**Soil Fertility of Coarse-Textured Ultisols and Soybean Growth in Response to Natural and Synthetic Lime and P-Fertilizer Amendments**

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**Abstract**

In an eighteen-week glasshouse study, effects of wood ash (WA) and calcium oxide (CaO-88%) and those of rock phosphate (RP) and single superphosphate (SSP) as organic and inorganic lime/P-fertilizer sources, respectively on fertility status of coarse-textured Ultisols at Nsukka and soybean growth were assessed. The study involved a control while added amendments were equivalent to 157 and 5 kg ha-1 for WA and CaO and 50 and 333 kg ha-1 for RP and SSP, respectively; thus, it was a 3×3 factorial experiment with nine treatments. Data were analyzed by ANOVA. All amendments significantly enhanced soil properties and soybean growth compared to the control. Soil pH in the control (4.2) was raised in WA and WA+RP by 54.83 and 51.72 % in both phases of the study. Soil total nitrogen was highest in WA+RP (95.91), Ca2+ (79.65), Mg2+ (65.03), base saturation (71.60 %) in WA and AvP (53.75 %) in WA+SSP compared to the control. The CaO+SSP had the tallest plants (65.25), highest number of leaves in WA+SSP (67.32) and leaf area in WA+RP (67.32 %). Nitrogen (83.33), P (83.63) and K (71.42) uptake were highest in WA+RP. The highest shoot biomass was obtained from CaO+SSP (47.03%). A similar trend was observed for the residual effect where, apart from WA, combined application of lime and P, regardless of source, improved soil properties and enhanced soybean growth. The WA and RP can be used as alternatives or compliments to inorganic lime and P sources, respectively to enhance soybean production in

coarse-textured acid soils.

**Keywords:** soil acidity, soil amendments, wood ash, rock phosphate, soybean growth

**Introduction**

Soil nutrient depletion and degradation have been identified as major causes of decreased crop yields and per capita food production in sub-Saharan Africa (SSA) (Henao and Baanante, 2006). There is an even greater challenge in acidic soils with high P-fixing potential (Khan *et al.* 2009). According to Chude *et al*. (2005), soils with a pH less than 5.5 are considered acidic and result in complex interactions of chemical, physical and biological properties of the soil which limit plant growth and yield (Fageria and Baligar 2008). ). Tropical soil with low pH and prevalence of kaolinite and Fe and Al oxides in the clay fraction have high propensity for P adsorption (Fink *et al*., 2014). Unsustainable use of inorganic fertilizers has aggravated the problems of soil acidity (Ayuke *et al.* 2007). It is paramount therefore to enhance P use efficiency of such soils (Menezes-Blackburn *et al*., 2017).

Phosphorus (P) is considered one of the key plant elements whose deficiency is a limiting factor in crop production (Onasanya *et al.* 2009). It plays an essential role in many physiological processes such as photosynthesis, cell division, seed and fruit formation, grain quality, nodulation in legumes, crop maturation and disease resistance (Ezawa *et al.* 2002). High concentrations of Iron (Fe3+) and Aluminum ions (Al3+) in acidic soils and calcium and magnesium ions ( Ca2+ and Mg2+) in calcareous soils to form less soluble phosphates and maintain low concentrations of inorganic P in solution for plant uptake (Penn and Camerato, 2019). Among other options, liming and mineral P application are strategies often employed to manage P availability and enhance the productivity of highly weathered acidic soils. However, their prolonged and unsustainable use may lead to soil acidification and nutrient imbalances (Karmakar *et al.* 2020). These, coupled with the scarcity and high cost of these conventional liming materials and mineral fertilizers (Haynes and Mokolobate, 2001), as well as their threat to environmental and human health, research interest has tilted towards alternative, cheaper, available and environmentally friendly options of organic liming and P sources such as wood ash (Mbah *et al.* 2010) and rock phosphate (Hallal *et al.* 2019), respectively.

