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# Synergistic effects of cattle dung, urea and lime on agronomic productivity and physicochemical properties of coarse-textured tropical soils

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**Abstract:** A major limitation to the use of some biowaste as manure is their high C/N ratio and hence slow mineralisation rate. Combined use of such slow-mineralising animal manures with N-rich fertilizers and/or synthetic lime may valorize them. The objective of this study was to assess the synergistic effects of cattle dung (CD), Urea and lime on crop productivity and physicochemical properties of sandy tropical soils. Treatments of CD, Urea, Lime, CD+Urea, CD+Lime, Urea+Lime, CD+Urea+Lime, standardized CD+Urea and Control were used to grow okra on sandy soils from a long-term fallow land. The CD and Lime were added at 20 and 0.15-t/ha equivalents three weeks before okra sowing, and Urea at 5-t/ha equivalent at sowing except for standardized CD+Urea where this mix (with reduced C/N of ca.10) was added three weeks before sowing. Agronomic and soil data were collected during and after nine-week crop growth phase, respectively. Treatment affected okra growth and soil variables. Plant height and leaf area generally showed CD+Urea+Lime > CD+Urea/CD+Lime/CD > Urea+Lime/Control, with 56-81% and 124-125% increases, respectively in CD+Urea+Lime relative to Urea+Lime/Control. However, CD+Urea and Urea+Lime/Urea/Lime/Control produced the most and fewest leaves per plant, respectively. Treatment CD+Urea+Lime gave the highest okra dry matter, lowest soil bulk density and highest available P and cations exchange. The CD+Lime improved macro-aggregation the most but, together with standardized CD+Urea, also caused soil colloidal dispersion. Okra dry matter reflected soil available P ($R^2$ = 0.63). Fortifying CD-manure with lime and, afterward, Urea could produce synergistic agronomic effects mostly via boosted P-bioavailability, and is hereby proposed for physicochemical fertility management of coarse-textured acid tropical soils.

*Keywords: slow-mineralizing animal manures, Urea N-fertilizer, synthetic lime, low-fertility tropical soils, phosphorus bioavailability, enhanced crop growth.*

## Introduction

In sub-Saharan Africa, soil acidity and low soil organic matter including deficiencies of such key nutrients as nitrogen (N) and phosphorus (P) are the most frequently reported factors contributing to low soil fertility and poor crop yields (Stewart et al., 2020). This situation has been attributed to the prevailing high rainfall and temperatures (Onah et al. 2022, 2023), and unsustainable soil management practices. Rather than the out-fashioned shifting cultivation and bush fallowing, various organic and/or mineral fertilizers are no used to promote soil fertility and productivity. Organic fertilizers, or manures, mostly of animal origin, could be incorporated directly into the soil or composted before use. Soil application of manures, besides reducing environmental pollution (Sharma and Chetani, 2017), reduces soil compaction and density (Nwite et al., 2012; Obalum et al., 2020a), increases soil aggregate stability (Igwe et al., 2013; Ogunezi et al., 2019), ameliorates soil acidity (Adeniyan et al., 2011; Umeugokwe et al., 2021; Unagwu and Ayogu, 2022), maintains soil organic matter (Martius et al., 2001; Ayeni, 2012), reduces leaching of nutrients (Akande et al., 2010; Nyande et al., 2021), and ultimately increases crop yields (Abou El-Magd et al., 2006; Nwite et al., 2013; Nnadi et al., 2021).

However, the problem with manures, compared to mineral fertilizers, is not just low nutrient composition for which they are usually required in large quantities, but also slow decomposition and mineralization in the soil (Omogoye, 2015; Adekiya et al., 2020). The commonest mineral fertilizers are N-, P-, and K-based fertilizers. These fertilizers are scarce and very expensive, and their applications in crop production systems have often been associated with increased soil acidity, nutrient losses and imbalance, and environmental degradation in the tropics (Agbede et al., 2008; Moyin-Jesu, 2008). Based on the prospects and constraints of manures and fertilizers, their integration has been promoted as a viable strategy for managing soil fertility and enhancing agronomic production (Baiyeri et al., 2020; Nnadi et al., 2020; Obalum et al., 2020a; Ogumba et al., 2024a).

In terms of availability and affordability, cattle dung (CD) is perhaps the topmost ranking among animal waste commonly used as manures. This manure is often associated with high positive residual effects on soil physico-hydraulic, physico-chemical and microbial properties (Damiyal et al., 2017; Sharma and Chetani, 2017; Ezenne et al, 2019). It is also about the most difficultly decomposed/mineralized manure in the soil. Uzoh et al. (2015) noted that CD is underutilized as manure due to its slow decomposition and mineralization rate when compared with manures from the piggery and poultry. This slow nutrient release attribute of CD relative to pig slurry and poultry manure was recently demonstrated for available P using two sandy-loam tropical soils (Chukwuma et al., 2024). Complementary application of CD and a mix of equal volumes of poultry droppings and fruit-waste compost has been reported to be superior to sole application of CD in enhancing soil fertility and productivity of coarse-textured tropical soils (Ogumba et al., 2024b). Though CD co-application with NPK fertilizers has severally been reported to be successful (Omogoye, 2015; Francioli et al., 2016; Li et al., 2017), research efforts are still ongoing on how to improve the effectiveness of this combination. For instance, Das et al. (2017) reported that co-application of composted CD and NPK fertilizer increased soil microbial activity and soil fertility and productivity of submerged rice paddy more than composted pig manure and NPK fertilizer.

A rather more cost-effective strategy toward valorizing CD-manure in tropical Africa is to use single N-fertilizer as the mineral additive. Tanimu et al. (2013) reported that composted CD complemented with Urea N-fertilizer gave the highest grain yields of maize in the northern Guinea Savannah of Nigeria. However, there have been similar reports for non-composted CD fortified with Urea regarding improvements in soil physicochemical properties and performance of arable crops in southern part of the country (Ayoola and Makinde, 2008; Ayeni and Adeleye, 2012; Nweke and Nsoanya, 2015). Recent further research in this regard involving some other potential options of effectively utilizing the CD-manure for increased soil productivity has upheld the prospects of its being supported Urea (Ndzeshala et al., 2023).

The study by Chukwuma et al. (2024) showed post-treatment soil acidity level to be an important factor in the P-mineralization gradients among soils treated with poultry droppings and pig slurry and CD-treated ones over a seven-month period. Though application of CD-manure can help to decrease soil acidity (Whalen et al., 2000), more so in deeply weathered tropical soils (Ayeni and Adeleye, 2012; Obalum et al., 2020a; Unagwu and Ayogu, 2022), soil acidity has traditionally been mitigated by the application of limes to affected soils, globally. Besides, complementary application of manure and lime could increase soil fertility and productivity of acid soils over their sole applications (Islam et al., 2021; Kimiti et al., 2021). There are, therefore, prospects of valorizing further the CD-manure fortified with Urea toward overcoming the soil acidity and productivity problem of deeply weathered, coarse-textured tropical soils.

Considering the severity of the soil acidity/fertility problem of the majority of soil resources of tropical Africa, the trio of CD, Urea and lime could produce interesting synergistic effects in the soils. From agronomic and soil quality perspectives, however, there is a dearth of empirical information supporting this hypothesis in these soils. Hence, this study assessed the effects of sole and combined application of CD, Urea N-fertilizer and synthetic lime on productivity of sandy tropical soils, agronomic evaluations on okra (*Abelmoschus esculentus* L. Moench) growth of which were related to the ensuing changes in soil structure-related and physicochemical properties.

