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Effects of lime on soil chemical characteristics and performance of cowpea [*Vigna unguiculata* (L.) Walp.] on Oxic Haplustalf of a derived savanna ecology of Nigeria

ARUNA OLASEKAN ADEKIYA*, BOLAJOKO BISOLA AYORINDE[1], ELIZABETH TEMITOPE ALORI[1], CHARITY AREMU[1] AND WUTEM SUNNY EJUE[1]

Agriculture Programme, College of Agriculture
Engineering and Science, Bowen University, Iwo, Osun State. Nigeria
**(e-mail: adekiya2009@yahoo.com)*

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ABSTRACT

The use of lime in reducing acidity, increasing nodulation and grain yield of field cowpea in Nigeria had not been determined. Hence, field experiments were conducted in 2020 and 2021 cropping seasons at the Landmark University, Omu-Aran, Nigeria. The study was undertaken to evaluate the effects of lime on soil chemical characteristics, growth, nodulation, and yield of cowpea on tropical-derived savanna. The treatments in each year consisted of five levels (0, 2.5, 5.0, 7.5 and 10 t/ha) of lime ($CaCO_3$). The treatments were arranged in a RCBD and replicated three times. Findings showed that the application of lime improved soil chemical characteristics (pH, N, P, K, Ca, Na, Mg and CEC), growth, nodulation and yield of cowpea compared to the control. Lime application reduced acidity ($H+Al^{3+}$) relative to the control. Lime increased the yield of cowpea from 0 to 2.5 t/ha after which there was a decrease. 2.5 t/ha lime increased pod weight of cowpea relative to the control by 51.2% in 2020 and 48.2% in 2021. 10 t/ha lime reduced pod weight of cowpea relative to the 2.5 t/ha by 237.62% in 2020 and 257.1% in 2021, the reduction in the yield of cowpea can best be explained by the presence of unfavourable soil pH conditions. Therefore, the optimum yield of the cowpea crop was achieved at 2.5 t/ha of lime for the agro ecological zone.

Key words: Cowpea, lime, nodulation, pod weight, soil chemical characteristics

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is one of the most important grain legume crops grown and consumed in Sub-Saharan Africa (SSA), particularly in Nigeria, contributing to food security and environmental preservation for millions of small-scale farmers in the region (Boukar *et al.*, 2019). Cowpea is a cheapest source of dietary protein complementing the low protein of cereals and tuber crop-based food consumed in sub–Saharan African countries (Fatokun *et al.*, 2020). Dried seeds of cowpea are used in various food preparations, green pods and seeds are used as vegetables for human consumption (Simon, 2018). The pods and leaves of cowpea are used as fodder for livestock (Ghady and Alkoaiki, 2010).

Yield per unit area of land in Nigeria is gradually reducing daily due to low fertility and degradation especially in savanna soil where cowpea is mostly grown that is faced with a lot of challenges. Under tropical conditions, the soil's organic matter level drops dramatically due to the typical intense rainfall and express mineralization of organic matter, resulting in the loss of some nutrients, particularly cations, which lower the soil pH. Reports also indicate that poor legume productivity on most small holder farms in sub-Saharan Africa is due to degradation as a result of poor soil management practices (Chianu *et al.,* 2011; Balume 2013). One of the main causes of soil degeneration is soil acidity, which lowers the pH of the soil and the amount of vital nutrients that are available, lowering crop output. According to Adekiya (2022), soil acidity may

[1]College of Agricultural Sciences, Landmark University, PMB 1001, Omu-Aran, Kwara State, Nigeria.

result in lower yields, poor legume nodulation and stunted root growth. Soil acidity limits symbiotic N_2-fixation, reduces nodulation, and causes nutrient imbalance (Fageria *et al.*, 2013; Kamble *et al.*, 2017; Abera and Abebe, 2018; Jinisha Blessie *et al.*, 2021). In order to improve the productivity of the soil and cowpea performance, the pH of such soil should be raised to a level that it becomes suitable for optimum growth of plants.