Wood ash contains oxides and hydroxides of Ca, Mg and potassium (K), and to a lesser extent, sodium (Na), making it similar to the conventional liming materials (Brady and Weil, 2006). It also contains many of the nutrients originally absorbed from the soil by plants, which may improve crop growth and yield (Nwite *et al.* 2011). Several research works have portrayed the effectiveness of wood ash as a liming material (Nwite *et al.* 2011; Nottidge and Nottidge, 2012; Osundare, 2014).

Among the rock phosphate (RP) deposits found in Nigeria (Edo and Imo), those of Sokoto and Ogun have potentials for exploitation and commercialization, existing in pellet, nodule, vesicular and granular forms (Adediran and Sobulo, 1998). Since the discovery of these deposits, several researchers have investigated their suitability for direct application as P sources on different soil and crop types across Nigeria (Obigbesan and Udosen, 1995; Akande *et al.* 1998; Akinrinde and Obigbesan, 2006; Obaje *et al.* 2013; Fayiga and Obigbesan, 2017). According to Akinrinde and Obigbesan (2006), the Sokoto and Ogun deposits are highly reactive and have high carbonate content, which could also have a liming effect on acidic soils. The Sokoto RP has been shown to be more suitable for direct application due to its low content of Fe2+ and Al3+ oxides which are responsible for P-fixation (Akinrinde *et al.* 2003). These qualities make it similar to the Togo RP which is used by Nigerian fertilizer companies for the production of single superphosphate (SSP) fertilizer (Fayiga and Obigbesan, 2017).

Soybean (*Glycine max* (L*.*) which belongs to the Fabaceae family is highly valued in the world for its oil (21 %) and protein (39-40 %) content (Hou et al. 2009). In Nigeria, it is in in high demand due to its competing uses especially as a a raw material for the food and animal feed industries. The major challenge in increasing its current production to meet this continuously growing demand is the low nutrient status of the soil (Adeyeye *et al*. 2014). Among other nutrients P plays a pivotal role in the development, growth and productivity of soybean (Khan *et al*. 2020), through its influence on nodulation (Bakari *et al*., 2020) and N-fixation (Míguez-Montero *et al*. 2020). The aim of this study was therefore to assess the potentials of wood ash and rock phosphate as alternatives to calcium oxide (CaO) and SSP as lime and P sources, respectively for soybean production in an acidic P-deficient soil.

**Materials and Methods**

**Experimental Setup and Treatments**

A glasshouse pot experiment was carried out at the University of Nigeria Teaching and Research Farm, Nsukka, located at latitude 06o52 N′ and longitude 07o24′ E. The soil is well-drained, coarse sandy-loam texture, highly weathered, with very low total exchangeable base, cation exchange capacity, base saturation and organic matter content. There also exists the risk of leaching due to the porous granular surface structure of the soil (Obalum and Obi, 2014). The soil is classified in the order Ultisols (Igwe and Udegbunam, 2008).

Wood ash (WA) was collected randomly from homes of the local inhabitants around Owerre-Eze, Orba neighboring to the site of the experiment. It was homogenized and sieved to remove debris. Calcium oxide (CaO) with 88% calcium carbonate equivalent was obtained from the stock owned by the Soil Physics and Water Management Research Team in the Soil Science Department of the Faculty of Agriculture of the University of Nigeria, Nsukka. Rock phosphate (RP) obtained from the Sokoto deposit, was used as the natural/organic P source while single superphosphate (SSP) purchased from the local market in Nsukka served as the inorganic P source. Topsoil (0-20 cm) samples were randomly collected from spots in the University of Nigeria Teaching and Research Farm. The soil samples were bulked to obtain a composite sample which was then sieved through a 2 mm mesh and 5 kg of the soil weighed, thoroughly mixed with the amendments according to the treatments and put in labeled plastic pots. In a 3 x 3 factorial experiment, organic and inorganic sources of lime were investigated concurrently with three sources of P, namely; no liming, WA and CaO and no P addition, RP and SSP. These treatments were applied at rates equivalent to 157 kg ha-1 and 5 kg ha-1 (for WA and CaO, respectively) and 50 kg ha-1 and 333 kg ha-1 (for RP and SSP, respectively). Organic amendments were applied two weeks prior to sowing. All treatments were replicated three times and laid in a completely randomized design (CRD). Three seeds of soybean (*Glycine max* (L*.*) were sown at a depth of about 2-3 cm and later thinned to one seedling, two weeks after sowing (WAS). At one WAS, seed replacement was done for those that failed to germinate. Water was supplied to each pot at 75 cl every other day while weed was removed by hand-picking.

