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ORIGINAL RESEARCH

Some utilisation options for cattle dung as soil amendment and their effects in coarse-textured Ultisols and maize growth

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Abstract

Purpose Scarcity of effective manures frustrates the adoption of organic-based soil fertility management in tropical agriculture. Cattle dung (CD) is hugely generated but underutilised due to its high carbon-nitrogen ratio and low mineralisation rate compared with poultry droppings (PD), hence the need to enhance CD's efficacy.

Method Effects of CD utilisation options on fertility of sandy-loam Ultisols and maize growth were assessed under glasshouse conditions. Four options, CD in its cured form (CD), CD-derived biochar (BC), CD water-soaked CD fermentate (FM) and CD+urea (CDU), were assessed against cured PD and NPK-15:15:15 as reference manure and fertilizer, respectively, using 5-kg potted soils watered to and maintained at field capacity. Organic amendments were added at 10-t-ha^{-1} equivalents before sowing except FM added alongside CDU's urea at 250 kg ha^{-1} equivalent after sowing. Also, NPK-15:15:15 was added at 400 kg ha^{-1} equivalent after sowing.

Results After 9 weeks, BC, CDU and PD had similar effects on soil pH, organic matter, total N and available P which increased by 49-51%, 30-34%, 200-333% and 164-176%, respectively relative to the control. The BC always showed maize plants similar to the tallest ones in PD. Maize dry matter was the highest in CDU/PD (35.06-35.56 g pot^{-1}) and the lowest in control (9.56 g pot^{-1}). Residual effects showed that BC and PD maintained the increases in soil pH, while CDU/PD always showed tallest plants and enhanced dry matter over the rest except BC. Soil pH, Mg^{2+} and base saturation together caused 93% of treatments' effects on dry matter.

Conclusion Converting CD to BC or supplementing it with urea (CDU) in coarse-textured tropical soils could have prolonged liming and/or biomass productivity-enhancing effects as PD.

Keywords Agronomic evaluation, Cattle-dung biochar, Liquid fermentate, Low-fertility tropical soils, Organic amendments, Urea addition

Introduction

Ensuring food security is a major challenge due to the low productivity of tropical soils (Obalum et al. 2012a; Zingore 2016; Damiyal et al. 2017). Human-based and physico-climatic factors are among principal factors affecting the productivity potential of these soils. The soils are highly weathered and inherently infertile (Damiyal et al. 2017), with multiple nutrient deficiencies and imbalances; as such, they show variable responses to agricultural inputs (Stewart et al. 2020). Conflicting interests in the exploitation of these soil resources by various stakeholders have also led to their mismanagement and hence accelerated depletion

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of the natural plant nutrient base, leading to perennially stagnating or declining crop yields.

In the past, farmers relied on viable practices such as extended fallowing and crop rotation to increase soil fertility and productivity (Obalum et al. 2012b; Franke et al. 2018; Onah et al. 2021). These soil fertility management systems are no longer fashionable due to population growth-induced scarcity of agricultural lands and enormous pressure on existing ones vis-à-vis their soil-restoring effects (Igwe and Udegbunam 2008; Kanonge et al. 2009; Nweke 2015). Considering this pressure on land resources, agricultural intensification with sustainable soil fertility management practices must be explored. Mineral fertilizers which offer immediate corrective measures to nutrient deficiencies in intensive cropping systems are not only costly but also have limited residual effects (Olatunji and Ayuba 2012; Ameeta and Ronak 2017; Otieno et al. 2018). Also, their prolonged use could create nutrient imbalance in the soil and other ecological problems (Usman et al. 2015; Ameeta and Ronak 2017). Sole use of mineral fertilizers in arable cropping in a bid to meet the food demand of the ever-growing population is, therefore, not sustainable (Muyayabantu et al. 2013; Usman et al. 2015; Hussein et al. 2017), for which alternative ways of soil fertility conservation and management have become popular.