## Materials and Methods

### *Soil and experimental materials*

The study involved pot trials with top-(0-15 cm) soil collected from the Research & Demonstration Farm of Prince Audu Abubakar University, Anyigba (7º 29" N; 7º 11" E), Kogi State, Nigeria. Anyigba is in the southern Guinea Savannah zone, a warm humid climate of the middle belt zone of Nigeria, commonly referred to as the Middle Belt. Mean annual rainfall is about 1,800 mm, while mean monthly temperature varies from 17 to 36 ºC. Relative humidity is moderately high and is within the range of 65%-85% throughout the year. The soil has been classified, based on the FAO/UNESCO and Soil Taxonomy systems, as Haplic Luvisol and Ustic Alfisols, respectively (Aina, 2023).

In this study, cattle dung (CD) was used as slow-mineralizing manure, Urea as N-rich fertilizer and $Ca(OH)_2$ as synthetic lime. Fresh CD was procured from a cattle farm in Anyigba and was cured by sun-drying for one week. Urea fertilizer and $Ca(OH)_2$ lime were procured from reputable dealers. Okra was the test crop for the pot trials. The variety used, Lady's Fingers, was procured from Agricultural Development Project (ADP) office, Anyigba. The choice of okra as test crop was not just because of its being an indigenous vegetable crop in tropical Africa whose young leaves are often used as cattle feed (Siemonsma and Kouame, 2004), but also because of its yields in especially the savannah region of Nigeria (Muhammad et al., 2020), where cattle rearing is a prominent agricultural enterprise. According to Muhammad et al. (2020), fruit yields as low as 2-3 t/ha even with high yielding cultivars due to the inherently low fertility status of the soils. With this situation, we reasoned that using CD-based soil amendments to boost okra production would, by sustaining the partial dependency cycle between okra and cattle, contribute to the pursuit of the trending circular economy.

### *Treatments and experimental procedures*

The study was executed under glasshouse conditions at Prince Audu Abubakar University, Anyigba, Kogi State of Nigeria. The heap of the collected topsoil was spread to air-dry for about two weeks, after which the air-dry soil was passed through a 2-mm sieve. Then, 10 kg of the air-dry soil was weighed into 15-L plastic pots with perforations at the bottom. There were nine treatments viz CD, Urea, Lime, CD+Urea, CD+Lime, Urea+Lime, CD+Urea+Lime, standardized CD+Urea, and a no-amendment control. The treatment referred to as standardized CD+Urea, described shortly, was first proposed by Ndzeshala et al. (2023). These nine treatments were replicated three times, giving 27 potted soils (observations), laid out in a completely randomized design.

In both sole and combined applications, CD, Urea and Lime were added to the soil at the rates of 66.67, 1.00 and 16.67 g per 10-kg soil, corresponding to field application rates of 20, 0.15 and 5 t/ha, respectively. These hectarage equivalents were computed assuming a soil bulk density of 1.50 $Mg/m^3$ and amendment incorporation to 20-cm depth of the soil. For the standardized CD+Urea, however, the mixing ratio of CD and Urea was based on the C and N contents of the former, and the management target was to reduce its C/N ratio to around 10 (Ndzeshala et al., 2023). To achieve this, 66.67 g of CD and 6.27 g of Urea were thoroughly mixed together before application.

The CD and Lime were added to the potted soils three weeks before sowing okra seeds, but treatments having Urea received it at sowing. The only exception was the standardized CD+Urea where the CD and the Urea were added at once three weeks before sowing of okra. The potted soils were thoroughly mixed with the amendments. Each potted soil was brought to field capacity by separately placing them in a bowl of water, to enable watering of the soil by water movement from bottom up through capillary forces. Thereafter, the potted soils were watered at three-day intervals for three weeks, to allow the amendments have some effects in the soil before okra sowing.

### *Okra sowing and collection of agronomic data*

At the end of the three-week pre-sowing period, two okra seeds were sown per pot at 2.5 cm depth. Thinning of the okra seedlings was done one week after sowing to one seedling per potted soil. Watering to carrying capacity of the potted soils continued at two-day intervals until 9 weeks after sowing (WAS). Agronomic data collection started 3 WAS and was repeated at two-week intervals till 9 WAS. Treatment effects on okra growth were assessed based on plant height, number of leaves per plant and mean leaf area. To obtain the leaf area, lamina length and broadest width of the most representative leaves were measured, and their product multiplied by 0.62 (Musa and Usman, 2016).

At the last growth data collection 9 WAS, the okra plants were harvested by cutting off from the soil level and their fresh weights per pot taken immediately. Thereafter, the harvested plants were kept separately in brown paper envelopes and hung in the glasshouse to dry to constant weight, following which their dry weights were also taken.

### *Laboratory soil analyses*

Laboratory analyses of the treatments were carried out at the termination of crop growth at 9 WAS. Undisturbed soils were collected using 100-$cm^3$ core samplers. They were trimmed and oven-dried at 105 °C for 24 h, for determination of soil bulk density, calculated as the ratio of oven-dry mass to volume of the soil being the volume of the core sampler. Corresponding loose soils were also collected, air-dried to constant weight and passed through the 2-mm sieve. They were used to assess soil macro- and micro-aggregate stability and to determine soil physicochemical properties.

Macro-aggregate stability was determined by the wet sieving method (Kemper and Rosenau, 1986). The dry soils were sieved through a 2-mm nest of sieve. Thereafter, 40 g of the <-2-mm soil sample was placed on a nest of four sieves 0.42, 0.25, 0.125 and 0.060 mm and soaked in water for 5 min. in an aggregate sieving machine. The set-up was oscillated vertically for 20 times in about 35 s after which the sieves were brought out and the soil sample remaining on each of them washed into separate containers. They were oven dried at 105°C for 24 h and weighed. Water-stable aggregates (WSAs) retained on the 0.42- and 0.25-mm sieves were summed up and used to calculate %WSAs as follows:

$$\%WSA = \frac{mass\ of\ WSA}{mass\ of\ sample} \times 100\%.$$

The method of Van Bavel (1950), modified by Kemper and Rosenau (1986), was used to evaluate the mean-weight diameter of aggregate thus:

$$MWD = \Sigma_{i=1}^{n} X_i\, W_i;$$

where MWD is mean-weight diameter of aggregates, $X_i$ is mean diameter of the aggregates, and $W_i$ is proportion of the total sample weight in their corresponding sizes.

Micro-aggregate stability of the soil was indexed from silt and clay dispersion determined by pseudo-mechanical analysis of the air-dry soil samples. In this analysis, we followed the procedure for mechanical analysis by the Bouyoucous hydrometer method (Gee and Or, 2002), but without using any chemical dispersant. Micro-aggregate stability of the soil was indexed by the silt and clay contents from this analysis, designated water-dispersible silt (WDSi) and water-dispersible clay (WDC), respectively.

