International Journal of Recycling of Organic Waste in Agriculture (2023) Special Issue: 119-128
Doi: 10.30486/IJROWA.2023.1968757.1544

ORIGINAL RESEARCH

Cow bone meal applications: Changes in physicochemical properties of a degraded coarse-textured soil and cucumber performance

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Received: 04 October 2022 / Accepted: 30 July 2023/ Published online: 07 August 2023

Abstract

Purpose: Degraded soils are associated with low organic matter and nutrient contents, which limit their productive capacity to produce sufficient food. Improving the productivity of degraded soils is key to achieving sustainable food production and tackling global food crises.

Method: A study was carried out between September 2021 to March 2022 in a greenhouse at the University of Nigeria Nsukka Teaching and Research Farm to evaluate effect of cow bone meal (CBM) application on soil physicochemical properties and performance of cucumber grown on a degraded coarse-textured soil. The study treatments were: CBM10 (CBM at 10 t ha^{-1}; equivalent to 22 g per 5 kg soil), CBM20 (CBM at 20 t ha^{-1}; equivalent to 44 g per 5 kg soil), and NPK 20:10:10 fertilizer applied at recommended rate 150 kg ha^{-1} (0.33 g per 5 kg soil) and control.

Results: CBM treatments application had remarkable positive effects on the soil physicochemical properties as well as on cucumber performance. Relative to the initial soil status, CBM application increased organic C by 139 -179%; available P by 388-396% and total N by 78-111%. Summarily, CBM20 treatment outperformed NPK fertilizer treatment on the measured soil parameters and cucumber performance, while CBM10 treatment had comparable effects with NPK treatment.

Conclusion: The results obtained demonstrate the effectiveness of CBM in improving the physicochemical properties of a degraded soil. Further research work (under field conditions) is required to validate the findings of this study prior to practical implementation by end users.

Keywords: Cow bone meal, Degraded soil, Physicochemical properties, Yield performance

Introduction

Cucumber, (*Cucumis sativus* L.), an important member of the Cucubitaceae family (Thoa 1998; Eifediyi and Remison 2009), is cultivated for its fruits, which are eaten fresh and in salads as accompaniment with other vegetables (Eifediyi and Remison 2009; Osundare et al. 2019). Cucumber fruits are rich in minerals, potassium, magnesium, phosphorus, copper, manganese, vitamins (A, C, K, and B6) and pantothenic acid (Vimala et al. 1999). Cucumber, an unpopular vegetable crop in Southeastern Nigeria, is gaining huge market demands and could become an important vegetable crop in future as its demand is increasing. This is because the present consumers' demands for cucumber far exceed its domestic production. Cucumber, as a high-nutrient demanding crop, if cultivated on nutrient deficient soils, it pro-

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duces low yields, bitter and misshapen fruits (Grubben and Denton 2004). Thus, moderate to high nutrient rich soils are needed to achieve high cucumber yields.

Cucumber productivity in Southeastern Nigeria is far below its potential yield due to less fertile (degraded) soils (Unagwu et al. 2020). Poor soil management approach by farmers further deplete soil nutrients as the lands are continuously cropped with little or no fertilizer (organic or inorganic) inputs. Low agricultural productivity poses an imminent danger to achieving global food security (Unagwu 2019). This implies that a healthy functional soil is critical to achieving optimum crop production (Unagwu et al. 2020).

Thus, improving the productivity of degraded soils is key to achieving sustainable food production (Unagwu 2019) and tackling global food crises. There are reports on the use of organic amendments (food wastes, composts, cow bone meal, cow dung, sewage sludge, manures etc.) to improve soil physical, chemical and biological properties (Bouajila and Sanaa 2011; Gonfa et al. 2018). The long-term negative effects associated with chemical fertilizer application emphasize the need to practice integrated nutrient management and look forward to other alternate nutrient sources.