With the glaring situation of halting agricultural expansion and opting for sustainable intensification in order to close yield gaps in tropical agriculture, an efficient soil fertility management which entails cycling of nutrients between soil, crops and animals soil is crucial (Vanlauwe and Zingore 2011; Yates et al. 2011; Kravchenko et al. 2017). To actualise this promising concept of nutrients cycling in tropical Africa, the practice of minimising wastage of agricultural residue by converting them into organic soil amendments has been advocated (Baiyeri et al. 2020). In Nigeria, the demand for cereals especially maize is particularly high for they serve as staple food crops, animal feeds and raw materials for agro-based industries. Since most soils in this country are not suitable for crop production without external inputs (Akinrinde and Obigbesan 2000), the proposed cycling of nutrients may be a viable resource management option in agriculture. Such nutrients cycling concept must, however, devise ways of improving the efficacy of organic wastes converted into soil amendments.

Of all common animal manures, cattle dung (CD) appears to be the most suitable candidate for improvement of efficacy as organic soil amendment. Though relatively available and cheap, CD is underutilised due to its slow decomposition and mineralisation rate compared with manures from monogastric animals such as pig (Uzoh et al. 2015). However, CD improves soil physico-chemical and microbial properties with high residual effects (Ameeta and Ronak 2017; Damiyal et al. 2017; Ezenne et al. 2019). These attributes of CD are mainly due to its high carbon-nitrogen (CN) ratio and associated immobilisation of soil N (Adeniyan et al. 2011, Usman et al. 2015). Studies abound on the utilisation of CD in its natural form or in combination with NPK fertilizers in soil fertility management (Omogoye 2015; Damiyal et al. 2017; Hussein et al. 2017; Suvendu et al. 2017; Gunnamatta and Widana 2018), but not its utilisation after conversion to more readily mineralisable forms.

There are indications, however, that if properly handled, modified and/or transformed, CD could be a valuable manure. For instance, the potential of CD to improve soil quality in Indonesia was found greater after conversion to biochar (Gunamantha and Widana 2018). Studies comparing CD and its liquid form showed higher soil fertility status and/or increased crop yields for the latter (Zhang et al. 2006; Asadu and Igboka 2014). In Nigeria, the practice of enriching CD with urea fertilizer as N source has been found effective in overcoming this manure's common problem of delayed mineralisation, and low nutrients supply and crop yields (Ayoola and Makinde 2008; Ayeni 2012; Tanimu et al. 2013; Nweke and Nsoanya 2015). For a better inference, there is a need to concurrently study the effects of these various options for enhancing the organo-fertilizer value of CD before use. Therefore, the objective of this work was to assess the effects of some options for pre- or in-utilisation enhancement of organo-fertilizer value of CD on physicochemical properties of coarse-textured tropical soils (represented here by coarse-textured Ultisols of southeastern Nigeria), evaluated by maize performance.

Materials and methods

Glasshouse pot trials were carried out from June to October 2019 at the University of Nigeria Teaching & Research Farm, Nsukka (06^{o}52 N′, 07^{o}24′ E). The dominant minerals in the soils of the Farm are quartz, hematite and kaolinite (Obalum et al. 2013). The soils are developed from false-bedded stone and have been classified as Ultisols (Igwe and Udegbunam 2008). They are deep, coarse and well-drained, with very low to low values for soil organic matter, total exchangeable bases, cation exchange capacity, and base saturation. The coarse texture of the soils, coupled with their granular surface structure, makes for marked leaching in this area (Obalum and Obi 2014), and this aggravates the problem of low base saturation of the soils.

Collection and processing of the cattle-dung manure

Fresh cattle dung (CD) was obtained from Ikpa, a local dairy market at Nsukka. The CD was air-dried to constant moisture for two months. The manure was then finely crushed, homogenised and divided into four portions from which four CD utilisation options were derived. One portion was used to produce biochar (BC) and another to prepare a fermentate (FM). The third portion of CD was augmented with urea N-fertilizer (CDU) to reduce its CN ratio, while the fourth portion was sieved and used in its natural form (CD).