Soil pH was determined in water and in 0.1N KCl solutions. The mixtures were stirred for 30 min. and the pH values were read using a glass electrode pH meter (McLean, 1982). The SOC was determined by the modified Walkey and Black wet digestion and oxidation method (Nelson and Sommer, 2016). Total N was determined using the Kjeldahl distillation method (Bremner, 1996). The ammonia from the digestion was distilled with 45% NaOH into 2.5% boric acid and determined by titrating with 0.05N KCl. Available P was extracted from the air-dry soil samples using Bray-1 solution following the procedure described by Juo et al. (1996). The P in the extract was determined by a blue colour method (Murphy and Riley, 1962). The exchangeable bases ($K^+$, $Ca^{2+}$, $Mg^{2+}$ and $Na^+$) were extracted by leaching the soil at its own pH using $NH_4OAc$ solution after neutralizing this reagent (pH 7), after which their contents in the extract were determined using a flame photometer ($K^+$ and $Na^+$) and by EDTA titration ($Ca^{2+}$ and $Mg^{2+}$). The sum total of these four base-forming cations was regarded as the total exchangeable bases (TEB). Exchangeable acidity (EA) was determined by the titration method after extraction with 1.0M KCl (McLean, 1982). Thereafter, effective CEC (ECEC) of the soil was calculated as the summation of TEB and EA.

### *Data analysis*

Data were subjected to one-way analysis of variance using the software GenStat, 11 Edition (VSN International Ltd., Hemel Hempstead, UK) to determine treatment effects, with the means separated using the least significant difference at 5% probability level ($LSD_{0.05}$). Pearson's correlations of okra vegetative growth traits (including fresh and dry matter per potted soil determined at the termination of the experiment 9 WAS) were carried out on soil properties and also among soil properties. Okra dry matter was also related to all soil properties by stepwise multiple linear regressions.

## Results

### *Initial properties of the soil and the cattle dung used for the study*

The key physicochemical properties of the soil used are shown in Table 1. The soil is an acid loamy sand, with low contents of macro-nutrients (particularly total N and available P). Table 2 shows the chemical properties of CD used in the study.

*Table 1. Some physicochemical properties of the soil before the study*

| PARAMETER | VALUE |
|---|---|
| % Sand | 83 |
| % Silt | 6 |
| % Clay | 11 |
| Texture class | Loamy Sand |
| Soil pH in $H_2O$ | 4.9 |
| Soil pH in KCl | 4.6 |
| % Soil organic carbon, SOC | 0.84 |
| % Total nitrogen, N | 0.033 |
| Available phosphorus, P (mg/kg) | 1.17 |
| Exchangeable potassium, $K^+$ (cmol/kg) | 2.06 |
| Exchangeable calcium, $Ca^{2+}$ (cmol/kg) | 3.75 |
| Exchangeable magnesium, $Mg^{2+}$ (cmol/kg) | 2.29 |
| Exchangeable sodium, $Na^+$ (cmol/kg) | 0.42 |

*Table 2. Some physicochemical properties of cattle dung used for the study*

| PARAMETER | VALUE |
|---|---|
| Soil pH in $H_2O$ | 8.50 |
| Soil pH in KCl | 7.70 |
| % organic matter, OM | 77.26 |
| % organic carbon, OC | 44.82 |
| % Total nitrogen, N | 0.15 |
| % phosphorus, P | 0.23 |
| % potassium, K | 0.05 |
| % calcium, Ca | 2.40 |
| % magnesium, Mg | 0.96 |
| % sodium, Na | 0.48 |

### *Effects of cattle dung, urea fertilizer and synthetic lime on okra performance*

#### ***Plant height***

Treatment effects on plant height of okra are shown (Figure 1). At first sampling 3 WAS, okra plants growing in treatments Urea and CD+Urea+Lime were among the tallest. Beyond this stage, okra plants growing in treatments CD, CD+Urea, CD+Lime and CD+Urea+Lime were consistently similar and among the tallest. Within this period of 5-9 WAS, treatment Urea+Lime and the Control had the shortest plants.

### *Number of leaves per plant and leaf area*

Treatment effects on number of okra leaves per plant are shown (Figure 2). Generally, CD+Urea produced the most leaves per plant and was, notably, consistently superior to Lime. At 5 WAS, this CD+Urea was superior to all other treatments; at 7 and 9 WAS, it was still superior to all other treatments except CD and standardized CD+Urea.

Treatment also affected leaf area of okra as shown in Figure 3. At 3 and 5 WAS, treatments CD, CD+Urea, CD+Lime and CD+Urea+Lime all showed the broadest leaves, while Urea+Lime and standardized CD+Urea showed the narrowest leaves. At 9 WAS, however, treatmentt CD+Urea+Lime was similar to only treatment sole CD but outperformed CD+Urea and CD+Lime which were rather similar to standardized CD+Urea, while Urea+Lime remained among the worst performing treatments. Treatments that were similar to this Urea+Lime at both 7 and 9 WAS included Urea and Control. Generally, the leaf area of okra plants increased with time.

### *Above-ground okra fresh and dry matter*

Treatment effects on biomass yield of okra as assessed at 9 WAS are shown (Figure 4). The CD+Urea+Lime had the highest fresh and dry matter of 53.90 and 14.71 g/pot, respectively, while Urea+Lime had the lowest values of 11.2 and 2.17 g/pot, respectively, being similar to Urea and Control. Therefore, neither Urea nor Urea+Lime significantly affected the above-soil biomass yield of okra. Examining the data more closely, treatments having CD generally had positive effect on the growth of okra. The CD+Urea+Lime produced the highest okra biomass, and was similar to CD, CD+Urea and CD+Lime in terms of fresh matter but not dry matter.

## *Effects of cattle dung, urea fertilizer and synthetic lime on soil properties*

### *Soil bulk density and aggregate stability*

Treatment effects on soil bulk density and aggregate stability are presented in Table 3. These parameters generally differed among treatments. The range for soil bulk density was 1.31-1.63 g/cm$^3$, with the treatment differing thus CD $\geq$ CD+Lime > Urea+Lime = standardized CD+Urea = Lime $\geq$ Urea = CD+Urea = Control $\geq$ CD+Urea+Lime. For the %WSA indexing soil aggregation, CD+Lime showed the highest values, followed by Urea+Lime and Lime, while CD, CD+Urea and Control had the lowest values.

The WDSi content showed a wider range of 29-130 g/kg compared to WDC content whose range was 92-141 g/kg. The CD+Lime and standardized CD+Urea generally showed higher WDSi and WDC contents compared to the rest of the treatments.

### *Soil physicochemical properties*

Treatment effects on soil physicochemical properties are shown (Table 4). Soil pH increased in all treatments relative to the pre-treatment value of 4.90. The highest values were found in Lime, CD+Lime, Urea+Lime and CD+Urea+Lime. For the soil exchangeable acidity (EA), CD+Urea+Lime showed lower values than the rest of the treatments except CD+Lime, while the Control had the highest values, followed by Urea.