**Data Collection**

Agronomic data on plant height, number of leaves, and leaf area were collected at a weekly interval beginning from 2 WAS till the 8th week. At the end of the experiment (9 WAS), the shoots were harvest and oven-dried at 70 °C to constant weight to obtain the shoot biomass yield. The pots were replanted immediately without application of any amendments, to assess the residual effects.

**Laboratory Analyses**

Pre-planting and postharvest soil samples, as well as organic amendments used in the experiments were air-dried, crushed and sieved through a 2-mm mesh. Soil pH was determined using a glass electrode pH meter in water and KCl in a ratio of 1: 0 and 2:5 (McLean 1982). Soil organic carbon was determined using the Walkley and Black wet dichromate oxidation method (Nelson and Sommers, 1982). Organic matter was extrapolated from organic carbon by multiplying its value with Van Bemmeller constant of 1.723 (Allison, 1982). Total nitrogen was determined using Micro-Kjeldahl wet digestion method (Bremmer and Mulvaney, 1982) and available phosphorus by Bray II method. Exchangeable bases were extracted using neutral 1 N NH4OAc, Ca2+ and Mg2+ were determined by atomic absorption, while potassium was determined using the flame photo-meter. Exchangeable acidity was determined by KCl displacement method and cation exchange capacity was determined according to Page *et al*. (1982). The same oven-dried shoots were ground and passed through 2 mm sieve and 0.5 g of it used to analyze N, P, and K content in soybean.

**Nutrient Uptake**

Total shoot uptake of N/P/K was calculated as follows;

Shoot uptake of N*/*P*/*K (5 kg potted soil) = N%P%K% *×* dry matter

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**Properties of the Soil and Amendments Used in the Study Prior to Sowing**

The physical and chemical properties of the soil before planting are presented in Table 1 while Table 2 shows the composition of the WA and RP. The soil was sandy-loam, slightly acidic and of low fertility. According to Akinrinde and Obigbesan 2000, such soils are not suitable for crop production without external inputs.

**Table 1:** physicochemical properties of the soil used in the study prior to sowing

|  |  |
| --- | --- |
| Parameter | Content |
| Clay (g kg-1) | 120 |
| Silt (g kg-1) | 50 |
| Fine sand (g kg-1) | 390 |
| Coarse sand (g kg-1) | 440 |
| Textural class | Sandy loam |
| pH (H2O) | 4.9 |
| % SOM | 22.9 |
| Na+ g kg-1) | 12 |
| Ca2+ (g kg-1) | 50 |
| Mg2+ (g kg-1) | 60 |
| % Total N | 22.5 |
| AvP (g kg-1) | 36 |
| K+ (g kg-1) | 11 |
| EA (g kg-1) | 13 |
| CEC (g kg-1) | 63 |

SOM - soil organic matter, AvP - available P, CEC - cation exchange capacity, EA -exchangeable acidity

**Table 2:** Chemical composition of wood ash and rock phosphate used in the study

|  |  |  |
| --- | --- | --- |
| Amendments | RP | WA |
| pH (H2O) | 9.5 | 12.4 |
| % SOM | 147.9 | 235.0 |
| % Total N | 10.4 | 32.8 |
| AvP (g kg-1) | 32.5 | 85.7 |
| K+ (g kg-1) | 12.6 | 87.2 |
| Na+ g kg-1) | 0.1 | 6.4 |
| Ca2+ (g kg-1) | 10.4 | 543.6 |
| Mg2+ (g kg-1) | 8.9 | 29.0 |

RP – rock phosphate, WA – wood ash, SOM - soil organic matter, AvP - available P

**Statistical Analysis**

Data generated from this experiment was subjected to analysis of variance (ANOVA), using SPSS software version 21 to test for significant differences. Significant means were compared using the Duncan multiple range test (*p* ≤ 0.05).