In recent years, there is a huge decline in NPK fertilizers usage in Nigeria, especially among resource-poor farmers. This is primarily due to unavailability and high costs of NPK fertilizers and financial constraints on the part of the farmers. Thus, there is a need for alternative sources of fertilizer to increase crop yields as well as improve soil fertility status. Study by Carcia and Rosentrater (2008) indicated that meat and bone meal, a by-product of the rendering industry, contains about 8% nitrogen, 5% phosphorus, 1% Potassium and 10% Calcium. In addition, it also supplies micronutrients and organic matter (Nogalska and Zalewska 2013). This suggests that meat and bone meal has great potential as soil nutrient source and huge effects in ameliorating less fertile soils and enhancing crop production (Mondini et al. 2008; Cascarosa et al. 2012; Nogalska and Zalewska 2013; Yasmin et al. 2018; Nogalska et al. 2018; Nogalska and Załuszniewska 2021).

Unlike animal manures, composts, inorganic fertilizers, etc., the use of cow bone meal (CBM) as soil amendment is uncommon among farmers in Nigeria especially in Nsukka, Southeast Nigeria. More so, there is sparse published information on the use of CBM as soil conditioner in Nigeria. Hence, this study was conducted to evaluate the effectiveness of cow bone meal application over inorganic fertilizer in enhancing the physicochemical properties of a degraded soil and cucumber performance.

Materials and methods

This pot culture experiment was carried out during September 2021 to March 2022 in a greenhouse at the University of Nigeria Nsukka (UNN) Farm. The Teaching and Research Farm lies on a latitude 6°51’43"N and a longitude of 7°25'22”E with an altitude of 410 m. The study soil samples were collected from a degraded site in the Teaching and Research Farm. The soil samples (ultisol) were air dried and sieved through a 2 mm sieve. Five-kilogram (kg) soil was weighed into an experimental pot, 30 cm high and 18 cm diameter. The nutrient treatments were: Cow bone meal (CBM) applied at 10 t ha^{-1} (equivalent to 22 g per 5 kg soil), CBM applied at 20 t ha^{-1} (44 g per 5 kg soil), NPK 20:10:10 fertilizer applied at 150 kg ha^{-1} recommended rate (0.33 g per 5 kg soil) and Control. The treatments were replicated three times. Cow bone meal is a by-product obtained after heating, drying and crushing cow carcasses. After amendment application, the treatments were incubated for two weeks and irrigated intermittently to enhance and activate soil microbial activities and mineralize the organic amendments applied; especially the CBM amended pots. NPK fertilizer was applied two weeks after planting the test crop (cucumber).

Cucumber seed, Greengo F1 variety, was sourced from the Department of Crop Science, University of Nigeria Nsukka. The cucumber seed was sown at the rate of three (3) seeds per pot at a depth of three (3) cm. Two days after germination, the seedlings were thinned down to one seedling per pot. Following the seedling emergence, the plants were irrigated with 250 ml of water at a two-day interval. Two weeks after seedling emergence, irrigation was increased to 400 ml daily to satisfy crop water needs. Plant growth was assessed at weekly intervals from the first week to the 8^{th} week after seedling emergence. The following plant growth parameters were accessed: vine length, number of leaf and leaf area (cm^2).

Soil analyses were carried out on the sample soils collected prior and after plant harvest. Soil bulk density was determined using an undisturbed soil core (5.0cm deep x 5.0cm internal diameter) following Grossman and Reinsch (2002) method. Subsequently, total soil porosity (TP) was derived from the BD and calculated thus;

TP $=100 \times (1-\frac{db}{dp})$ where *db* is the soil bulk density and *dp* is the particle density of soil solids (2.65 Mg m^{-3}). Soil saturated hydraulic conductivity determined following Klute and Dirksen (1986) core method.

Soil samples (about 100 g) were taken for chemical analysis. pH meter was used to measure soil pH in the soil: distilled water (in 1:2.5 ratio suspension) Soil:KCl suspension reading is not required. Organic carbon was determined by the Walkley-Black Method (Nelson and Somners 1996). Exchangeable potassium was extracted using 1 M ammonium acetate and read using a flame photometer (Thomas 1982). Phosphorus was determined using the Bray II Method (Bray and Kurtz 1945) while total nitrogen was determined by the Macro Kjeldahl Method (Bremner 1996).