Soil acidity can be corrected through the application of agricultural lime. It is the application of calcium and magnesium-rich materials to soil in various forms, including marl, chalk, limestone, or hydrated lime. Liming can help boost the productivity of an agricultural soil by reducing the possible amount of manganese and aluminum ion toxicity, it can also contribute to improve microbial activities of the soil, improve the physical condition of the soil, improve the symbiotic nitrogen fixation by legumes, makes nutrients available for plant uptake. The improvement of acidic soils raises the availability of various plant nutrients, raises the base saturation, and inactivates iron, aluminum and manganese in the soil solution. As a result, the amount of phosphorus that is fixed by iron and aluminum is reduced (Meena and Prakasha, 2020; Asiwe and Nkuna, 2021).

However, the contribution of lime in reducing acidity, increasing nodulation and grain yield of field cowpea in Nigeria had not been determined. In fact, to the best of my knowledge, no study on the effects of lime on cowpea soil and cowpea productivity existed in Nigeria. The optimum rate of lime for cowpea production in the agro-ecological zone has not been properly documented, this is necessary for profitable farming to avoid wastage of lime or reduction in crop yield. Therefore, the objectives of this current study were to determine the effects of lime on soil chemical properties, growth, nodulation and yield of cowpea grown on a derived savanna Alfisol.

MATERIALS AND METHODS

Site Description and Experimental Layout

A field experiment was conducted for two years (2020 and 2021) at the Teaching and Research Farm, Landmark University, Omu-Aran, Kwara State. The study was conceived to evaluate the effects of lime on soil chemical characteristics, growth, nodulation and yield of cowpea on tropical-derived savanna. Alfisol. Landmark University lies within Latitude 8°7' 26.21388" and 5° 5'0.1788". The total annual rainfall in the area is about 1300 mm, while the mean annual temperature is 32°C. The soil of the experimental sites is Alfisol classified as Oxic Haplustalf or Luvisol (USDA, 1999).

The treatments in each year consisted of five levels (0, 2.5, 5.0, 7.5 and 10 t/ha) of lime [calcium carbonate ($CaCO_3$)]. The treatments were arranged in a randomized complete block design (RCBD) and each treatment was replicated three times. Each block comprised five plots and each plot measured 2 × 2 m. The space between blocks was 1 m apart, while the spacing between plots was 1 m apart.

Application of Lime and Crop Establishment

The lime used for the experiment was calcium carbonate ($CaCO_3$) and was purchased from Agric. Center Ilorin, Kwara State. Each year, the land was prepared by the conventional method of ploughing and harrowing, after which the experimental site was laid out to the required plot size of 2 × 2 m. Immediately after land preparation, lime was weighed at the specified rates of 0, 2.5, 5.0, 7.5 and 10 t/ha which were, respectively, equivalent to 0, 0.5, 1.0, 1.5 and 2.0 kg per plot and were spread evenly on the plots and was incorporated using a hoe to a depth of about 10 cm. This was done two weeks before the sowing of cowpea seeds.

Sowing of cowpea seeds (Variety Paiyur 1 released during 1985 by Tamil Nadu Agricultural University, India) was done on August 20 each year. Three seeds were sown using inter-row spacing of 20 cm and intra-row spacing of 75 cm apart. Thinning to one plant per stand was done two weeks after sowing to give a plant population of 21 plants per plot and 53,333 plants per ha for the erect variety. Two manual weedings were done during the experiment. Insect-pests were controlled by spraying cypermethrin weekly at the rate of 30 ml per 10 l of water from two weeks after sowing.

Determination of Soil Properties

Before the application of treatments each year, soil samples from 0–0.15 m depth were randomly collected from 10 points from each experimental site (year). The soil samples were bulked together, air-dried and sieved with a 2 mm sieve for soil physical and chemical analysis. The hydrometer method was used for the determination of particle size (Gee and Or, 2002). Soil organic carbon (OC) was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). Total N was determined by the micro-Kjeldahl digestion method (Bremner, 1996). Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank *et al.*, 1998). Exchangeable K, Na, Ca and Mg were extracted using 1 M ammonium acetate (Hendershot *et al.*, 2007). Thereafter, the concentration of K was determined on a flame photometer, while Na, Ca and Mg were read on an Atomic Absorption Spectrophotometer. Soil pH was determined using a soil-water medium at a ratio of 1:2 with a digital electronic pH meter. Exchange acidity was determined by weighing 5 g of dried soil into a sample bottle and 50 ml of 1M Kcl was added to it. The mixture was shaken for 1 h and the suspension was filtered using filter paper to obtain a filtrate. Four drops of phenolphthalein indicator were added to 25 ml of the extract in a 100 ml conical flask. 0.01M NaOH was used to titrate the mixture. At the final point, the colour shifted from colourless to pink.