**Results**

**Effect of treatments on selected soil properties**

Based on the results, all the amendments except SSP, significantly raised the pH of the soil relative to the control (Table 3); however, WA (54.83) and WA+RP (51.72 %) had the highest significant effects. Sole application of WA significantly improved Ca2+, Mg2+ and base saturation in the soil by 79, 65.03 and 71.64%, respectively, while there was a 53.75 % increase in AvP in pots amended with WA+SSP compared to the control. Treatments with combined applications of WA+RP and CaO+SSP had highest significant increases in total N (95.91 %) and cation exchange capacity (76.45 %) compared to the control. There was no significant effect on SOM in this phase of the experiment.

In the residual experiment (Table 4) a similar trend was observed in which WA and WA+RP significantly enhanced the pH of the soil by 50.58 and 48.78 %, respectively. Soil organic matter was highest in pots treated with CaO+RP (39.31 %) while the pots with WA alone had maximum values for Ca2+ (28.22), AvP (70.23) and base saturation (55.61%). Treatments with WA, CaO+RP and RP had the same values for K+ which was increased by 50%. Meanwhile, the highest values for Mg2+ (61.51 %) and TN (96 %) were recorded in treatments with WA+RP. Cation exchange capacity was highest in CaO+RP (53.80 %) and WA+RP (51.98 %) amended pots.

**Effect of treatments on nutrient uptake**

In the immediate phase of the experiment, WA+RP had the highest overall significant effect on N, P and K up take compared to the other treatments. Treatments with WA+RP, WA+SSP and WA had similar significant effects on N uptake which was increased by 83.33, 81.81 and 80 %, respectively. Also, pots treated with WA+RP and WA+SSP significantly enhanced P uptake by 83.63 and 81.25%, respectively. Apart from WA+RP which increased K uptake by 71.42%, there were no significant differences between treatments while CaO was not significantly different from the control (Figure 1a 1band 1c). In the residual experiment, the highest values for N uptake were recorded in WA+RP (83.33 %). Though the highest P uptake was obtained in treatments with WA+RP (85 %), this was not significantly different from WA+SSP (84.61), CaO+RP (84.61) and WA (83.33 %). The same trend was observed for K uptake as in the immediate phase of the experiment with WA+RP (71.42 %) still recording the highest value (Figure 2a, 2b and 2c).

**Effect of treatments on soybean growth parameters and shoot biomass yield**

All the amendments significantly increased soybean height, number of leaves and leaf area compared to the control treatments. The highest value for plant height was obtained from pots treated with CaO+SSP (65.25 %) which was similar to WA+RP, WA+SSP, WA and CaO+RP treatments. Leaf area was increased by 61.34 % in pots amended with WA+RP while WA+SSP (67.32 %) had the highest number of leaves compared to the control. In the residual experiment, the highest significant effect on plant height, number of leaves and leaf area were recorded in WA+SSP (49.13), WA+RP, WA+SSP and CaO+RP (18.10) and WA+SSP (54.74 %), respectively. The highest amount of shoot biomass was obtained from pots amended with CaO+SSP in both the immediate (47.03) and residual experiments (56.27%), not significantly different from WA+SSP, WA+RP and WA (Figure 3a and 3b).

**Discussion**

An increase in soil pH upon the addition of lime improves the physical, chemical and biological properties of the soil (Nana, 2011), thereby increasing nutrient availability, especially P, K, Ca and Mg (Tugel, 2011). Liming also increases microbial activities, resulting in increased decomposition and mineralization of N and P (Mkhonza *et al.* 2020). The outstanding performance of WA alone in this study could be attributed to its initial high pH (Table 2). Apart from its liming effect, WA also contains many of the nutrients originally absorbed from the soil by plants such as Ca, Mg, Na, K, and P (Nwite *et al.* 2016).This could account for its significant increase in Ca2+ and Mg2+. Nwite *et al*. (2011) recorded a 100 % increase in pH following the application of rice husk ash, wood ash and leaf ash. Similar results were also obtained by Nottidge and Nottidge (2012) who noted an increase in pH, nutrient content, nodulation, N accumulation and soybean grain yield following the application of WA at 4 t/ha in an acidic soil. Osundare (2014) equally reported the highest maize grain yield in soils limed with wood ash compared to calcium ammonium nitrate and calcium carbonate.