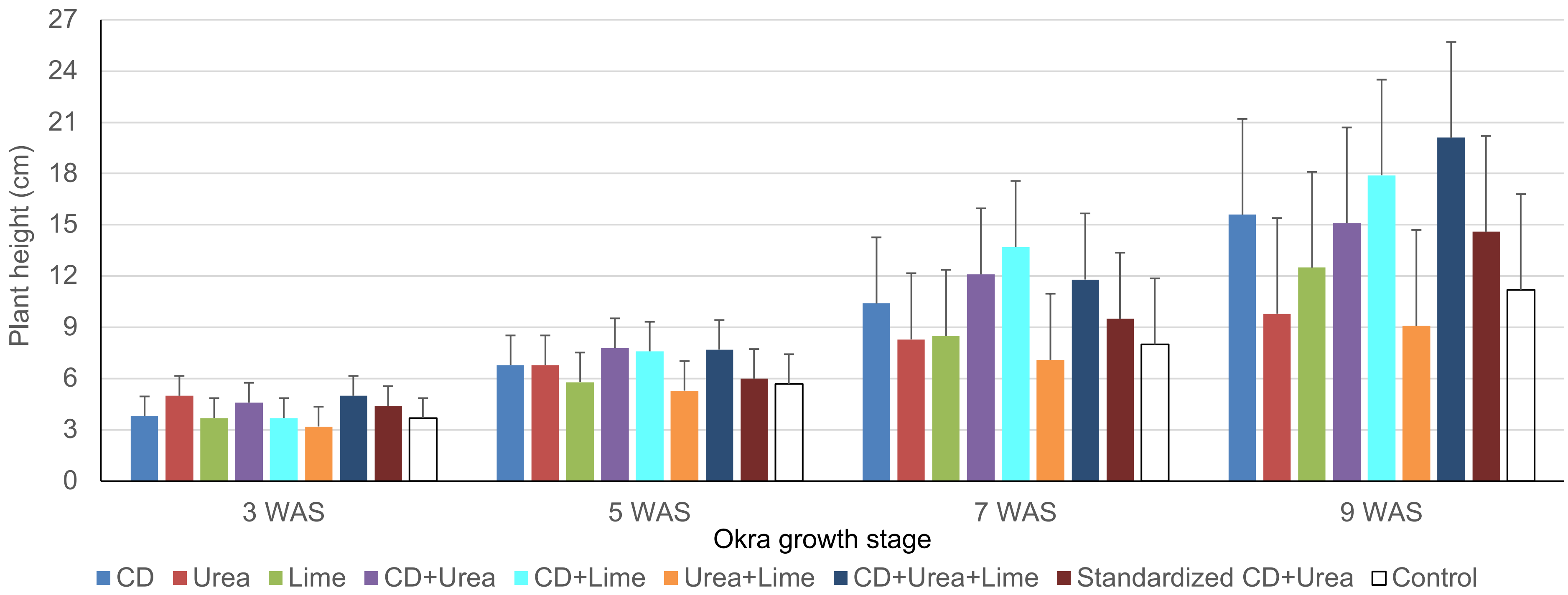


*Figure 1: Plant height of okra at the different growth stages corresponding to weeks after sowing (WAS) as affected by application of cattle dung, Urea and/or lime to the coarse-textured soil. CD, cattle dung. Error bars represent least significant difference (LSD) at p ≤ 0.05 for all growth stages.*

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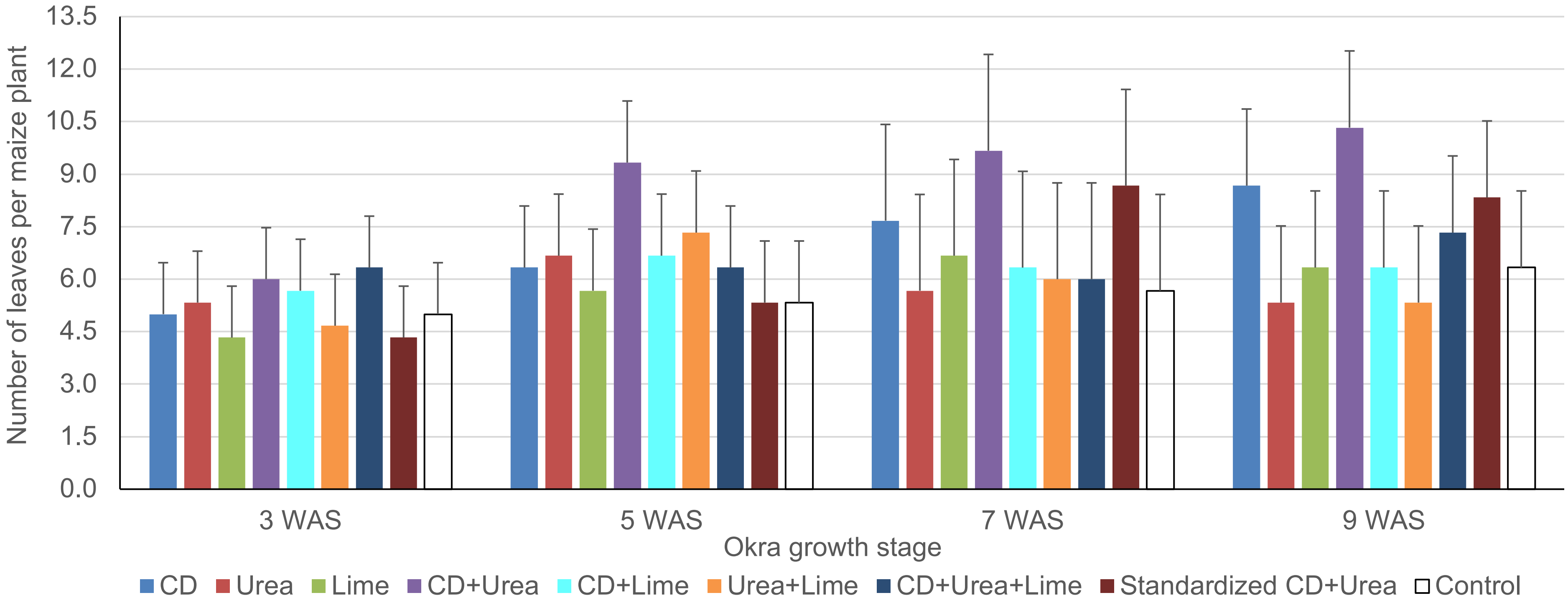


*Figure 2: Number of leaves per okra plant at the different growth stages corresponding to weeks after sowing (WAS) as affected by application of cattle dung, Urea and/or lime to the coarse-textured soil. CD, cattle dung. Error bars represent least significant difference (LSD) at $p \leq 0.05$ for all growth stages except 3 and 7 WAS when $p \leq 0.10$.*

