Amelioration of soil acidity in Ferralsols of Central Uganda

Abstract

Soil acidity is one of the major constraints limiting crop productivity in Central Uganda. Thus, the ideal soil pH for crop production ranges from 5.5 to 6.8, but in Central Uganda, crops are believed to be cultivated in soils with pH below these ranges. Given the adverse effects of soil acidity to agricultural production, appropriate measures such as the use of lime could be an option to improve the productive capacity. Henceforward, soils were sampled from farmers' fields in Mpigi, Mubende and Wakiso Districts representing Central Uganda to evaluate rates of $CaCO_3$ and corncob biochar in a greenhouse incubation study. Afterwards, 2 kg of soil was weighed, placed in a plastic container and thoroughly mixed with 0, 1, 3 and 5 g equivalent to 0, 1, 3 and 5 tons/ha $CaCO_3$ and corncob biochar. Soils were arranged in a Complete Randomized Design (CRD) and moistened with 500 ml of water to bring it to about field capacity and pH determination done for a period of three (3) months until equilibration. The analysis of variance (ANOVA) showed significant effect ($P<0.001$) on soil pH when $CaCO_3$ and corncob biochar were applied with the three districts recording a near neutral pH of 6.7.

After pH equilibration in the greenhouse, rates of $CaCO_3$ and corncob biochar that raised the soil pH in each medium were used to calculate the lime rates i.e., 0, 120, 360 and 600 g applied in the fields. In a Complete Randomized Design (CRD) consisting of four replications, soybean varieties were applied as the main plots while rates of $CaCO_3$ and corncob biochar were applied as the sub plots. The analysis of variance (ANOVA) showed that $CaCO_3$ had significant effect ($p<0.001$) on soil pH with Mpigi recording the highest soil pH (6.7) followed by Mubende (pH 6.6). Rates of $CaCO_3$ and corncob biochar also showed significant effect ($p<0.001$) on soybean grain yield compared to 0 g $CaCO_3$ and corncob biochar. Application of 600 g of corncob biochar showed significant effect ($p<0.001$) on soil pH in the different study locations. Besides, increased in $CaCO_3$ rate to 600 g recorded the highest (7137.5 kg ha^{-1}) soybean grain yield in Wakiso District while 600 g of corncob biochar recorded the highest (5637.5 kg ha^{-1}) soybean grain yield in Mpigi District thus signifying the potential effect of $CaCO_3$ and corncob biochar in Acid Ferralsols.

Key words: Soil acidity, Ferralsols, $CaCO_3$, corncob biochar, soybean grain yield

1.0 Introduction

Ferralsols in Central Uganda have been established to be strongly to very strongly acidic with pH ranging from 4.7 to 5.0. Besides, the soils have low exchangeable cation and low available N, P and K coupled with low organic matter and high Al^{3+} ion concentration (Drake *et al.,* 2017). The soils are becoming unfavorable for agricultural production thus requiring remediation strategy to reverse the threat. The soils are mostly found in the humid and sub-humid tropics, where temperatures and precipitation are high (FAO and ITPS, 2015). The ferralsols are the most dominant of the 22 soil types with 25 % spatial coverage in Uganda (Bamutaze, 2015). The extent and management of these soils are inadequate among smallholder farmers in Central Uganda due to the high cost of inorganic lime. Increasing crop production and productivity on these soils require the addition of soil amendments such as calcium carbonate, biochar etc., as soil fertility has shown to be a manageable practice, and its management is important for optimizing available plant nutrients to achieve crop yield. Notably, rapid soil fertility decline in Central Uganda is largely contributing towards reduce agricultural production and food security among smallholder farmers where majority of the population relies on subsistence farming as a source of livelihood. Inorganic fertilizer used as a significant soil nutrient replenishment is unsustainable, causing adverse environmental effects, including soil acidity (Kabasiita *et al*., 2022). Generally, soil acidity elevates aluminum (Al^{3+}) concentration within the soil solution to a level toxic to plants, limits the availability of essential plant nutrients, and restricts crop performance (Alvarez *et al.,* 2020). Restoring soil pH to an ideal range for agriculture production can have significant impact on crop yield. Henceforth, liming is the most common management practice used to neutralize and overcome problems associated with soil acidity (Fekadu *et al.,* 2019).