$$\text{Exchangeable acidity} = \frac{(T - B) \times CNaOH \times V1 \times 100}{\text{Weight of soil} \times V2}$$

Where, T = sample titre value (ml), B = blank titre value (ml), W = soil weight (g), V1 = volume of extracting solution (ml), V2 = volume of soil extract (ml), CNaOH = standardized concentration of NaOH (0.002 M NaOH). The summation approach was used to calculate the CEC in this study, which is the total of the exchangeable bases and exchangeable acidity (Anderson and Ingram, 1993).

Three plants were excavated with their rhizosphere soils intact, this was done when the cowpea plants had attained 50% flowering on a plot basis (65 days after sowing). The nodules in the roots of the excavated plants were counted with the aid of a magnifying glass. At the end of the experiment, soil samples were also collected on a per plot basis. The collected soil samples were air-dried and sieved using a 2-mm sieve and analyzed for soil chemical properties as described above.

Determination of Growth and Yield Parameters

Growth data were collected at mid-flowering of the cowpea plant (65 days after sowing). The number of leaves was determined by counting the number of fully expanded leaves, vine length was determined using a measuring tape and the number of branches per plant was determined by counting the number of branches on the plant.

The cowpea pods were harvested at maturity and the number of harvested pods were counted and recorded per plot and per treatment. Harvested matured cowpea pods were weighed using a sensitive weighing balance and the value recorded on plot basis.

Statistical Analysis

Data collected were subjected to statistical analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS, Institute Inc., 2009). The treatment means were compared using the Duncan Multiple Range Test (DMRT) at 0.05 level of probability.

RESULTS AND DISCUSSION

Soil Physical and Chemical Characteristics of the Sites Before Sowing of Cowpea

The physical and chemical characteristics of the soils of the experimental sites before experimentation in 2020 and 2021 are given in Table 1. The soils of the two years were sandy loam in texture, strongly acidic (FFD, 2011), low in nutrients (Organic C, N, P, K and Ca) and adequate in Mg according to the critical level of 3.0% OM, 0.20% N, 10.0 mg/kg available P, 0.16-0.20 cmol/kg exchangeable K, 2.0 cmol/kg exchangeable Ca and 0.40 cmol/kg exchangeable Mg recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000) The CEC

Table 1. Soil physical and chemical properties of the experimental sites prior to planting

Property	2020	2021
Sand (%)	68.2	68.1
Silt (%)	16.1	16.1
Clay (%)	15.7	15.8
Textural class	Sandy loam	Sandy loam
Organic C (%)	1.13	1.14
pH (water)	5.33	5.30
pH (KCL)	5.28	5.28
N (%)	0.11	0.15
P (mg/kg)	9.2	9.6
K (cmol/kg)	0.14	0.14
Ca (cmol/kg)	0.99	0.99
Mg (cmol/kg)	0.81	0.82
Na (cmol/kg)	0.11	0.11
(H+AL) (cmol/kg)	1.80	1.82
CEC (cmol/kg)	3.85	3.88

value for 2020 was 9.2 cmol/kg, while 2021 contained 9.9 cmol/kg.

Effect of Lime on Soil Chemical Properties

The effects of lime on soil chemical properties are shown in Tables 2 and 3. Lime application significantly influenced soil pH, N and P values of the soil relative to the control. Application of lime did not affect the organic C content of the soil relative to the control. Lime increased pH from 0-10 t/ha lime rate, while N and P values were increased only up to 7.5 t/ha after which there was a decrease. Also, the application of lime significantly influenced the amount of Na, Ca, Mg, K and CEC in the soil. The increase was from 0-10 t/ha. There was, however, a reduction of soil acidity (H+AL) as the level of lime was increased from 0-10 t/ha (Table 3).