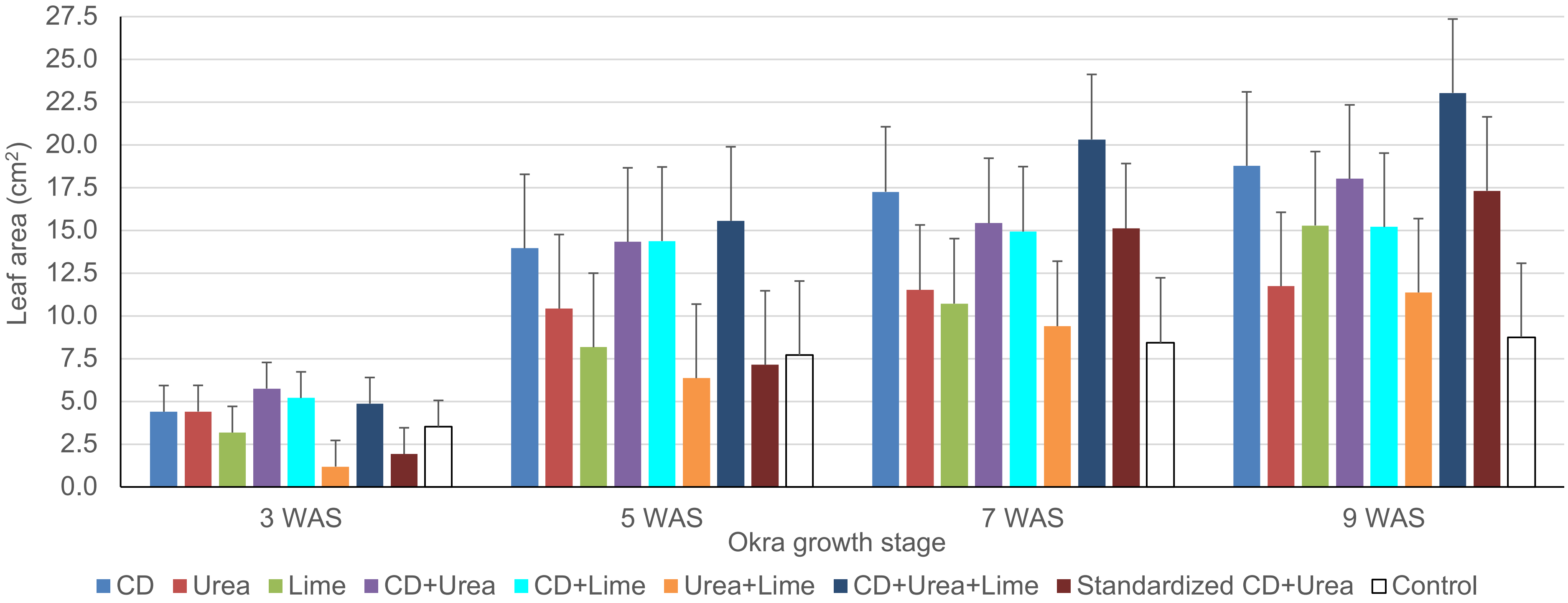


*Figure 3: Leaf area of okra plant at the different growth stages corresponding to weeks after sowing (WAS) as affected by application of cattle dung, Urea and/or lime to the coarse-textured soil. CD, cattle dung. Error bars represent least significant difference (LSD) at $p \leq 0.05$ for all growth stage.*

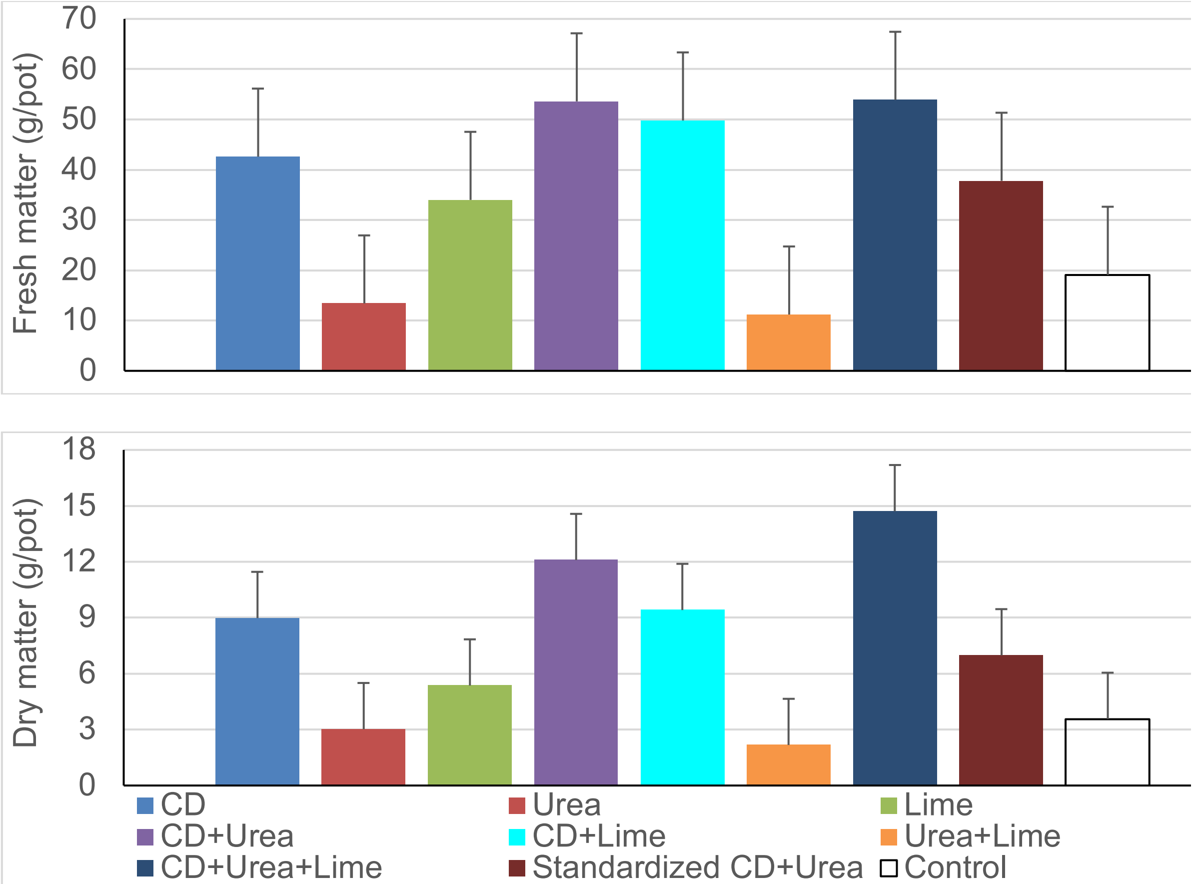


*Figure 4: Above-soil fresh and dry matter of okra at the 9th week of growth as affected by application of cattle dung, urea and/or lime to the coarse-textured soil. CD, cattle dung; LSD(0.05), least significant difference at $p \leq 0.05$*

*Table 3. Soil bulk density and some macro- and microaggregate stability indices of the soil at okra harvest 9 weeks after sowing as affected by treatments of cattle dung, urea and/or lime*

| TREATMENTS | BULK DENSITY ($G/CM^3$) | % WSA | MWD (MM) | WDSI (G/KG) | WDC (G/KG) |
|---|---|---|---|---|---|
| CD | 1.63 | 77.41 | 0.53 | 33 | 92 |
| Urea | 1.36 | 84.77 | 0.60 | 30 | 98 |
| Lime | 1.41 | 89.35 | 0.57 | 31 | 97 |
| CD+Urea | 1.36 | 77.84 | 0.57 | 29 | 97 |
| CD+Lime | 1.61 | 93.00 | 0.62 | 128 | 140 |
| Urea+Lime | 1.42 | 90.43 | 0.58 | 30 | 96 |
| CD+Urea+Lime | 1.31 | 82.72 | 0.56 | 29 | 97 |
| Standardized CD+Urea | 1.42 | 78.54 | 0.60 | 130 | 141 |
| Control | 1.36 | 76.84 | 0.53 | 30 | 96 |
| *$LSD_{(0.05)}$* | *0.10* | *8.38* | *ns* | *4.40* | *3.20* |

*WSA, Water-stable aggregates; MWD, mean-weight diameter of aggregates; WDSi, water-dispersible silt; WDC, water-dispersible clay; CD, cattle dung; $LSD_{(0.05)}$, least significant difference at $p \leq 0.05$. Note: The lime used was $Ca(OH)_2$; standardized CD+Urea was to achieve CN ratio in the CD of around 10.*