Dai *et al*., (2017) reported significant increase in soil pH when different rates of biochar were added. The ability of biochar particles to absorb the H^+ ions as well as decarboxylation processes are probably the main factors in soil acidity neutralization (Wang and Liang, 2013). Additionally, biochar has a large surface area, which improves soil structure, retains soil water, and impacts soil acidity (Jatav et al., 2021 and Latawiec., 2021). Research has shown that biochar produced from agricultural waste has high concentration of basic cations and available P that could be exploited for use as liming material and/or P source. Soils in Central Uganda are mostly acidic, and the use of agriculture lime is uncommon among farmers. The high cost of the material on the local market has made it difficult for used by farmers. There is also a problem of high transportation cost of the material to remote farming communities thus rendering it unavailable at agriculture supply stores. It is practically suitable to ensure alternative solutions are provided to farmers that would help ameliorate the deteriorating soil conditions to encourage production of soybean and other crops that are intolerable to acidic soil's conditions in the region. Said alternative material that would be suitable to farmers for liming acidic soils for crop production should be relatively cheap, readily available and preferably be in close proximity to their farms (Frimpong-Manso et al., 2020). Biochar, a biomass-derived carbonaceous material is often alkaline in nature, and therefore, it can be used as a liming material (Bolan et al., 2022). For example, biochar applied in acidic soils showed an increase in soil pH, resulting in positive plant responses (Deus et al., 2020 and Shi et al., 2019).

As soils become more acidic, plants that are intolerant to their conditions would be negatively affected leading to yield decline (Fekadu *et al.,* 2019). Achalu *et al.,* (2012) conducted a greenhouse-based incubation of acid soils treated with lime and the result showed that the application of 10 t ha^{-1} calcium carbonate incubated for 90 days significantly reduced the strength of soil acidity levels and severity of exchangeable acidity and Al^{3+} saturation in the soils. However, the current soil fertility management practices that smallholder farmers are using in the study area namely: recycling of crop residues, addition of cow dung manure, short fallow and biomass transfer appeared to be inadequate to counter the effects of soil acidity. Furthermore, the lack of awareness among farmers and the beneficial effects of agricultural lime in the study area is lacking. A preliminary study observed that, soil acidity coupled with the unavailability and high cost of conventional liming materials are among the major constraints to soil improvement for crop production in the area. Nonetheless, many smallholder farmers in Central Uganda depend on these soils to sustain themselves. Therefore, more attention needs to be directed to their improvement to increase and sustain production. Corncob biochar, a locally available material on farmers' fields in Central Uganda will serve as an alternative source to address the problem of soil acidity thereby helping resource limited farmers save on the cost of purchasing inorganic lime ($CaCO_3$). The study therefore seeks to determine the liming potential of $CaCO_3$ and corncob biochar on Acid Ferralsols in the Central Region of Uganda.

2.0 Materials and Methods

2.1 Description of the Study Location

The study was conducted in Central Uganda. Central Uganda has 19 districts. Three of which representing Central Uganda were randomly selected for the study. The greenhouse study was setup at Uganda Martyrs University (UMU) farm in Nkozi. Uganda Martyrs University (UMU) farm lies alongside the equator line at Latitude $0^0$00'7''N and Longitude $32^0$00'57''E. Generally, the rainfall distribution is bimodal with the first season (long rains) lasting from March to May while the second season (long rains) lasting from September to November. Annual rainfall is between 1,000 mm to 1,500 mm with minimum annual temperature ranging between 20-23 ^{0}C and the maximum between 23-36 ^{0}C (UMA, 2023). The field experiment to evaluate the different lime rates in Ferralsols and on soybean yield performance was setup and hosted by farmers in Mpigi, Wakiso and Mubende Districts respectively. The soils in these areas are predominantly Ferralsols (reddish in color), highly leached and weathered. They are generally acidic, infertile and are characterized with low levels of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+) and high levels of Al^{3+} and Fe^{2+}(Drake *et al.,* 2017).