The significant increase in AvP in pots amended with WA+SSP could be due to the synergetic effects of liming from WA and P supply from SSP. Soil acidity and P-deficiency have been reported to retard nodulation and N-fixation in soybean (Míguez-Montero *et al.* 2020). Thus the maximum increase in the TN content of the soil amended with combined applications of WA+RP and CaO+SSP could be due to the limning effects of WA and CaO, as well as the supply of P from RP and SSP. According to a review by Hallal *et al*. (2019), RP from sedimentary origin are variable and have complex chemical composition, making them a source of other plant nutrients apart from P. High carbonate content has also been reported in the RP from the Sokoto deposit which accords it a liming effect (Akinrinde and Obigbesan, 2006). This could be a contributing factor to the observed significant effect of its combination with WA on most of the soil properties.

The significant effects of WA and the combined applications of treatments on soybean growth parameters irrespective of source could be attributed partly to the increase in soil pH and the concentration of Ca2+ and Mg2+ in the soil. This reduces aluminum toxicity in the root region and encourages root growth and proliferation (Sanjay *et al*. 2018), nodulation (Bakari *et al*. 2020) and enhances efficiency in nutrient uptake (Onwuka *et al*. 2009). The the increase in TN following the application of WA+RP and CaO+SSP and WA+SSP may be responsible for their effects on soybean vegetative growth and assimilation. An increase in plant height, number of leaves and leaf area imply greater surface area, better light interception by leaves of the incoming photosynthetically active radiation as well as the ability of the plants to transform the intercepted radiation into biomass (Mohammadi *et al*. 2015). Similar positive results on dry matter yield have also been reported by Chiezey (2013) with the combined application of farmyard manure and inorganic P fertilizers compared to the control plots.

Liming produces phytohormones which enhance root surface area thus facilitating uptake of less mobile nutrients such as P as well as mobilizing and solubilizing unavailable nutrients (Nduwumuremyi, 2013). The increase in P uptake in treatments with WA+RP could be due to an increase in soil pH which enhances P-availability (Nottidge and Nottidge, 2012). On the other hand, the ability of soybean to biologically fix N (Bakari *et al.* 2020), as well as the significant role played by liming and P in nodule formation and N-fixation (Bakari *et al.* 2020; Míguez-Montero *et al.* 2020) may be responsible for the increase in N uptake.

Apart from treatments with sole WA, combined application of P and lime irrespective of source (natural/organic or inorganic) significantly and consistently ameliorated soil properties and improved soybean growth and biomass yield compared to their sole application. This could be due to the inherent low pH and P content of the native soil and its high P-sorption potential. The complementary effect of lime and external P supply could explain the better effects obtained with the combined application. Similar results have been reported by several authors with combined applications of lime and P (Akande *et al*. 2005; Inagaki *et al*. 2016; Alemu *et al*. 2017; Yadesa *et al*. 2019). The inability of sole SSP and CaO, to increase AvP in the soil affirms the limited content of P in the native soil and high level of sorption due to low pH. The relatively non-significant effect of sole RP may be attributed to its low solubility compared to SSP, which is further compromised under conditions of low pH, high P-sorption, low organic matter content and low microbial activity (Arenberg and Arai, 2019). The solubility of RP in this experiment when combined with either WA or CaO may have been enhanced by their effect on soil pH (Akande *et al*. 2004).

Organic/natural amendments are known for their slow but steady release of nutrients compared to their inorganic counterparts. Thus the observed relatively higher residual effect of WA and RP as well as their complementary application in this study is not unusual. The residual effect of SSP and CaO could be attributed to the short duration of the experiment.

**Conclusions**

All the amendments significantly improved the selected soil properties and soybean height, number of leaves, leaf area and shoot biomass compared to the control. The organic lime (WA and P sources (RP) compared favorably with the inorganic sources (CaO and SSP), respectively; however, WA and co-application of CaO+SSP, WA+RP, WA+SSP and CaO+RP proved more efficient than their sole application. Bearing in mind, the environmental as well as the economic implications of inorganic amendments, WA and RP can be used as alternatives or compliments to inorganic lime and P sources, respectively to enhance soybean production in coarse-textured acid soils.