*Table 4. Selected indices of soil fertility of the coarse-textured soil at okra harvest around 9 weeks after sowing as affected by application of cattle dung, urea and/or lime to the soil*

| Treatments | Soil pH | % SOC | % Total N | AvP (mg/kg) | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | TEB | EA | ECEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (cmol/kg) | | | | | | |
| CD | 5.3 | 1.23 | 0.084 | 8.84 | 1.82 | 4.347 | 4.347 | 0.133 | 10.65 | 1.1767 | 11.82 |
| Urea | 5.2 | 1.15 | 0.079 | 8.18 | 1.28 | 3.850 | 1.623 | 0.157 | 6.91 | 1.2533 | 8.16 |
| Lime | 6.5 | 1.16 | 0.076 | 8.10 | 1.28 | 5.233 | 1.423 | 1.010 | 8.65 | 1.1600 | 9.81 |
| CD+Urea | 5.6 | 1.53 | 0.102 | 9.12 | 1.42 | 4.113 | 1.580 | 0.103 | 7.22 | 1.2200 | 8.44 |
| CD+Lime | 6.5 | 1.28 | 0.102 | 9.86 | 1.49 | 6.417 | 1.720 | 0.130 | 9.76 | 1.0700 | 10.83 |
| Urea+Lime | 6.4 | 1.50 | 0.101 | 8.72 | 1.14 | 5.427 | 1.823 | 0.133 | 8.52 | 1.1467 | 9.67 |
| CD+Urea+Lime | 6.5 | 1.39 | 0.068 | 12.60 | 2.26 | 5.663 | 5.983 | 0.140 | 14.04 | 1.0200 | 15.06 |
| Standardized CD+Urea | 5.2 | 1.16 | 0.080 | 9.25 | 2.11 | 4.450 | 2.287 | 0.180 | 9.02 | 1.1400 | 10.16 |
| Control | 5.2 | 1.14 | 0.074 | 8.36 | 1.02 | 3.343 | 1.277 | 0.120 | 5.81 | 1.3333 | 7.14 |
| *$LSD_{(0.05)}$* | *0.27* | *0.25* | *NS* | *1.42* | *0.19* | *0.747* | *0.453* | *0.061* | *1.25* | *0.0757* | *1.20* |

*SOC, soil organic carbon; N, nitrogen; AvP, available phosphorus; $K^+$, exchangeable potassium; $Ca^{2+}$, exchangeable calcium; $Mg^{2+}$, exchangeable magnesium; $Na^+$, exchangeable sodium; TEB, total exchangeable bases; EA, exchangeable acidity; ECEC, effective cation exchange capacity; $LSD_{(0.05)}$, least significant difference at $p \leq 0.05$; NS, not significant at $p \leq 0.05$*

Treatment also affected SOC concentration as well as soil contents of available P and the three plant-nutrient exchangeable bases ($K^+$, $Ca^{2+}$ and $Mg^{2+}$), but not total N. The highest SOC values were found in CD+Urea, Urea+Lime and CD+Urea+Lime and the lowest in Urea, Lime, standardized CD+Urea and Control. The CD only nominally increased SOC content over the Control. Soil available P was higher in treatment CD+Urea+Lime than the rest. For the three plant-nutrient exchangeable bases, this same best-performing treatment CD+Urea+Lime either showed the highest values or was among treatments showing the highest values (Table 4).

Furthermore, treatment affected total exchangeable bases (TEB) in a manner somewhat opposite to the results for soil exchangeable acidity (EA). The soil ECEC, though generally low, also differed among treatments, following a similar trend as TEB whereby CD+Urea+Lime showed the highest values of these two soil fertility indices. Notably, $Na^+$ was much higher in treatment Lime compared to the rest (Table 4).

## *Relationships between okra performance indices and soil properties*

Table 5 shows the relationships between okra performance indices in response to treatment and associated variations in soil properties of the study. All okra growth indices showed very weak positive correlations with soil bulk density, which in turn showed very weak positive correlations with %WSA, WDSi, WDC, soil pH and SOC. Thus, these growth indices had weak negative correlations with %WSA which, however, had strong positive relationships with MWD of aggregates and soil pH. This was evident in the effects of CD+Lime which recorded the highest %WSA, one of the highest soil pH, and the highest MWD of aggregates (see Tables 3 and 4).

The WDSi and WDC indexing soil microaggregate stability had strong positive correlations with MWD of aggregates and very weak correlations with okra growth indices. Thus, soil aggregation did not have direct effects on okra growth.

Plant height, leaf area, fresh matter and dry matter of okra generally had significant positive relationships with soil available P, $K^+$, $Ca^{2+}$, TEB and ECEC. By contrast, these okra growth indices had marginally significant negative relationships with EA of the soil. It is also evident that TEB alone almost entirely defined ECEC of the soil. Though non-significant, okra growth indices consistently showed negative correlations with soil content of $Na^+$. The SOC content had positive relationships with soil total N content and number of leaves produced by the okra plant.

From the coefficients of the pair-wise correlations shown, the strongest relationship was that between soil pH and $Mg^{2+}$ (0.89**), while the only negative relationship was that found between EA and soil pH (–0.72*). With the exception of this EA, none of the other soil properties that defined okra dry matter accumulation correlated with soil pH (Table 5). Notably, $Mg^{2+}$ was the only one out of the plant-nutrient base-forming cations ($K^+$, $Ca^{2+}$ and $Mg^{2+}$) not among these biomass productivity-defining soil properties but which correlated positively with soil pH.

When okra performance indices were regressed on all soil properties by stepwise procedure, the regression selected only available P (AvP) as predictor of not just plant height of okra but, more importantly, its dry matter by the following relationship:

$$Y = -15.323 + 2.459 AvP$$

($R^2$, 0.63; Adj. $R^2$, 0.58; standard error of the estimate, 2.80).

*Table 5. Coefficient of the correlations between treatment-induced variations in okra performance indices and the corresponding variations in soil properties of the coarse-textured soil at okra harvest around 9 weeks after sowing (n = 9)*