2.2 Soil Sampling and Preparation

Mpigi, Mubende, and Wakiso Districts in Central Uganda were randomly selected. Thereafter, a zigzag path soil sampling pattern which is widely accepted and used across most regions in Sub-Saharan Africa (SSA) according to Esilaba et al., (2021) was used with the aid of an auger to collect soil samples from a depth of 0-20 cm. According to Okalebo et al. (2002), a minimum of nine core samples were taken and mixed thoroughly to form composite samples. Sub soil samples were placed in a plastic bag, labeled, and transported to “Les Rams Consultant, Water Quality, Soil and Plant Analysis Laboratory” situated in Kampala, Uganda, Apollo Kaggwa Road, Bwaise while the bulk soil samples were taken to Uganda Martyrs University Farm, Faculty of Agriculture in Nkozi for greenhouse incubation study. The sub soil samples were air dried and ground to pass through a 2 mm sieve and the initial pH determined.

2.3 Soil Chemical Analyses

Soil pH was determined in 1:2.5 soil water ratio using a glass electrode attached to a digital pH meter as described by Okalebo *et al*. (2002).

2.4 Greenhouse Incubation Study

Air-dried soil was ground to pass through a 2 mm sieve. Thereafter, 2 kg of soil was weighed and placed in a plastic container, and thoroughly mixed with different rates i.e., 0, 1, 3, and 5 g equivalent to 0, 1, 3 and 5 tons/ha of calcium carbonate and corncob biochar, moistened with 500 ml of distilled water to bring it to about field capacity thus allowing the reactions to take placed overtime. The soils were arranged in a factorial experiment layout in a Complete Randomized Design (CRD) consisting of four lime levels (0, 1, 3 and 5 tons ha^{-1}) replicated four (4) times and multiplied by the three (3) districts. Soils were continuously monitored and pH determination done biweekly for a period of three months until pH equilibration as described by Watson and Brown (1998).

2.5 Response and Determination of Soil pH to Liming

The lime levels 0, 1, 3 and 5 tons ha^{-1} were picked based on the work done by (Delfim *et al*., 2020) expecting to deliver pH 5.5, 6.0 and 6.5 in the field. The rates of lime applied in the field were determined by the below equation as described by (Van reeuwijk, 1992).

$$LR\ CaCO_3\ (kgha^{-1})\ \frac{cmol\ (+)\ EA\ of\ soil*0.15m*10^4\ m^2*BD\ (mg/m^3)*1000*1.5}{2000\ kg}$$

2.6 Experimental Design

The experimental design was a factorial layout in a Complete Randomized Design (CRD). The soybean varieties were used as the main plots while rates of calcium carbonate and corncob biochar were applied as the subplots. The treatments were replicated four times, and the crops spaced at 0.5 × 0.2 m for inter-row and intra-row. Subplot size was 2 × 2 m while main plot size was 8 × 2 m. Subplots were separated by 0.5 m pathways while main plots were separated by 1 m. The study had 16 main plots and 64 subplots. Each subplot had four rows with five plants per row. The length of the field was 41 m and width 11 m. The total area used for the experiment was 451 m^2.

2.7 Treatments Application

The different rates of $CaCO_3$ and corncob biochar determined from the greenhouse study as described in sub sections 2.4 and 2.5 were broadcasted and thoroughly incorporated into the soil at the depth of 15 cm, irrigated and allowed the reaction to take place for two weeks before sowing. Rates of $CaCO_3$ and corncob biochar were applied as the subplots while soybean varieties were applied as the main plots.

2.8 Agronomic practices

Soybean seeds were sown at a spacing described in sub section 2.6 while field irrigation was done at 50 % field capacity. Weed control measures were done at 3 weeks interval with the use of hand hoes. There were no insect and disease control measures applied neither were there serious insect or disease attack on the crop.

2.9 Average yield (kg/ha)

Yield in kg/ha was calculated by multiplying yield per plant by 10 000 m^2 and then dividing the sum by 1000 kg. This resulted to yield in kg/ha.

2.10 Data collected

For the greenhouse study, ten g of soil was collected from each plastic container for soil pH determination as described by Okalebo *et al*. (2002). For the field experiments, soil samples were collected before planting and at 50 % flowering and the pH was determined. For soybeans, data was collected on grain yield following the procedures described by Pedersen (2015).