Effect of Lime on the Growth and Yield Parameters of Cowpea

The effects of lime on the growth parameters (vine length per plant, number of leaves per plant and number of branches per plant) are shown in Table 4. Lime significantly influenced the vine length per plant number of leaves per plant and number of branches per plant relative to the control. The increase

Table 4. Effect of lime on the growth parameters of cowpea for sites A and B

Lime (t/ha)	Vine length (cm)		No. of leaves/ plant		No. of branches/ plant	
	2020	2021	2020	2021	2020	2021
0	105.9e	122.9e	420.0e	463.0e	140.0d	154.3d
2.5	223.5d	233.5d	942.0d	1010.0d	314.0c	336.7d
5.0	235.2c	257.0c	1206.0c	1256.0c	402.0b	418.7c
7.5	252.2b	263.5b	1246.0b	1300.0b	415.3b	433.3b
10	270.2a	288.7a	1368.0a	1348.0a	456.0a	459.0a

Values followed by similar letters under the same column are not significantly different at p = 0.05 according to Duncan's multiple range test.

Table 2. Effect of lime on soil chemical properties (pH, N, OC and P)

Lime (t/ha)	pH (H_20)		N (%)		OC (%)		P (mg/kg)	
	2020	2021	2020	2021	2020	2021	2020	2021
0	5.30d	5.28d	0.10e	0.11e	1.11ab	1.12ab	9..0e	9.3e
2.5	5.54c	5.80c	0.11d	0.13d	1.11ab	1.12ab	10.5d	10.8d
5.0	6.31b	6.3b1	0.11cd	0.14c	1.12ab	1.12ab	15.9c	18.8c
7.5	6.51b	6.61b	0.18a	0.17a	1.13a	1.12ab	23.4a	23.9a
10	7.22a	7.12a	0.14ab	0.16ab	1.13a	1.23a	19.1b	21.2ab

Values followed by similar letters under the same column are not significantly different at P = 0.05 according to Duncan's multiple range test.

Table 3. Effect of lime on soil chemical properties (Na, Ca, Mg, K, H+AL and CEC)

Lime (t/ha)	Na (cmol/kg)		Ca (cmol/kg)		Mg (cmol/kg)		K (cmol/kg)		H+AL (cmol/kg)		CEC (cmol/kg)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
0	0.10e	0.10e	0.98e	0.96e	0.78e	0.79e	0.10d	0.13d	1.90a	1.91a	3.86d	3.62d
2.5	0.26d	0.25d	2.89d	2.99d	2.59d	2.60d	0.52c	0.49c	1.80ab	1.81ab	8.06c	8.14c
5.0	0.32c	0.33c	3.01c	3.04c	3.03c	3.05c	0.55b	0.53b	1.20c	1.19c	8.11c	8.14c
7.5	0.43b	0.42b	3.65b	3.67b	3.75b	3.77b	0.56b	0.55b	0.80d	0.81d	9.19a	9.22a
10	0.53a	0.54a	3.85a	3.88a	3.85a	3.88a	0.59a	0.61a	0.00e	0.00e	8.84b	8.91b

Values followed by similar letters under the same column are not significantly different at P = 0.05 according to Duncan's multiple range test.

in growth parameters with lime application was from 0-10 t/ha lime rate.

The effects of lime on the pod weight per plant and number of pods per plant are shown in Figs. 1 and 2, respectively. There was a significant increase in the pod weight and the number of pods of the cowpea when lime was applied relative to the control. 2.5 t/ha lime increased pod weight of cowpea relative to the control by 51.2% in 2020 and 48.2% in 2021. However, the increase in cowpea pod weight was only up to 2.5 t/ha, while that of the number of pods was 5.0 t/ha lime after which there was a reduction in cowpea yield parameters. 10 t/ha lime reduced pod weight of cowpea relative to the 2.5 t/ha by 237.62% in 2020 and 257.1% in 2021.

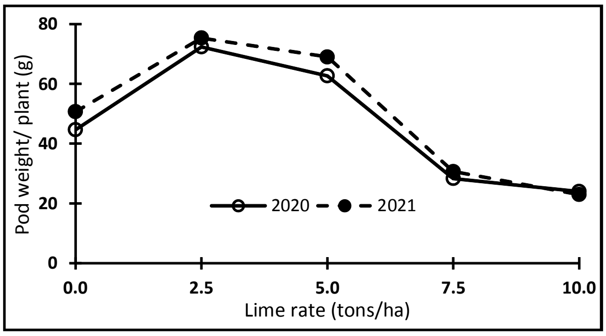

Fig. 1. Effects of lime application on pod weight of cowpea.