Result and discussion

The test soil was acidic as evidenced by low soil pH level and has low organic carbon and nutrient contents (Table 1). The initial soil test results suggest that low soil fertility, low organic matter content and pH level will not only impede crop yields but also adversely affect soil properties. Thus, this suggests that the test soil critically needs soil nutrient enhancement to boost its fertility status for any meaningful crop yield as well as improve the overall soil health status. In contrast, cow bone meal (CBM) characterization indicated that the organic amendment is associated with high pH level (6.8) and has rich chemical nutrient contents (Table 1).

Table 1 Chemical composition of cow bone meal and test soil used

Parameters	Test soil	Cow bone meal
pH (H_2O)	5.4	6.8
Organic carbon (%)	0.48	57
Total nitrogen (%)	0.18	1.26
Available phosphorus	25.2	ND
Total phosphorus (%)	ND	3.84
Exchangeable potassium	0.52	ND
Total potassium (%)	ND	0.63
Exchangeable calcium	1.82	85.7
Total calcium (%)	ND	0.86

ND; Not determined

Treatment application effects on soil physical properties

Treatment application has varied significant ($p < 0.05$) effect on soil physical properties (Table 2). Soil bulk density (BD) was significantly affected following CBM application. CBM10 and CBM20 treatments had lower ($p < 0.05$) BD as compared with the NPK and Control treatments. Soil BD for CBM10 and CBM20 treatments was statistically the same but was significantly reduced by 14.8%, 14.0% and 24.4%, 23.5%; relative to NPK and Control treatments, respectively. NPK and Control treatments had an insignificant effect on soil BD. The significant ($p < 0.05$) reduction in soil BD for CBM amended soils is attributed to high organic matter content associated with CBM amendment (Table 1). Unagwu et al. (2020) reported a similar finding. Hati et al. (2007) found significant decrease in BD following organic amendment application, which they attributed to the significant relationship (r = -0.59) between BD and soil organic carbon. A study by Phullan et al. (2017) showed that farmyard manure application reduced bulk density by 13% when compared to mineral fertilizer amended plots. Unagwu et al. (2020) noted that the soil BD associated with amended (poultry manure, anaerobic digested waste, and mushroom compost) treatments application was significantly ($p < 0.05$) lower (by over 11%) compared with the Control treatment.

Table 2 Effects of cow bone meal application on soil physical properties

Treatments	Bulk density (g/cm^3)	Hydraulic conductivity (cm/min)	Total Porosity (%)
CBM10	1.36	5.81	47.9
CBM20	1.35	6.69	54.6
NPK	1.55	3.03	41.0
Control	1.68	2.45	39.8
$LSD_{(0.05)}$	0.13	1.09	2.58

CBM; Cow bone meal, $LSD_{(0.05)}$; Least significant difference at 5% probability level

Application of CBM had a significant ($p < 0.05$) effect on soil hydraulic conductivity (HC). CBM10 and CBM20 treatments had significantly higher HC ($p < 0.05$) relative to NPK and Control treatments. The hydraulic conductivity values were statistically at par with NPK and Control treatments. The result showed (Table 2) that CBM20 treatment recorded the highest (6.69 cm^3/cm^3) HC value but was statistically at par with CBM10 treatment. There were varied significant changes on soil total porosity (TP) following treatment application. The soil TP ranged from 38.9% (for the Control treatment) to 54.6% (for CBM20 treatment). CBM20 treatments had significantly ($p < 0.05$) higher (54.6%) TP relative to CBM10, NPK and Control treatments. The effect on soil TP for NPK and Control treatments did not differ statistically.

The significant effects of CBM on the hydraulic conductivity and total porosity properties of the test soil following organic treatment application can be attributed to the high organic carbon content associated with CBM amendment (Table 1). CBM application lowers the soil BD and increases the soil pore space (porosity) by increasing soil pore size distribution and thereby increased the soil hydraulic conductivity (Unagwu et al. 2020). Nwite and Okolo (2016) reported similar findings. They found significant increases in soil water retention and hydraulic conductivity in plots amended with burnt rice mill wastes compared to the control. Unagwu et al. (2020) noted that soil TP in organic amended treatments was significantly ($p < 0.05$) higher than that of the Control treatment by over 25%.