2.11 Data analysis

All data collected were subjected to analysis of variance (ANOVA) using GENSTAT 16th edition and declared significant at $p<0.05$ using the statistical model as described by Gomez and Gomez (1984). Separation of mean was done using the Duncan's Multiple Range Test (DMRT) and conclusions made at $p<0.05$ levels of significance.

3.0 Results and Discussions

3.1 Main effect of lime rates and incubation period on soil pH optimization

The analysis of variance (ANOVA) showed that the main factors i.e., rates of $CaCO_3$ and corncob biochar application have significant effect ($P<0.001$) on the soil pH followed by the study locations ($P<0.001$). Interaction effect and incubation period also showed significant difference ($P<0.001$) when rates of $CaCO_3$ and corncob biochar were applied (Table 1). Besides, the study locations and treatments were observed to have showed significant effect ($P<0.001$) on the initial soil pH prior to treatment applications. When rates of $CaCO_3$ and corncob biochar were added, the study observed the soil pH gradually changing (Table 2). Hence, the application of 5 g $CaCO_3$ showed an increase in the soil pH to the targeted levels with Mubende recording the highest (6.7) in week 8 followed by Mpigi and Wakiso Districts in week 12 (Table 2). Our findings are in conformity to those of Fekadu et al. (2019) who reported increase soil pH from 3.9 to near optimal pH of 6.0 and 6.5 when rates of $CaCO_3$ were applied. Application rate of 3 g of $CaCO_3$, significantly altered the soil pH from 4.7 and 5.0 to 5.8, 6.0, 6.1, 6.2, 6.3, 6.4 and 6.6 in the three study locations with the highest pH recorded in Wakiso District (Table 2).

The study observed incubation period to have had significant adjustment on the initial soil pH at 4 weeks interval. In Mpigi District, application rate of 1 g $CaCO_3$ affected the soil pH from 4.7 to 5.2 in Week 4 and 5.5 in week 8 followed by 5.8 in week 12 while Mubende District observed the soil pH to have changed from 5.0 to 5.7 in week 4 and 5.9 in week 8 followed by 6.0 in week 12 (Table 2). In Wakiso District, the initial soil pH was also observed to have altered significantly from 5.0 to 5.9 in week 4 and 6.1 in week 8 followed by 6.2 in week 12 when 1 g of $CaCO_3$ was applied as treatment. Increased treatment rates to 3 and 5 g of $CaCO_3$, the soil pH was observed to have changed significantly to 5.8 and 6.7 in the different study locations as shown in Table 2. Our findings are in agreement to those of

Nyamaizi et al. (2021) who reported significant soil pH alteration from 4.1, 4.8, and 5.5 to 6.0 and from 5.8 to 6.5 at different intervals when higher rates of lime were applied.

Incubation period also observed application rates of corncob biochar shifting the soil pH across the different study locations with 5 g significantly changing the initial pH to 5.6 in week 4, 5.7 in week 8 and 5.9 in week 12 (Table 2). Our findings however recorded uncleared pH trends when rates of $CaCO_3$ and corncob biochar were applied. The uncleared trends showed that soil in the study area reacted differently to the two liming materials. Similarly, Fekadu *et al*. (2019) reported no clear trends on soil pH when rates of lime were applied to acid soil and allowed to incubate for four weeks. Nonetheless, the recorded soil pH in the study i.e., 5.5, 5.8, 5.9, 6.0, 6.1, 6.4, and 6.5 clearly offers an ideal soil environment for agricultural activities. Likewise, FAO (2012), reported soil pH of 6.5 to 7.5 as ideal for agricultural production. Application rates of 1 and 3 g biochar slowly observed the shift in soil pH as shown in Table 2. In week 4, 8 and 12, 1 g of biochar had increased the soil pH from 4.7 to 5.2, 5.3 and 5.4 in Mpigi District while in Mubende District, 1 g of biochar moved the soil pH from 5.0 to 5.4, 5.6 and 5.8 (Table 2). Similarly, in Wakiso District the initial soil pH of 5.0 was significantly influenced resulting to 5.6, 5.8 and 6.0 thus signifying 2 % increased when 1 g of biochar was applied.