**Table 3:** Immediate effect of lime and phosphorus sources on selected soil chemical properties

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Amendment | pH-H2O | % SOM | Na2+ (g kg-1) | Ca2+ (g kg-1) | Mg2+ (g kg-1) | % TN | AvP (g kg-1) | K+(g kg-1) | % Base saturation | CEC (g kg-1) |
| WA+RP | 8.7±0.30a | 14.0±0.12a | 0.2±0.01a | 52.0±0.02b | 19.3±0.15b | 9.8±0.01a | 111.8±0.01b | 0.4±0.01b | 60.4±1.71a | 17.7±1.18bc |
| WA+SSP | 7.4±0.11b | 14.0±0.10a | 0.2±0.01a | 26.7±0.55c | 14.7±0.45cd | 0.7±0.01d | 153.8±0.40a | 0.3±0.01b | 25.3±0.80bc | 17.5±1.26bc |
| WA | 9.3±0.65a | 14.6±0.05a | 0.2±0.01a | 70.0±0.10a | 28.6±0.05a | 0.7±0.02d | 130.2±0.03ab | 0.6±0.01a | 61.4±0.93a | 21.0±0.54b |
| CaO+RP | 7.0±0.34b | 15.1±0.01a | 0.3±0.01a | 23.3±0.61d | 13.0±0.17cd | 0.7±0.01d | 83.0±0.11c | 0.6±0.01a | 13.8±1.94de | 41.2±0.08a |
| CaO+SSP | 5.9±0.34c | 14.4±0.01a | 0.3±0.01a | 12.3±0.15e | 14.7±0.15cd | 1.1±0.05b | 86.6±1.13c | 0.6±0.01a | 30.1±1.82b | 18.8±1.96bc |
| CaO | 5.2±0.40cd | 14.8±0.02a | 0.3±0.01a | 14.0±1.15e | 17.7±0.66bc | 0.6±0.01e | 42.3±1.80e | 0.5±0.05a | 15.6±1.72de | 21.0±1.22b |
| RP | 5.1±0.60d | 14.8±0.02a | 0.3±0.01a | 13.3±1.00e | 19.0±0.65b | 0.9±0.01c | 46.6±0.13d | 0.6±0.01a | 19.7±1.57cd | 19.5±1.80b |
| SSP | 4.6±0.12e | 14.3±0.09a | 0.3±0.01a | 13.3±1.15e | 16.3±0.51c | 0.7±0.02d | 95.0±0.97c | 0.6±0.05a | 23.5±1.64bc | 14.4±1.51c |
| Control | 4.2±0.05e | 13.3±0.05a | 0.3±0.01a | 14.7±0.55f | 10.0±0.01e | 0.4±0.01f | 24.8±1.50e | 0.4±0.05b | 12.5±1.58e | 9.7±0.81d |

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide, SOM – soil organic matter, TN – total nitrogen,