| SOIL PROPERTIES | OKRA PERFORMANCE INDICES | | | | | SELECTED SOIL PROPERTIES | | | |
|---|---|---|---|---|---|---|---|---|---|
| | †PLANT HEIGHT | †NO. OF LEAVES | †LEAF AREA | FRESH MATTER | DRY MATTER | %WSA | MWD | SOIL pH | SOC |
| Bulk density | 0.21 | 0.02 | 0.17 | 0.23 | 0.04 | 0.22 | 0.08 | 0.05 | –0.15 |
| %WSA | –0.08 | –0.45 | –0.19 | –0.16 | –0.23 | - | - | - | - |
| MWD | 0.11 | –0.12 | –0.05 | –0.01 | –0.10 | 0.64* | - | - | - |
| Soil pH | 0.25 | –0.17 | 0.18 | 0.26 | 0.25 | 0.78* | 0.28 | - | - |
| SOC | 0.24 | 0.57§ | 0.31 | 0.29 | 0.41 | 0.13 | –0.01 | 0.43 | - |
| WDSi | 0.33 | 0.00 | 0.08 | 0.29 | 0.10 | 0.20 | 0.67* | 0.01 | –0.24 |
| WDC | 0.33 | –0.01 | 0.06 | 0.28 | 0.10 | 0.23 | 0.72* | 0.04 | –0.22 |
| Total N | 0.04 | 0.42 | –0.04 | 0.09 | -0.02 | 0.36 | 0.36 | 0.20 | 0.61§ |
| AvP | 0.76* | 0.20 | 0.74* | 0.63* | 0.79* | 0.01 | 0.05 | 0.44 | 0.38 |
| $K^+$ | 0.68* | 0.31 | 0.75* | 0.65* | 0.71* | –0.28 | 0.07 | 0.03 | 0.03 |
| $Ca^{2+}$ | 0.57§ | 0.14 | 0.74* | 0.49 | 0.66* | –0.24 | –0.32 | 0.17 | 0.18 |
| $Mg^{2+}$ | 0.43 | –0.12 | 0.33 | 0.39 | 0.34 | 0.78* | 0.50 | 0.89** | 0.33 |
| $Na^+$ | –0.24 | –0.29 | –0.21 | –0.04 | –0.19 | 0.36 | 0.03 | 0.38 | –0.33 |
| TEB | 0.66* | 0.07 | 0.74* | 0.59§ | 0.69* | 0.14 | 0.01 | 0.51 | 0.23 |
| EA | –0.62§ | –0.07 | –0.60§ | –0.57§ | –0.59§ | –0.47 | –0.41 | –0.72* | –0.33 |
| ECEC | 0.65* | 0.07 | 0.75* | 0.59§ | 0.69* | 0.12 | –0.01 | 0.50 | 0.22 |

*WSA, water-stable aggregates; MWD, mean-weight diameter of aggregates; WDSi, water-dispersible silt; WDC, water-dispersible clay; SOC, soil organic carbon; N, nitrogen; AvP, available phosphorus; $K^+$, exchangeable potassium; $Ca^{2+}$, exchangeable calcium; $Mg^{2+}$, exchangeable magnesium; $Na^+$, exchangeable sodium; TEB, total exchangeable bases; EA, exchangeable acidity; ECEC, effective cation exchange capacity; **significant at $p \leq 0.01$; *significant at $p \leq 0.05$; §significant at $p \leq 0.10$; †Values are means for the four growth stages of 3, 5, 7 and 9 weeks after sowing.*

## Discussion

By its key physicochemical properties, the soil of this study could be described to be of low fertility status (Chude et al., 2011), incapable of supporting sustainable arable crop production. The CD showed high organic C and low N contents compared to those used in some other studies (Adubasim et al., 2018; Ndzeshala et al., 2023). This implies higher C/N ratio of the CD in the present study and a relatively large amount of Urea N-fertilizer to reduce this ratio. It was anticipated that these organomineral soil amendments would enhance okra growth and productivity and have a positive net effect on the fertility status of the soil.

The results for okra plant height portray CD as indispensable in promoting plant growth, due to its liming effect in soils and mineralisation to release plant nutrients. Comparison of CD and CD+Lime would, however, suggest that liming effects of soil amendments are expressed more in plant growth in coarse-textured acid soils when such agronomic effects come from both organic and synthetic sources. This, coupled with the increases in vegetative growth due to N supply from urea, would explain why CD+Urea+Lime produced the tallest plants 9 WAS. Ojomah et al. (2020) similarly reported that the mixture of CD and N-supplying fertilizer increased crop productivity at the location of the present study.

The high number of leaves recorded in CD+Urea and the broadest leaves shown by CD+Urea+Lime could be due to increased availability of N, P and K all of which usually promote leaf growth. Broad leaves guarantee greater exposure to sunlight for photosynthesis, transpiration and food absorption and translocation within the plant. During the experiment, okra plants treated with Urea and Urea+Lime were observed to have interveinal chlorosis, and this could be as a result of P and Mg deficiencies in the these treatments.

Though treatments having CD generally enhanced okra growth, CD+Urea+Lime produced higher okra dry matter than the rest. Based on these observations, we can infer that CD is indispensable for increasing fresh matter production in these soils but require urea and lime to increase dry matter production. The CD+Urea+Lime produced the highest okra biomass because of increased nutrients bioavailability. Acid soils contain large amounts of $Al^{3+}$, $Fe^{3+}$ and $Mn^{3+}$ that adsorb P and displace base-forming cations, thereby making them unavailable to plants (Nair et al., 2013). This is especially true in highly weathered tropical soils (Akinrinade et al., 2006). By effectively decreasing the acidity of these soils, manures make essential nutrients including $Ca^{2+}$ and $Mg^{2+}$ available for plants' use (Otieno et al., 2018).

In this study, CD increased the bulk density of the soils, implying potential for soil compaction when using CD alone as organic amendment. This is attributed to the high C/N ratio of CD (see Table 2) which is far above the ideal ratio of 24:1 for microbial activities and decomposition (Stenger and Hobgood, 2018), as well as the short-term duration of this study. By contrast, research has shown that readily decomposed manures decrease soil bulk density (Khaliq and Abbasi, 2015; Adekiya et al., 2020; Obalum et al., 2020a; Bilong et al., 2022). However, the combination of CD with urea (treatment CD+Urea) reduced the soil bulk density, unlike the combination of CD with lime which acting alone also reduced the bulk density. Urea alone did not produce a similar effect in the soil, an observation that is consistent with Kolawole et al. (2014), Khaliq and Abbasi (2015) and Hafifah et al. (2016).

The synergistic effect of CD+Urea and Lime on soil bulk density was evident in CD+Urea+Lime which showed the lowest. These results are partly because of the N from urea reducing the C/N ratio of CD to favour microbial activities, and partly because of the increased decomposition of CD in the presence of N-rich urea manifesting as increased SOC (see Table 4), which in the presence of $Ca^{2+}$ released from the $Ca(OH)_2$ lime promoted soil aggregation and porosity. Soil bulk density depends primarily not only on soil texture, but also on organic matter content, and influences infiltration rate, water retention, soil porosity, microbial activities, root penetration and overall soil fertility.

The %WSA and MWD of aggregates are two related parameters used to index soil aggregation. Their values in this study are characteristic of highly weathered tropical soils which are known to have high aggregate stability with proportion of water-stable or macro-aggregates (> 0.25 mm) as high as 85% (Igwe et al., 1999), due to the predominance of kaolinites, Fe and Al oxides, quartz, etc. in the mineralogical composition of these soils (Alekseeva et al., 2008; Igwe, 2011). Treatment CD+Lime showed the highest %WSA because, by dissociating to supply $Ca^{2+}$ in the soil, the $Ca(OH)_2$ lime was expected to have aggregating effect. It appears that this effect manifests better in the presence of manure.

The values of WDSi and WDC contents of the soils could be judged moderate to high (Igwe and Udegbunam, 2008). These two microaggregate stability indices are used to derive a number of colloidal dispersion indices used to predict soil susceptibility to water erosion (Igwe and Udegbunam, 2008; Igwe and Obalum, 2013). The high values of WDSi and WDC in the CD+Lime and standardized CD+Urea indicate poor flocculation and high erodibility (Igwe and Udegbunam, 2008). This attribute being associated with CD+Lime that had macro-aggregating effect in the present study is rather surprising. The WDSi and WDC have been shown to correlate negatively with soil pH and positively with exchangeable acidity, EA (Igwe and Agbatah, 2008; Igwe and Udegbunam, 2008). So, for standardized CD+Urea, the high WDSi and WDC values could be as a result of its low soil pH (see Table 4).