The BC was produced using a make-shift manual biomass pyrolysing furnace at about 500 ^{o}C for 30 min. This consisted of a 60-L metal cylinder opened on one end with a lid and tightly sealed on the other end to limit oxygen supply. The cylinder was three-quarter filled with CD and mounted on a frame and rotated at regular intervals to ensure uniform heating and mixing. Heating was discontinued when the smoke exuding from the furnace turned colourless to indicate complete carbonisation (Billa et al. 2018; Gunamantha and Widana 2018). The BC obtained was cooled, crushed and stored for use.

To prepare the FM, the milled CD was soaked in water in a CD-water ratio of 1:5 using a simple barrel unit with a 20-L capacity. The content was thoroughly mixed and allowed to ferment for four weeks, a duration adopted after Asadu and Igboka (2014) who soaked CD for one, two and three weeks and reported a steady increase in maize dry matter with increasing duration of soaking. At the end of four-week duration, the soaked CD was sieved to extract the liquid FM.

Additionally, poultry droppings (PD) were obtained from the battery cage production system of Animal Section of the University of Nigeria Teaching & Research Farm. It was cured by air-drying to constant moisture content and crushed. The urea N-fertilizer (46% N) and a compound fertilizer NPK-15:15:15 (NPK), manufactured by Stallion Group Ltd Nigeria, were also purchased from an agro-based shop in a local market at Nsukka in southeastern Nigeria.

Initial properties of the soil and organic amendments used for the experiment

Some key physicochemical properties of the soil before potting are shown (Table 1). The soil, sandy loam, was slightly acidic and of low fertility status. The physicochemical properties of the soil were within the ranges of values shown by others in this location at the beginning of their studies (Obalum et al. 2011; Adubasim et al. 2018), which often typify those found under short-term fallows in the study area (Onah et al. 2021). The chemical composition of the organic amendments used in the study is shown in Table 2. They were moderately alkaline, and high in organic carbon and N contents except for the FM. The PD had the highest N and the organic amendments also varied in their contents of the four base-forming elements, with BC and PD generally the richest and FM the poorest. Differences in their CN ratio were driven by their N contents, in which the CD showed the highest values, followed by FM and then BC, while PD showed the lowest values.

Factors such as age of the animal, production systems, handling and processing affect the quality of animal manure (Ameeta and Ronak 2017). Our target in the present study was to lower the CN ratio of CD to come close to a value close to that of the PD.

Treatments and experimental procedure

The four fresh CD utilisation options viz CD, BC, FM and CDU as soil organic amendments, as well as PD and NPK as references, representing organic and inorganic amendments, respectively, formed the treatments of this study. An unamended control was included to bring the number of treatments to seven. All treatments were replicated three times in a completely randomised design. Topsoil, randomly collected at a depth of 0-20 cm, was bulked, air-dried and sieved through a 2-mm mesh. Then 5 kg of the air-dry soil was put in labelled 6-L-capacity (height 20 cm; internal diameter 19.6 cm) plastic pots, with perforations at the base for drainage. The CD, BC and PD were mixed with the potted soils 2 weeks before sowing at equivalent rates of 10 t ha^{-1} each. The amended potted soils were then watered to field capacity, and 75 Cl of water was added to them every other day to facilitate decomposition. Three seeds of hybrid maize (*Zea mays*), var Oba Super II, were sown per pot and thinned to one 3-4 days after germination. The application of FM as prepared from 10-t-ha^{-1} equivalent of CD to potted soils meant to receive it and the supplementing of some CD-amended potted soils with urea to implement CDU were done 2 weeks after sowing (WAS). For the CDU, the CD-amended potted soils received urea at 250 kg ha^{-1} equivalent, giving a CD-urea combining ratio of 40. If CD (23.49% C, 0.5% N) and urea (46% N) were homogenously mixed and applied together, this combining ratio of 40 would translate into a CN ratio of 14.24 for the CDU, a value close to that of PD as desired.