3.3 Effect of lime rates on soil pH in Ferralsols of Central Uganda

Significant difference ($p<0.001$) was observed on soil pH in plots sown with improved soybean genotype with Mubende recoding the highest soil pH (6.7) followed by Mpigi (pH 6.6) and Wakiso (pH 6.3) Districts respectively. The application of 600 g of $CaCO_{3,}$ altered the soil pH from 4.7 in Mpigi District to 6.7. Likewise, in Mubende District the soil pH was observed to have changed from 5.0 to 6.6 when 600 g of $CaCO_3$ was applied. In agreement to our findings, Warner *et al.* (2023) reported highest dose of lime application in acid soil to the highest value of soil pH (6.7). The study also observed that plots treated with extra quantities of liming materials recorded the highest soil pH in the selected districts as shown in figure 1.

Besides, the study observed that plots treated with 120 g of corncob biochar increased the soil pH across the selected districts used in the study. The soil pH prior to treatment application was observed to have changed from 4.7 and 5.0 to 5.2, 5.3, 5.4 and 5.5 in Mpigi, Wakiso and Mubende Districts as shown in Figure 1. Our findings conformed to studies done by Frimpong (2018) who reported significant increased ($p<0.001$) in soil pH when rates of corncob biochar were applied as liming material for soil pH improvement in acid soil. Similarly, a field trial conducted by Bass *et al.* (2016), observed the application of biochar to have significantly increased the soil pH in the first half of a field trial and at the trial completion. It was observed that, plots treated with 360 g of $CaCO_3$ and sown with improved soybean recorded the highest soil pH in Mpigi District with a slight increase in plots sown with local soybean in Mubende and Wakiso Districts (Figure 1). The study showed that $CaCO_3$ is a superior liming material for soil pH adjustment in Ferralsols as opposed to corncob biochar.

3.4 Effects of liming on soybean grain yield in Acid Ferralsols

The study recorded significant difference ($p<0.001$) on soybean grain yield as shown in Figure 2. When interaction of treatment and soybean yield were evaluated, the study observed significant difference ($p<0.001$) on grain yield among the two soybean genotypes. Plots sown with improved soybean and treated with 600 g of $CaCO_3$ recorded the highest (7137.5 kg ha^{-1}) grain yield in Wakiso District followed by 6600 kg ha^{-1} grain yield in Mubende District. The study also found that plots treated with 600 g of corncob biochar recorded significantly higher (5637.5 kg ha^{-1}) soybean yield in Mpigi compared to plots treated with 120 and 360 g of biochar. Our findings conformed to those of Yooyen *et al.* (2015) who reported elevated levels of soil pH, and showed statistically significant difference ($p<0.05$) on soybean grain yield when treated with corncob biochar compared to the control plot (0 kg ha^{-1}).

The study recorded considerable increase in soybean grain yield with extra application of $CaCO_3$ and corncob biochar in the three study locations compared to plots treated with 0 g of $CaCO_3$ and corncob biochar. Similarly, Bedassa *et al.* (2022) reported maximum soybean grain yield of 1943.93 kg ha^{-1} under lime treated soil as opposed to 510.49 kg ha^{-1} under lime untreated acid soil. In the same way, Ameyu *et al*. (2022) showed that 'no lime' gave the lowest grain yield of 1269 kg ha^{-1} compared to 6268.9 kg $ha-^{1}$ of soybean grain yield in limed acid soils.

4.0 Conclusion

At the end of the greenhouse incubation and field study, soil pH was successfully raised to the target values with the addition of $CaCO_3$ and corncob biochar. We observed increasing trends of soil pH from the initial to near neutral at which plants thrived. Because extra amount of $CaCO_3$ and corncob biochar were added, the final soil pH reached 6.7 in the selected districts. The results highlight the potential effects $CaCO_3$ has on soil acidity as opposed to corncob biochar. The relationship indicates that the increasing trends of soil pH could be due to the association of Ca^{2+} acting as a sink for the suspension of Al^{3+} and H^+ on the soil exchange sites. The role of $CaCO_3$ and corncob biochar certainly deserve combined investigation when studying liming effects in acid Ferralsols for soil pH improvement and soybean grain yield.