AvP – available phosphorus, CEC – cation exchange capacity

**Table 4:** Residual effect of lime and phosphorus sources on selected soil chemical properties

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Amendment | pH-H2O | % SOM | Na2+ (g kg-1) | Ca2+ (g kg-1) | Mg2+ (g kg-1) | % TN | AvP (g kg-1) | K+(g kg-1) | Base saturation | CEC(g kg-1) |
| WA+RP | 8.2±0.10a | 13.8±0.17bc | 0.2±0.05b | 54.3±0.10b | 29.0±0.10a | 10.0±0.01a | 112.0±0.01b | 0.5±0.01abcd | 55.1±1.30b | 20.2±0.63a |
| WA+SSP | 5.7±0.43b | 13.7±0.10bc | 0.2±0.05b | 34.7±0.57cd | 19.0±0.10b | 7.3±0.05ab | 75.6±0.01bcd | 0.4±0.05abc | 26.8±1.90cd | 11.3±1.15b |
| WA | 8.50±0.20a | 14.1±0.05bc | 0.2±0.01b | 71.0±0.01a | 28.6±0.10a | 5.9±0.44b | 125.3±0.55a | 0.6±0.05a | 68.9±1.45a | 12.1±0.57ab |
| CaO+RP | 5.2±0.68bc | 16.3±0.11a | 0.3±0.01a | 46.3±1.52bc | 15.0±0.05bc | 0.7±0.01c | 83.8±0.02abcd | 0.6±0.05a | 13.7±1.65e | 21.0±1.53a |
| CaO+SSP | 4.9±0.60cd | 14.3±0.05bc | 0.3±0.01a | 30.7±0.05cd | 14.7±0.05bc | 1.1±0.05c | 82.5±0.01abcd | 0.5±0.01abcd | 31.5±1.81c | 18.8±0.60ab |
| CaO | 4.8±0.68cd | 14.5±0.08ac | 0.3±0.01a | 20.7±0.10ef | 19.7±0.05b | 0.5±0.01c | 60.3±0.01cd | 0.5±0.05abcd | 15.5±0.94de | 17.0±0.50ab |
| RP | 4.9±0.32cd | 15.1±0.03ab | 0.3±0.01a | 28.3±0.10de | 19.0±0.05b | 0.8±0.05c | 82.5±0.02abcd | 0.6±0.05 a | 22.0±1.24cde | 11.8±0.20b |
| SSP | 4.3±0.01d | 13.1±0.11cd | 0.3±0.01a | 23.3±0.05de | 12.3±0.05c | 0.7±0.01c | 95.0±0.01abc | 0.4±0.05cd | 17.5±1.43ce | 14.4±1.00ab |
| Control | 4.2±0.05d | 11.7±0.05d | 0.1±0.05c | 9.0±0.10f | 10.0±0.01e | 0.4±0.01c | 37.3±0.01d | 0.3±0.01d | 10.5±0.06e | 9.7±0.05c |

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.05

WAS – weeks after sowing, WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide, SOM – soil organic matter, TN – total nitrogen, AvP – available phosphorus, CEC – cation exchange capacity

**Table 5:** Immediate effect of lime and phosphorus sources on plant height, number of leaves, and leaf area at 2, 4 and 6 weeks after sowing

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Amendment | Plant Height (cm) | | | Number of Leaves (cm) | | | Leaf Area | | |
| WAS | 2 | 4 | 6 | 2 | 4 | 6 | 2 | 4 | 6 |
| WA+RP | 28.1±0.76a | 56.5±1.21a | 80.3±0.59a | 13.3±1.15b | 12.6±1.51abcd | 13.3±1.15b | 34.0±0.52abc | 43.1±1.10ab | 86.4±1.48a |
| WA+SSP | 28.1±0.86a | 57.5±1.04a | 81.0±0.46a | 15.3±0.01a | 15.3±0.57a | 16.3±0.57a | 36.3±0.01ab | 46.8±1.40a | 81.0±1.76ab |
| WA | 26.0±0.40ab | 52.1±1.11a | 75.6±0.01a | 12.3±0.01bc | 13.6±0.57abc | 12.3±0.57bc | 34.4±0.18ab | 40.4±1.05b | 81.3±0.88ab |
| CaO+RP | 28.0±1.08a | 54.0±1.16a | 81.0±0.57a | 13.0±1.73b | 13.3±1.30abcd | 13.0±0.01b | 35.9±0.98ab | 44.5±1.8ab | 71.5±1.08cd |
| CaO+SSP | 24.2±1.25bc | 50.8±1.46ab | 82.3±0.48a | 15.6±1.73a | 14.6±1.16ab | 15.6±1.15a | 40.4±0.66a | 45.5±1.59ab | 74.2±1.56bc |
| CaO | 22.5±1.25cd | 39.0±1.15cd | 58.3±1.64b | 11.6±1.15bc | 10.0±1.00cd | 11.6±0.57bc | 27.9±0.32d | 34.5±1.04b | 65.4±0.92d |
| RP | 26.4±1.88ab | 49.3±1.73abc | 66.3±1.52b | 13.0±1.51b | 13.3±0.57bcd | 13.0±1.00b | 31.2±0.86bcd | 32.8±1.52cd | 66.7±1.20cd |
| SSP | 22.6±1.00cd | 39.6±1.21bcd | 59.6±1.60b | 12.3±1.00bc | 14.0±1.20ab | 12.3±1.52bc | 34.5±0.88ab | 35.5±1.04c | 67.2±1.33cd |
| Control | 11.3±0.57d | 17.6±1.30d | 28.6±1.07c | 9.6±0.01c | 5.6±1.15d | 9.3±0.57c | 19.6±0.69d | 29.0±1.62d | 33.4±1.01d |