The addition of NPK at 400 kg ha^{-1} to potted soils for this treatment was also done 2 WAS. All the potted soils were irrigated every other day throughout maize growth phase of up till 9 WAS using tap water.

After harvest, the residual effects of these treatments were assessed by replanting maize without further application of the amendments.

Data collection

Agronomic data on plant height, number of leaves per plant and leaf area were collected at weekly intervals, starting from two weeks after sowing (WAS) till the 8th week.

At 9 WAS, the stubbles were harvested by cutting from the base of the shoot on the potted soil, weighed immediately to obtain fresh weight and oven-dried to constant weight at 65 °C and weighed again to obtain dry matter yield.

The same procedure was repeated for the residual experiment. Following harvest of maize plants at 9 WAS, soil samples were collected from the potted soils. These samples were taken to the laboratory where they were processed for further analyses.

Table 1 Pre-planting physicochemical properties of the soil of the experiment

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 (H_2O)	4.9
pH (KCl)	4.5
SOM (g kg^{-1})	22.90
Total N (g kg^{-1})	0.20
Available P (mg kg^{-1})	10.60
K^+ (cmol kg^{-1})	0.01
Ca^{2+} (cmol kg^{-1})	0.50
Mg^{2+} (cmol kg^{-1})	0.60
Na^+ (cmol kg^{-1})	0.12
CEC (cmol kg^{-1})	6.30

SOM - soil organic matter, CEC - cation exchange capacity

Laboratory analyses

Pre-planting and post-harvest soil samples as well as organic amendments used in the experiment were air-dried, crushed and sieved through a 2-mm mesh. Soil pH was determined using a glass electrode pH meter in de-ionised water and KCl at a soil/liquid ratio of 1:2.5 (McLean 1982). Soil organic carbon was determined using the Walkley-Black wet dichromate oxidation method (Nelson and Sommers 1982), and converted to organic matter by multiplying by the van Bemmelen factor of 1.724. Total nitrogen was determined using Micro-Kjeldahl wet digestion method (Bremmer and Mulvaney 1982). Available phosphorus was extracted with Bray 2, and then determined following the steps described in Ukabiala et al. (2021). Exchangeable bases were extracted using neutral 1N NH_4OAc. Ca^{2+} and Mg^{2+} in the extract were determined by atomic absorption method (Thomas 1982), while K^+ was determined using the flame photometer. Exchangeable acidity was determined by KCl displacement method and cation exchange capacity according to Page et al. (1982). Organic amendments were digested with nitric-perchloric-sulphuric acid mixture and analyzed for pH, organic carbon, nitrogen, phosphorus and base-forming nutrients following similar procedures as for soil analyses.

Statistical analysis

Data collected from these trials were analyzed using SPSS software Version 21. The data were subjected to one-way analysis of variance to test for the treatment effects. In this procedure, treatment means found to differ significantly ($p \leq 0.05$) were separated by the Duncan's multiple range test. Also, the relationships between maize dry matter and soil fertility indices of the study were examined using step-wise multiple linear regression, setting p at 0.05.

Table 2 Chemical composition of the organic amendments used in the experiment

Parameters	**pH-H_2O**	**OC** (g kg^{-1})	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**CN ratio**
CD	9.3	234.90	5.00	7.00	2.00	8.00	1.00	1.00	46.98
BC	11.7	241.90	8.00	6.00	9.00	5.00	7.00	7.00	30.24
FM	8.3	36.50	1.00	5.00	7.00	1.00	1.00	1.00	36.50
PD	9.7	327.70	22.00	70.00	1.00	13.00	8.00	7.00	14.90

CD - cattle dung, BC - biochar, FM - fermentate, PD - poultry droppings, OC - organic carbon, N - nitrogen, P - phosphorus, K – potassium, Ca – Calcium, Mg - Magnesium, Na – Sodium

Results and Discussion

Effects of cattle dung and its derivatives on selected fertility indices of the soil