Treatment application effects on soil chemical properties

There were varied effects on the chemical properties of the test soil following treatment application. CBM10, CBM20 and NPK treatments recorded significantly ($p < 0.05$) high soil pH values relative to the Control treatment (Table 3). The effect on soil pH for CBM20 and CBM10 treatments did not differ statistically but were higher ($p < 0.05$) compared with NPK and Control treatments. The higher pH in CBM treated soils was due to the high pH associated with CBM amendment in addition to its calcium content (Table 1), which is attributed to have positive effects on soil pH (Nogalska and Zalewska 2013). Nogalska et al. (2018) reported considerable increase in soil pH values with meat and bone meal (MBM) treatments application. Contrary to our findings, Nogalska and Zalewska (2013) reported lower soil pH following yearly application of higher doses of MBM despite the supply of considerable amounts of calcium (ca. 200–250 kg Ca/ha) associated with MBM. The total N in CBM20 and NPK treatments had statistically similar effects on the total N but were higher ($p < 0.05$) relative to the Control treatment. CBM10 had the highest ($p < 0.05$) total N content. The significantly low total N associated with CBM20 treatment relative to CBM10 treatment can be attributed to plant N uptake. Mondini et al. (2008) reported significant increases in extractable NH_4^+ and NO_3^- (mineral N) following application of MBM with respect to the control treatment. According to the authors, the NH_4^+ and NO_3^- contents were markedly influenced by the rate of MBM applied. Organic amendment application significantly ($p < 0.05$) increased total organic nitrogen and NH_4-N as compared with the Control treatment. Increasing treatment application rate increased soil total oxides of N by over 200% relative to the control (Unagwu et al. 2020).

Available P in CBM10 and CBM20 amended soils were nonsignificant ($p > 0.05$) but were significantly ($p < 0.05$) higher than those in NPK and Control treatments (Table 3). Percentage increases in available P for CBM10 and CBM20 relative to NPK and Control treatments were 76%; 84% and 76.5%; 83%, respectively. The soil available P content increased (34% increase) in response to NPK treatment application relative to the Control treatment. In a pot experiment, Nogalska et al. (2018) found that MBM applied at a lower rate (0.2%) supplied a comparable amount of available P with the control treatment. The authors further observed that higher rates of MBM had significant increases (9%) in available P content of soil relative to NPK treatment. The non-significant effect on available P observed for CBM10 and CBM20 treatments could be due to variation in plant P uptake or due to available P losses via leaching. This is because Jeng and Vagstad. (2009) found that about 50% of phosphorus from MBM was readily available for plant uptake in the first year of MBM application. Nogalska and Zalewska (2013) reported 11% increase in soil available phosphorus content from the initial value of 78.0 to 86.34 mg P/kg and approx. 5% increase in soil available phosphorus following MBM treatments application relative to mineral fertilization application.

Treatment application had insignificant effect on soil exchangeable K. Except CBM10 treatment, which had significantly ($p < 0.05$) higher exchangeable Ca, all other treatments had statistically similar exchangeable Ca content. For exchangeable Mg, CBM10 and CBM20 treatments had over 40% significantly higher exchangeable Mg as compared with NPK and Control treatments, both of which were statistically similar (Table 3).

Table 3 Effects of cow bone meal application on soil chemical properties

Treatments	pH (H_2O)	Total N (%)	Available P (mg/kg^{-1})	Exch. K (mg/kg^{-1})	Exch. Ca (mg/kg^{-1})	Exch. Mg (mg/kg^{-1})	Organic carbon (%)
CBM10	6.2	0.38	127	0.018	3.6	2.0	1.15
CBM20	6.3	0.32	123	0.009	2.8	2.0	1.34
NPK	5.8	0.34	29.8	0.009	2.0	1.2	0.75
Control	5.4	0.28	19.6	0.020	2.4	0.5	0.37
$LSD_{(0.05)}$	0.12	0.02	5.09	NS	1.02	0.44	0.09

CBM; Cow bone meal, Exch.; Exchangeable, $LSD_{(0.05)}$; Least significant difference at 5% probability