Soil pH being highest in Lime, CD+Lime, Urea+Lime and CD+Urea+Lime agrees with Otieno et al. (2018) and Kimiti et al. (2021) who recorded highest soil pH values in similar treatments in Kenyan acidic soils. Treatments CD+Urea+Lime and CD+Lime were, however, most effective in reducing the soil acidity. Manures help decrease soil acidity in tropical soils because of their appreciable contents of Ca and Mg, which correct soil acidity by displacing $Al^{3+}$ and $H^+$ (Otieno et al., 2018). The high soil pH could also be partly due to dissociation of the $Ca(OH)_2$ lime in soil water to release $Ca^{2+}$. The calcium ions ($Ca^{2+}$) so released displace $Al^{3+}$ and $H^+$ while the $OH^-$ reacts with the displaced $Al^{3+}$ and $H^+$ to form $Al(OH)_3$ and $H_2O$, respectively. Excess $OH^-$ in soil solution raises the soil pH hence the observed reductions in EA of the soil (Onwonga et al., 2008; Ardestani et al., 2016).

Increases in SOC content of the soil due to treatment CD being nominal, which could be linked to its aforementioned slow decomposition, was also reported by Obalum et al. (2020b) and Eyibio et al. (2025). Treatment CD+Urea+Lime gave higher soil available P than the rest because the CD-mediated concurrent increases in soil pH and release of P into the soil was complemented by the additional increases in P due to the raised soil pH (Chukwuma et al., 2024), which were from the lime component of the treatment. Co-application of poultry droppings and synthetic lime was found to increase soil available P in Sandy Loam of the derived savannah zone (Ugwu et al., 2024). By having the C/N ratio of cattle dung reduced due to the urea component of CD+Urea+Lime, the cattle dung with urea in this promising treatment probably decomposed/mineralized in the presence of lime with an effect on soil available P similar to that of co-applied poultry droppings and lime.

Additionally, treatment CD+Urea+Lime more than CD+Urea and the rest improved soil contents of the three plant-nutrient exchangeable bases ($K^+$, $Ca^{2+}$ and $Mg^{2+}$), TEB and ECEC. Under field conditions, Ogumba et al. (2024a) reported greater enhancement of mainly $Ca^{2+}$ and cation exchange capacity of sandy-loam soil of the derived savannah due to co-application of poultry droppings and synthetic lime than to sole application of poultry droppings. Again, the cattle dung in CD+Urea+Lime with reduced C/N ratio probably decomposed/mineralized in the presence of lime producing similar effects on the soil's cation exchange behaviour as would do co-applied poultry droppings and lime. The results for TEB and ECEC of the soil would further explain treatment effects on soil pH, as increased retention of the base-forming cations is always expected to raise soil pH. Because $Na^+$ is not an essential plant nutrient, and because its high soil concentrations induces dispersion which adversely affects soil structure (Tyopine et al., 2020), application of lime to these soils without organic amendment or N-rich fertilizers may have negative implications for the environment.

The SOC is a major component of soil organic matter which influences soil quality and fertility (Obalum et al., 2017). In the present study, there were 39% and 36% increases in SOC in CD+Urea and Urea+Lime, respectively, relative to the Control. Soil total N was generally low and, unlike SOC, did not differ among treatments, suggesting that the latter was not yet stabilized in the soils (Malhi et al., 2003; Swanston et al. 2004). With N-rich urea in some of the treatments, their similarity in total N is surprising, just as CD+Lime without urea being among those showing tendency for highest values. This observation suggests, however, that N retention in these sandy soils may not depend on urea input, but on some other factors. Most of the N in the added urea might have been lost via N-leaching of N, due to the yet-to-stabilize status of SOC (mentioned above) and/or the low ECEC of the soils which could compromise the binding of N in clay-SOC complexes to prevent its leaching.

The correlations results highlight the role of soil contents of available P and the exchangeable bases (except $Na^+$) in okra growth. Uddin et al. (2014) observed that okra plants nourished with P grew better than those with lower P levels. Okra growth indices tended to show negative correlations with soil $Na^+$ probably due to its tendency to cause soil dispersion and lower soil permeability, which could adversely influence soil fertility. The positive relationships between SOC content and each of soil total N content and number of leaves of okra are plausibly because SOC-associated N is a key nutrient in vegetative growth of plants (Ebido et al., 2024; Ogumba et al., 2024b), such that more soil N would imply more leaves.

The $Mg^{2+}$ not being among the productivity-defining soil properties but correlating positively with soil pH suggests that soil pH changes following organomineral amendments of these soils may not always be the mechanism behind changes in their physicochemical properties that influence okra growth. Available P contributing 63% to the variations in okra dry matter suggests that P is a critical nutrient element for arable crops production in coarse-textured acid tropical soils (Ugwu et al., 2024). This is attributed to the suppressive effect of P on base-forming cations ($K^+$ and $Ca^{2+}$) which equally contributed to dry matter accumulation (Ndzeshala et al., 2023). Overall, these observations also suggest that plant height and leaf area but not number of leaves were the growth traits influencing dry matter accumulation in okra in this study.

The strong positive correlations found between MWD and the micro-aggregate/colloidal stability indices (WDSi and WDC) vindicate the rather surprising results that CD+Lime improved soil macro-aggregation and, at the same time, lowered soil micro-aggregation. Increases in soil pH and corresponding decreases in EA can abate soil colloidal dispersion in managed ecosystems without organomineral soil amendments (Igwe and Agbatah, 2008). In the present soil fertility trials, however, the synergistic liming effect of cattle dung and synthetic lime in treatment CD+Lime probably caused disproportionate enhancement of the net negative charges on the cations exchange complex of the soil. As the soil pH increased, this situation caused greater release of the negatively charged silt and clay particles in soil solution which, with the associated increases in $Mg^{2+}$, became flocculated to ultimately manifest in the increased macro-aggregate stability (%WSA) of the soil (see Table 5).

## Conclusions

This study evaluated the effects of cattle dung (CD), urea fertilizer and synthetic lime ($Ca(OH)_2$) combination on the vegetative growth of okra in relation to some physicochemical properties of the coarse-textured, low-fertility soils of the Guinea savannah. The use of the carbon-rich CD as manure together with urea (to supply the much-needed nitrogen) and lime (to contribute to ameliorating soil acidity) outperformed the combinations of any two of these amendments, including CD-urea mix to reduce the CD's C:N ratio to around 10, termed standardized CD+Urea, or sole use of any one of them. The effectiveness of this best option

(CD+Urea+Lime) in the savannah region derives from improvements in soil physicochemical properties which can promote P nutrition for enhanced crop productivity.

Therefore, a combination of CD-manure, Urea and lime could be recommended as an organomineral soil amendment for adoption by farmers especially those producing okra and similar crops in the dominant coarse-textured and low-fertility acid soils of the savannah region. The combination should be such that, to ensure its effectiveness, CD and lime should be mixed and added three weeks before sowing and Urea at sowing. Research is still needed to check the performance of this proposed soil fertility management practice as well as its economic viability against the conventional practice of use of more readily mineralizable manures (such as poultry-droppings manure) and/or NPK fertilizers.

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