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WAS – weeks after sowing, WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide, WAS – weeks after sowing

**Table 6:** Residual effect of lime and phosphorus sources on plant height, number of leaves, and leaf area at 2, 4 and 6 weeks after sowing

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Amendment | Plant Height (cm) | | | Number of Leaves (cm) | | | Leaf Area | | |
| WAS | 2 | 4 | 6 | 2 | 4 | 6 | 2 | 4 | 6 |
| WA+RP | 17.3±1.05ab | 33.3±0.80a | 74.3±1.13a | 4.6±0.57a | 8.3±0.57a | 11.6±0.57a | 31.2±1.25ab | 52.3±0.52a | 98.7±0.66a |
| WA+SSP | 18.5±1.08a | 34.6±1.13a | 75.3±1.00a | 4.6±0.57a | 8.3±0.57a | 11.6±0.57a | 32.5±1.22a | 51.9±0.89a | 99.0±0.13a |
| WA | 15.5±1.00bc | 31.0±1.15ab | 67.3±0.88ab | 4.6±0.57a | 7.6±1.10b | 10.6±0.57abc | 26.0±1.53bc | 53.3±0.69a | 90.3±1.09ab |
| CaO+RP | 15.3±0.86bc | 31.3±1.13ab | 67.0±0.64ab | 4.6±0.57a | 7.0±0.01b | 11.6±0.57a | 25.5±0.91bc | 51.4±0.90a | 88.3±1.26b |
| CaO+SSP | 17.1±1.30ab | 30.0±1.05ab | 74.3±1.08a | 4.6±0.57a | 6.6±0.57bcd | 10.6±0.57abc | 25.1±0.69cd | 57.0±0.83a | 86.5±0.71b |
| CaO | 13.1±0.80de | 25.6±1.03b | 51.6±0.83c | 4.3±0.57a | 6.3±0.57cd | 10.0±1.00bcd | 23.5±0.62cd | 51.8±0.80a | 66.2±0.64c |
| RP | 14.3±1.45cd | 27.0±1.03b | 54.6±1.21bc | 4.6±0.57a | 7.0±1.00b | 11.0±0.01ab | 25.2±1.13cd | 51.8±0.89a | 85.2±0.60b |
| SSP | 15.0±.060cd | 26.3±0.76b | 55.3±0.50bc | 4.6±0.57a | 6.3±0.57cd | 9.6±0.57cd | 22.4±1.23c | 55.5±0.80a | 79.8±1.22b |
| Control | 11.3±0.79e | 17.1±0.74d | 38.3±0.60d | 3.6±0.57a | 5.6±0.57d | 9.5±0.57d | 19.0±1.33d | 20.0±0.75b | 44.8±0.88d |

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide, WAS – weeks after sowing

1a) N uptake

1b) P uptake

1c) K uptake

**Figure 1:** Immediate effects of lime and phosphorus sources on N (1a), P (1b) and K (1c) uptake

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide

2a) N uptake

2b) P uptake

2c) K uptake

**Figure 2:** Residual effect of lime and phosphorus sources on N (2a), P (2b) and K (2c) uptake

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide

3a) Immediate effect

3b) Residual effect

**Figure 3:** Immediate (3a) and residual (3b) effects of lime and phosphorus sources on shoot biomass

Means followed by the same letter(s) within a column are not significantly different at *p* ≤ 0.

WA= wood ash, RP = rock phosphate, SSP = single superphosphate, CaO = calcium oxide

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