Treatments application had significant ($p<0.05$) influence on the soil organic carbon content (SOC). The SOC ranged from 0.37%, for the Control treatment, to 1.34% for CBM20 treatment. CBM amended soil had significantly ($p<0.05$) higher SOC content than NPK and Control treatments. CBM20 treatments had 44% and 72.4% more SOC than NPK and Control treatments, respectively. The data indicated higher CBM application significantly increased the SOC content by 14.2%. Treatments effects on SOC were in the order: CBM20 > CBM10 > NPK > Control. The significant effect on SOC content of the CBM treated soils is due to the high organic carbon content associated with the organic amendment applied (Table 1). This result corroborates those of Unagwu et al. (2020) and Yang et al. (2014). Maltas et al. (2013) reported over 0.7 g kg^{-1} increase in soil organic matter content with organic amendment application.

Percentage changes in soil properties relative to the initial soil fertility status

Relative to the initial soil nutrient status, treatment application had huge varied effects on the soil nutrient condition after plant harvest (Table 4). For instance, there were no changes in the soil pH for the Control treatment, while CBM10, CBM20 and NPK treatments had 14.8%, 16.7% and 7.4% respective increases in soil pH after plant harvest. For soil total N, CBM10 treatment had the highest (111%) contribution, followed by NPK (89%), CBM20 (78%) and Control (55%) treatments. The Control treatment had a negative percentage contribution to available P, while CBM treatments recorded the highest residual available P percentage contribution and NPK treatment had the least percentage contribution (Table 4). The residual SOC was highest (179%) in CBM20 amended soil and least for the Control treatment. The observed varied differences in the post-harvest soil nutrient status (Table 3) can be attributed to differences in plant nutrient uptake. This is evidenced by the significant ($p<0.05$) differences in the plant growth performance (Figs 1 and 2). Data in Table 4 demonstrates that CBM amendment can be a viable option over NPK fertilizer in enhancing the fertility status of a degraded soil.

Treatment application effects on cucumber growth parameters

Treatments application had significant ($p<0.05$) effects on the measured cucumber growth parameters (Fig. 1). Cucumber vine length ranged from 36.7 to 167 cm. Fourteen days after cucumber seed sowing (DAS), CBM20 treatment had the longest ($p<0.05$; 16.3 cm) vine length, while all other treatments had statistically similar vine length (Fig. 1). At 28 DAS, CBM10, CBM20 and NPK treatments had significantly longer vine length than the Control treatment.

From 28-56 DAS, CBM20 treatment maintained a significantly ($p < 0.05$) longer vine length relative to NPK and Control treatments. CBM10 and NPK treatments had comparatively similar effects on cucumber vine length except at 28 DAS and 56 DAS where CBM10 treatments had significantly ($p < 0.05$) longer vine length relative to NPK treatment. Beyond 28 DAS, CBM10 and CBM20 treatments did not differ statistically in their effect on cucumber vine length.The Control treatment did not support appropriate crop growth (vine length) relative to the amended treatments, probably because the residual soil nutrient content was insufficient or was below the critical level (Hamma et al. 2012) hence resulting in the production of shorter vine length. The result corroborates the findings of Musara and Chitamba (2014) who reported significantly ($p<0.001$) highest mean vine length (145.1 cm) for poultry manure treatment applied 20 t ha^{-1} while treatment 0 t ha^{-1} had the lowest (101.5 cm) vine length. Yasmin et al. (2018) reported significant ($p<0.05$) increase in the number of red amaranth (*Amaranthus cruentus*) leaves following application of composted beef bone meal.

