55	19.13	4.81	2.66	133.3%	0.35
Manure+Lime+TSP	48.6	23.8	18.63	4.84	2.62	129.8%	0.35
Lime+TSP	42.0	22.7	18.05	4.86	1.7	49.1%	0.26
Control	39.9	22.3	17.65	3.76	1.14		0.23
p-value	**0.0044**	**0.0006**	**0.0238**	**0.0937**	**0.0011**		**0.0037**
$LSD_{(0.05)}$	**6.17**	**5.02**	**0.75**	**1.21**	**0.86**		**0.07**

broadcasted, while the soil samples were taken between the rows. The results also show that application of manure either alone or combined with lime, P fertilizer or both had significant effect on soil mineral N. These results are in agreement with those of Kihanda et al. (2004). The increase may be due to supply of N content in manure through mineralization associated to the improvement of soil conditions for microorganism's development and activity as a result of an increase in soil pH due to lime application.

The application of manure whether alone or combined with lime and P fertilizer influenced crop growth, yield components and yield of soybean. These results are similar with the results reported by Chiezey and Odunze (2009), and Umoetok et al. (2007). Manure is a source of nutrients, which are released through mineralization, thus supplying the necessary elements for plant growth (Chiezey and Odunze, 2009), and when combined with P fertilizers it increased nutrient supply which enhanced vegetative growth, affecting plant height and yields (Umoetok et al., 2007). Moreover, the high yields observed under manure application may be as a result of its ability for improving soil biological and physical properties which increase soil water retention and enhance nutrient uptake (Nwachukwu and Ikeadigh, 2012). During the growing season, K deficiency symptoms were observed mostly in unmanured plots, and it was evidenced with low soil available K in the soils at the study site. Potassium is a macronutrient very important to plants and it is involved in cell division, water and nutrient uptake (Tisdale et al., 1993), therefore its deficiency negatively affect shoot and root growth as well as water and nutrients uptake. In addition, K is the second nutrient mostly taken up by the crop after N and its deficiency greatly affects crop development and yields (Imas and Magen, 2007). Thus, the low yields observed under the treatments lacking manure may be, apart from other factors, caused by the low soil K and N. Therefore, it suggests that the use of manure combined with lime, P fertilizer or both enhanced good soil conditions which in turn contributed to relatively high yields.

CONCLUSION AND RECOMMENDATIONS

In conclusion, results showed that manure applied at the rate of 10 t ha^{-1} or 5 t ha^{-1} combined with lime or mineral

P fertilizer mostly improved soil conditions and soybean grain yields. These treatments improved soil extractable Ca, Mg, K, mineral N and pH. They also increased soybean yields by 114.9 to 145.6% above the control treatment. The good performance of combined application of manure and lime and P fertilizer, is in line with Integrated Soil Fertility Management (ISFM) principles that include the use of organic and inorganic resources, improved germplasm with agronomic practices adapted to local conditions. These preliminary results recommend the use of manure alongside with lime and mineral fertilizers to increase soybean yields. More research needs to be carried out for more seasons to assess the consistence of these findings, and the response of soybean to K fertilizer since K deficiency symptoms were observed during the study.

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