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Table 1: Source of variation for the greenhouse incubation study

Source of Variation	d.f	P.H
Location	4	21.58***
Treatment	7	19.77***
Week	4	0.14^{NS}
Location × treatment	28	2.59***
Location × Week	16	0.24*
Treatment × Week	28	0.07^{NS}
Location × Treatment × Week	112	0.10^{NS}
Residual	600	0.12
SE		0.3466
LSD		0.4813
CV (%)		6.4

***Significant at 0.1%, **Significant at 1%, *Significant at 5%, NS=Not Significant, df=degrees of freedom

Table 2: Weekly soil pH levels at different incubation periods

District	Treatment (g)		Week 4	Week 8	Week 12
Mpigi	$CaCO_3$	0	4.7c	4.7c	4.7c
		1	5.2b	5.5b	5.8b
		3	6.2a	6.3a	6.4a
		5	6.4a	6.5a	6.7a
	Biochar	0	4.7c	4.7c	4.7c
		1	5.2b	5.3b	5.4b
		3	5.4b	5.5b	5.7b
		5	5.6b	5.7b	5.9b
Mubende	$CaCO_3$	0	5.0b	5.0b	5.0b
		1	5.7b	5.9b	6.0a
		3	5.8b	6.1a	6.4a
		5	6.6a	6.7a	6.7a
	Biochar	0	5.0b	5.0b	5.0b
		1	5.4b	5.6b	5.8b
		3	5.5b	5.8b	6.0b
		5	5.9b	6.0a	6.2a
Wakiso	$CaCO_3$	0	5.0b	5.0b	5.0b
		1	5.9b	6.1a	6.2a
		3	6.0a	6.3a	6.6a
		5	6.3a	6.5a	6.7a
	Biochar	0	5.0b	5.0b	5.0b
		1	5.6b	5.8b	6.0a

3	5.8b	6.1a	6.3a
5	6.0a	6.3a	6.5a

Note: a, b and c means sharing a letter in their superscript are not significantly different at the 0.05 level. However, a and b, b and c and c and a are significantly different at 0.05 level.

Table 3: Quantity of lime applied to raise the soil pH to the expected pH

Rates of liming materials per 2 Kg weight of soil applied in the greenhouse	Amount of lime applied in the field (g/plot)	Expected pH value
Control	0	5.0
1g	120	5.5
3g	360	6.0
5g	600	6.5