Table 4 Percentage changes in soil properties relative to the initial soil characterization following treatment application

Treatments	pH (H_2O) (%)	Total N (%)	Available P (%)	Organic carbon (%)
CBM10	14.8	111	396	139
CBM20	16.7	77.8	388	179
NPK	7.40	88.9	18.3	16.7
Control	0.00	55.6	-22.2	-27.1

CBM; Cow bone meal

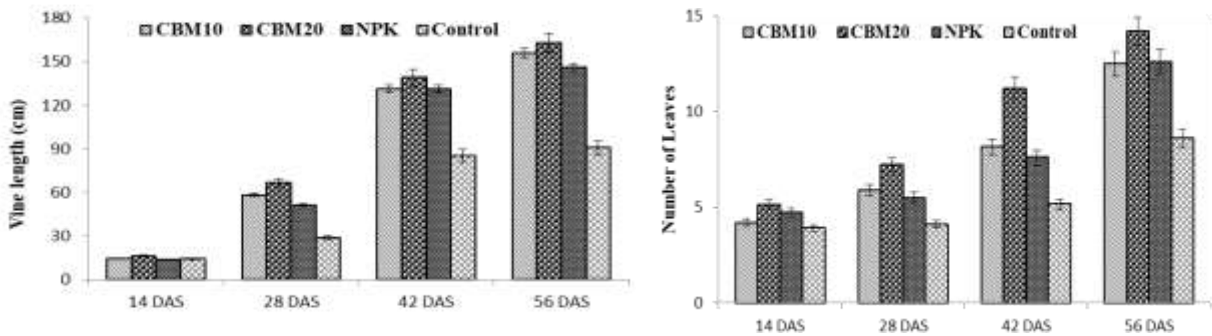

Fig. 1 Treatment effects on cucumber vine length and number of leaves

CBM; cow bone meal, bars; denote significant at 5% probability level

Treatments application recorded significant effects on the number of cucumber leaves produced at 14 DAS (Fig.1). Data show that the cucumber number of leaves per plant ranged from 3.9 to 14.2. The amended treatments had a greater ($p < 0.05$) number of cucumber leaves relative to the Control treatment. Throughout the plant vegetative growth period, CBM20 treatment consistently had significantly ($p < 0.05$) greatest number of cucumber leaves when compared with CBM10 and NPK treatments, both of which statistically produced the same number of cucumber leaves (Fig. 1). The greater number of plant leaves in CBM20 treated soil suggests greater nutrient provisioning relative to those of other treatments. Nogalska and Załuszniewska (2021) regarded meat and bone meal as a highly efficient organic fertilizer, whose fertilizing effect accounts for about 80% of that exerted by mineral N fertilizers. In a similar study, Orluchukwu and Amadi (2022) reported a significantly higher number of cucumber leaves following the application of poultry manure and spent mushroom substrate relative to NPK and control treatments. The authors attributed their findings to soil nutrient enrichment due to the organic fertilizers applied. Treatments application had significant ($p < 0.05$) effect on cucumber leaf area (Fig. 2). At 14 DAS, CBM20 treatment had significantly ($p < 0.05$) wider plant leaf area as compared with CBM10, NPK and Control treatments. Statistically, NPK and Control treatments did not vary in their effects on plant leaf area. Throughout the plant growth period, CBM20 treatment maintained significantly ($p < 0.05$) wider plant leaf area relative to CBM10, NPK and Control treatments (Fig. 2) except at 42 DAS, where CBM20 and CBM10 had insignificant ($p > 0.05$) effect on cucumber leaf area. Treatment's effect on cucumber leaf area is as follows: CBM20 > CBM10> NPK > Control.

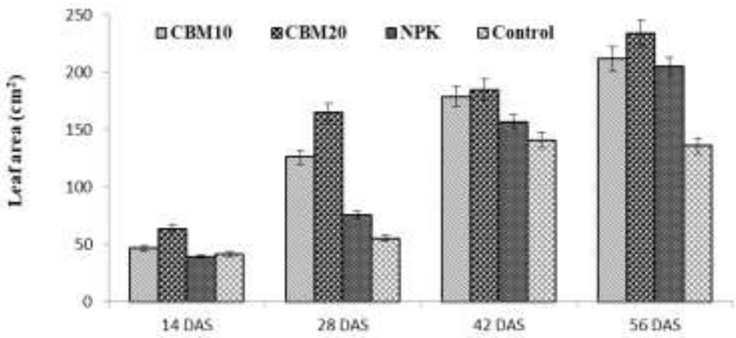

Fig. 2 Treatment effects on cucumber leaf area

CBM; cow bone meal, bars; denote significant at 5% probability level

Plant leaves are sites for photosynthesis. Plants with higher number of leaves and wider leaf area will have greater interception of the sunray and will have greater synthases. This is evidenced by significantly ($p < 0.05$) higher cucumber yield (Fig. 3) associated with CBM20 relative to other treatments.