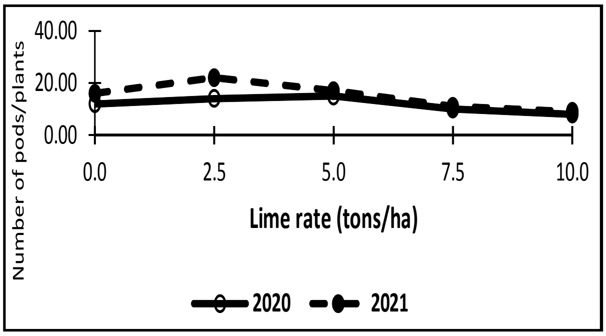

Fig. 2. Effects of lime application on number of pods of cowpea.

Effect of Lime and Biochar on the Number of Root Nodules of Cowpea

Fig. 3 shows the effects of lime on the number of nodules of cowpea. Lime increased the number of nodules of cowpea relative to the control. However, lime increased root nodules in this experiment up to 2.5 t/ha after which there was a decrease. The highest number of root nodules of cowpea was attained at 2.5 t/ha lime level.

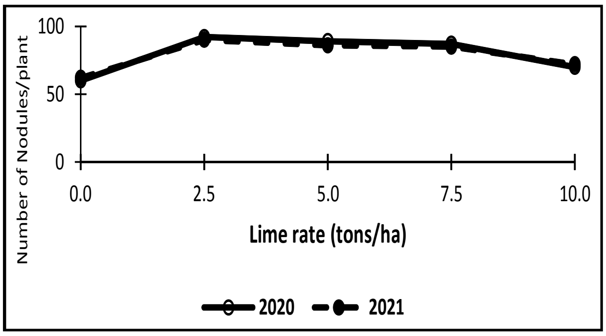

Fig. 3. Effects of lime application on number of nodules of cowpea.

The soil used for the experiment was low in nutrients. These conditions are the characteristics of savanna Alfisols (Adegbite *et al.*, 2020). The low soil fertility status could also be attributed to years of previous cultivation with implements such as disc plough, disc harrow, and disc ridger, as well as tractor wheel traffic, which compacts the soil and degrades its properties (Agbede *et al.*, 2020).

The pH of lime applied soil was increased due to the displacement of H^{+}, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption sites by the Ca^{2+} ion in the lime ($CaCO_3$) (Ameyu, 2019). The increase in soil N due to lime application has been linked to an increase in soil pH. When the pH of the soil is acidic, certain main critical elements, such as nitrogen, phosphorus, and potassium, become fixed in the soil and are no longer easily accessible to plants for consumption (Menzies, 2003). However, after applying lime, the pH of the soil increased, which led to an increase in the amount of nitrogen fertilizer that was accessible in the soil.

Cowpea is characterized by having the ability to house rhizobia bacteria, which contributes to the fixation of nitrogen for legume crops. This could be another reason for increased N. On the other hand, soils that are acidic (the control) can make it difficult for beneficial bacteria to thrive and fix atmospheric nitrogen into the soil. The addition of lime causes an elevation in the pH of the soil, which in turn facilitates an increase in the rate at which phosphate ions are released into the soil solution (Kisinyo, 2016). P is typically bonded to iron and aluminum oxides and hydroxides via chemical precipitation or physical adsorption (Li *et al.*, 2016). However, lime application may increase soil pH, so facilitating the release of phosphate ions fixed by Al and Fe ions. Thus, application of lime aids in hydrolyzing Al and Fe ions precipitated by P. Thus, the precipitated phosphate ion is released into the soil solution, making it available for plant absorption. Liming can also enhance soil P by providing an environment that is beneficial for the growth of microorganisms as a result of raising the pH of the soil. This increases the availability of P by mineralizing organic P, which makes P more readily available (Ameyu, 2019).

The addition of lime (calcium carbonate) increases the number of exchangeable cations in the soil. Negative charges of the soil exchange complex are displaced by basic cations following the neutralization of a portion of the soil's acidity through the application of lime (Achalu *et al.*, 2012). The application of lime ($CaCO_3$) to acidic soils led to a small increase in exchangeable Mg and K (Jafer and Hailu, 2017). The rise in CEC due to liming could be related to the change in pH and the release of the initially occluded amorphous and interlayer substitutive negative charge via Ca^{2+}-induced deprotonation of the variable charge minerals and functional groups of humic substances (Ameyu, 2019).