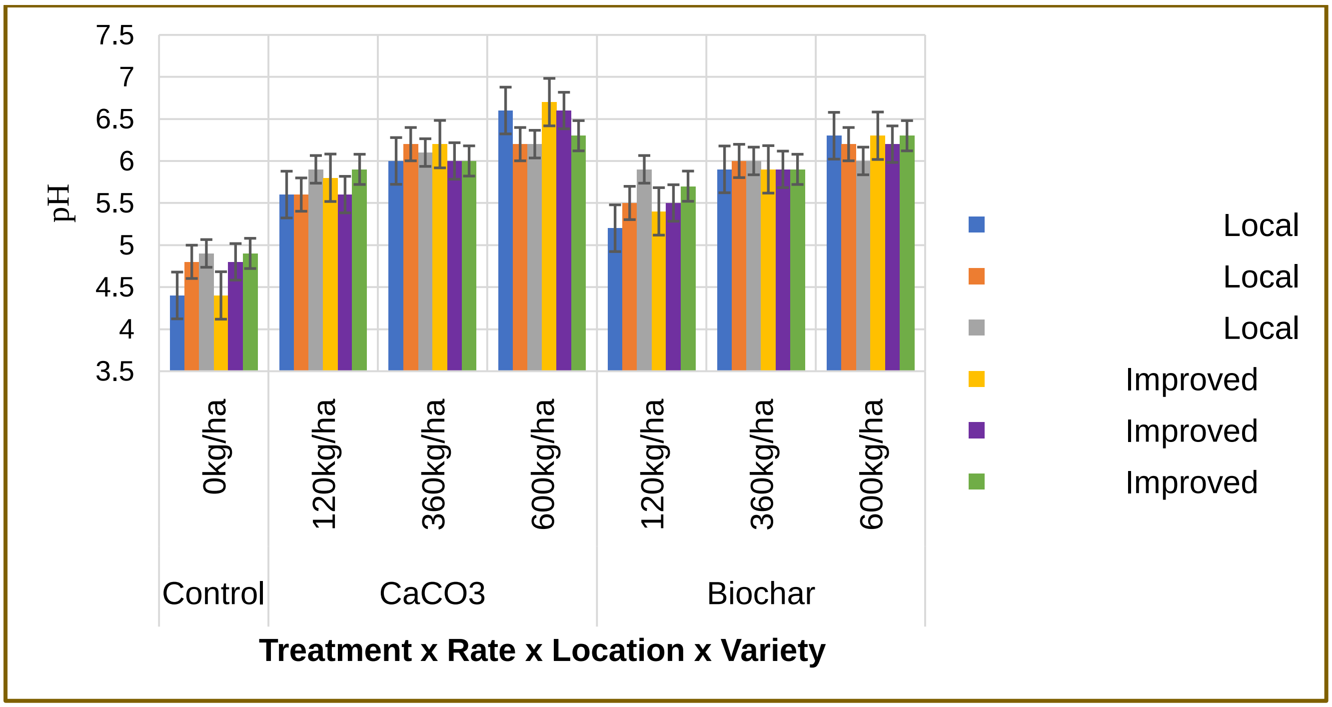

***Figure 1**: Soil pH response to liming on acid Ferralsols in Central Uganda*

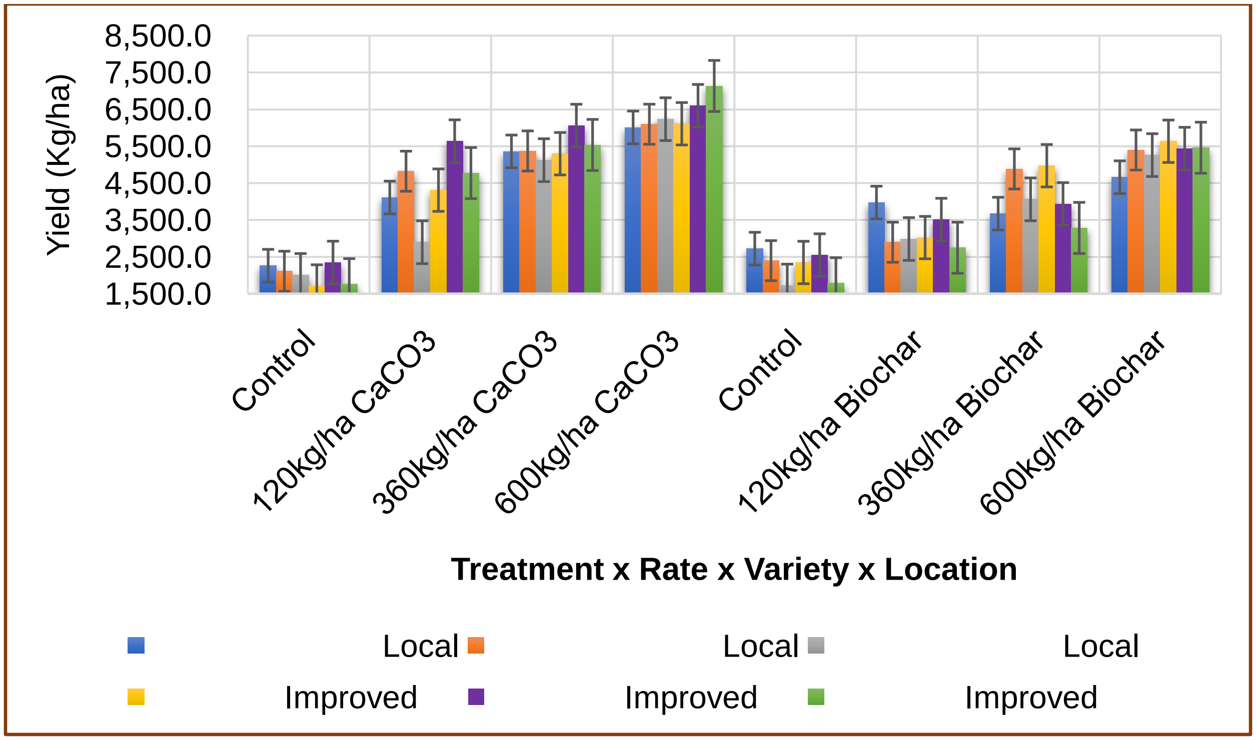

Figure 2: Effects of lime rates on soybean grain yield in Ferralsols of Central Uganda