Treatment application effect on cucumber yield

Treatment application had a significant effect on cucumber yield performance (Fig. 3). CBM20 had significantly higher cucumber yield compared with CBM10, NPK and Control treatments. CBM10 and NPK treatments had an insignificant effect on cucumbers. As a high-nutrient- demanding crop (Grubben and Denton 2004), the significantly high ($p < 0.05$) cucumber yield performance associated with CBM20 treatment could suggest adequate nutrient provisioning (Table 1). Also, the significantly longer ($p < 0.05$) vine length, higher number of plant leaves as well as wider leaf area contributed to the better yield performance associated with CBM20 treatment (Figs 1 and 2). This observation agrees with the findings of Ridge (1991), who noted that the number of plant leaves produced, leaf area and leaf area index are directly proportional to the photosynthates produced. The present result corroborates the findings of other studies. Orluchukwu and Amadi (2022) found significant higher cucumber yield with poultry manure treatment relative to spent mushroom substrate, NPK and control treatments. Musara and Chitamba (2014) obtained higher ($p < 0.05$) cucumber yield following cattle manure application relative to the control treatment.

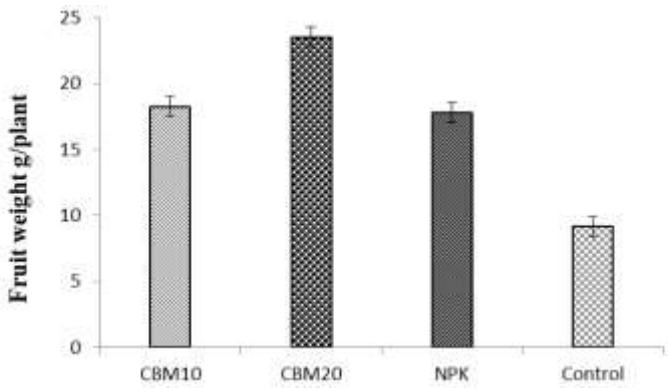

Fig. 3 Treatment effects on cucumber yield (fruit weight g/plant)
CBM; cow bone meal, bars; denote significant at 5% probability level

In a study on the effects of composted and powdered bones meal on the growth and yield of *amaranthus cruentus*, Yasmin et al. (2018) reported significant ($p < 0.05$) higher *amaranthus cruentus* yield following chicken bone compost, mutton bone compost and beef bone compost application relative to the control treatment. In a long-term (six years) study, Nogalska and Załuszniewska (2021) noted maize (herbage) yields (30% DM) varied from 45.6 Mg ha^{-1} in the Control treatment to 86.2 Mg ha^{-1} in the 1.0 Mg MBM + N79 treatment. The authors found no significant differences in maize yields among the fertilized treatments, but the yields obtained were significantly higher than the Control treatment.

Conclusion

Application of cow bone meal had remarkable positive effects on the soil physicochemical properties as well as on cucumber performance. The study shows that cow bone meal at higher application rate (20 t ha^{-1}) had greater ($p < 0.05$) effects on the plant parameters measured relative to that obtained when applied at lower rate (10 t ha^{-1}). Summarily, cow bone meal at 20 t ha^{-1} application rate outperformed NPK fertilizer application on their effects on soil and cucumber performance, while cow bone meal applied at lower (10 t ha^{-1}) rate had comparable effects as compared with NPK treatment. This study suggests that CBM amendment can be a viable option over NPK fertilizer in enhancing the fertility status of a degraded soil. Further research work (under field conditions) is required to validate the findings of this study to disseminate conclusive result findings to end users for practical implementation.

Acknowledgement: The authors acknowledge the help of laboratory staff of the Department of Soil Science, University of Nigeria, Nsukka for their help in the laboratory analysis.

Compliance with ethical standards

Conflict of interest: The authors declare that there are no conflicts of interest associated with this study.

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