The increased yield of cowpea associated with the application of lime over the control was since lime reduces acidity and, as a result, toxicity levels of Al, Fe and Mn, and, as a result, improves the chemical and biological properties of the cowpea soil. This was because lime improves the chemical and biological properties of cowpea soil (Badole *et al.,* 2015). The root system suffers immediate harm as a result of al toxicity (Silva *et al.*, 2010). The presence of aluminum in the soil close to the roots will obstruct the meristem cell division section, which will result in the cessation of root extension and a reduction in root penetration strength (Pavlovkin *et al.*, 2009) and therefore poor yield in the control plots. Costa and Rosolem (2007) had earlier reported that liming equivalent to 2.25 t/ha on acid soil (pH 4.5) decreased Al-exchangeable and increased soybean yield about 20% compared no liming. The use of lime could have been another factor that helped release some of the fixed phosphorus so that it could be used by cowpea. In Nigeria, Sarker *et al.* (2014) found that adding lime to the soil improved the pH and made phosphorus (P) more accessible to cowpea. Therefore, the application of lime in acidic soil maximizes the availability of P in the soil which is very important in cowpea cultivations (Adekiya, 2022). The increase in the yield of cowpea due to the lime application can also be adduced to the improvement of the Ca and Mg soil contents and reduction of soil acidity (Kisinyo *et al.,* 2014). In addition, liming also improves biological N_2 fixation in acid soils and enhances the net mineralization of organic N (Bakari *et al.*, 2020).

The application of lime also significantly improved nodulation when compared with the control. Lime had been reported to raise soil pH (Kisinyo *et al.,* 2014), which makes the soil P more readily available for cowpea uptake hence better nodulation. Whereas P is an important nutrient element for cowpea production. Phosphorus is critical to cowpea yield because it is reported to stimulate growth, initiate nodules formation as well as influence the efficiency of rhizobium-legume symbiosis (Haruna, 2011). Phares *et al.* (2020) also observed significantly increased nodulation of cowpea varieties due to high presence of P in the soil. Also, lime soils could improve nodulation of cowpea better than the control due to the fact that molybdenum which enhances the activity of the nitrogenase enzyme in nodules becomes available when acid soils are limed (Adhikari and Missaoui, 2017).

At higher levels of lime there were drastic reductions in the number of nodules and yield of cowpea, the reduction in the yield of cowpea can best be explained by the presence of unfavourable soil pH conditions. A pH condition above 7.0 is said to be alkaline (FFD, 2011). This is not the best pH condition to crop cowpea. The liming of acidic soils results in the release of P for plant uptake (Sarker *et al.*, 2014). Increase in availability of P in the pH range of 5.0 to 6.5 is associated with release of P ions from Al and Fe oxides, which is responsible for P fixation and therefore good nodulation and yield of the cowpea. But at high pH (> 6.5) soluble P precipitated as Ca phosphate (Jensen, 2010) and making nodulation and yield of cowpea reduced. Results (Soares *et al.*, 2014) have shown that just like low soil pH severe alkaline soils will reduce the yield of cowpea. Iron, zinc and often manganese deficiencies or lime-induced chlorosis brought about by high levels of calcium and magnesium carbonates in the soil are most probably also factors in causing lower cowpea yield (Goenaga *et al.*, 2010). A very severe alkaline condition can also poise the crop to experience some diseases such as very severe leaf chlorosis. Seed germination might occur in a very alkaline condition but will be very poor afterward can cause stunted growth without producing pods or death of the crop eventually.

CONCLUSION

Findings from this experiment showed that the application of lime improved soil chemical characteristics (pH, N, P, K, Ca, Na, Mg and CEC), growth (vine length per plant, number of leaves per plant, number of branches per plant), nodulation and yield parameters of cowpea (pod weight per plant and number of pods per plant) compared to the control. Lime application reduced acidity ($H+Al^{3+}$) relative to the control. Lime increased the yield of cowpea from 0 to 2.5 t/ha after which there was a decrease. At higher levels of lime there were drastic yield reductions of cowpea, the reduction in the yield of cowpea can best be explained by the presence of unfavourable soil pH conditions. Therefore, the optimum yield of the cowpea crop was achieved at 2.5 t/ha of lime for the agro-ecological zone. To reduce costs, the use of locally sourced lime (wood ash) should be investigated in the future.

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