In the first crop cycle of the experiment when the immediate effects of treatments were tested, all the amendment options enhanced the selected properties of the soil relative to the control (Table 3). Although both BC and PD recorded the highest soil pH values, they were similar to CD, CDU and FM. Soil pH in BC and PD represented ca. 51 % increase relative to the control; the corresponding proportional increase due to CDU was ca. 49 %. The initial high pH of the organic amendments could be responsible for the increase in the pH of the amended soils. This could also be attributed to the presence of base-forming elements in these amendments; the oxyhydroxides of base-forming elements have a mode of action similar to that of hydrated lime, whereby the associated cations displace acid-forming cations from the soil exchange complexes by neutralisation and precipitation, thereby increasing the soil pH (Nwite et al. 2011a, b; Babalola et al. 2012). Biochar often has a liming effect, especially when of animal waste origin and/or of alkaline pH (Uzoma et al. 2011; Glaser and Lehr 2019, Oraegbunam et al. 2022). Such effect of biochars is expected to be evident in the highly leached coarse-textured Ultisols with low initial soil pH in our study (Zhang et al. 2019). Similarly, CD and CDU were reported to enhance soil pH in some ecological zones of Nigeria (Ayeni and Adeleye 2012).

Soil organic matter (SOM) and total N were highest in PD and CDU-treated potted soils, respectively (Table 3). The highest SOM in PD-treated soils is attributed to highest content of carbon in PD (see Table 2), while the highest N in CDU reflects the supplementation of CD with N-rich urea in this treatment. The data showed that the PD was different from only FM and control, and CDU was different from CD, FM, NPK and control (Table 3). Therefore, PD, CDU and BC were similar in SOM and total N which increased by 30-34 % and 200-333 %, respectively relative to the control. Low biochar rates in sandy-loam Ultisols as was the case here (10 t ha^{-1}) could increase soil content of total N around 9 WAS (Ebido et al. 2021). Soil available P was also increased for PD, CDU and BC applications by 164-176 % relative to the control. The efficacy of BC was attributed to the pyrolysis temperature of 500°C used to produce it, the application rate of 10 t ha^{-1} and pre-amendment acidic pH of the soil (Glaser and Lehr 2019). This efficacy was also evident in the fact that CD and BC showed similar C and N contents and hence comparable CN ratio (see Table 2); yet CD needed an external N source in the form of urea (CDU) to enhance N- and P-fertility status of the soil to a similar extent as BC. The Ca^{2+} content was highest in PD and CDU treatments. The highest and lowest values of Mg^{2+} were recorded in PD-amended potted soils and control, respectively. The CEC showed highest values in PD- and NPK-amended potted soils (similar to others except FM treatment) and lowest values in the control. These effects on CEC somewhat mirrored those on SOM, understandably because of the homogeneity in texture of the potted soils. In the study area, clay and silt fractions have dominant influence over SOM on CEC of the soils, such that the said textural homogeneity allowed SOM to be the only negative charge-bearing component of the cations exchange site controlling the CEC of the treated potted soils (Obalum et al. 2013). Base saturation was higher in potted soils treated with PD and CDU compared with the rest. The observed positive effects of PD could be due to its rather low C: N ratio and high pH, organic matter and nitrogen of this soil amendment which created favourable conditions for microbial proliferation thus facilitating decomposition and mineralisation. Similar results were reported by Bakayoko et al. (2009) and Adubasim et al. (2018).

Table 3 Immediate and residual effects of treatments involving cattle dung and its derivatives and conventional organic and inorganic fertilizers on selected soil chemical properties

Amendment	**pH-H_2O**	**SOM**	**Total N**	**AvP (mg kg^{-1})**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**CEC**	**% Base saturation**
		(g kg^{-1})					(cmol kg^{-1})			
				Immediate effects						
CD	6.6^{a}	14.7^{ab}	0.40^{c}	11.81^{b}	0.08^{a}	0.56^{ab}	0.33^{d}	0.04^{a}	15.06^{ab}	21.63^{c}
BC	6.8^{a}	16.3^{a}	0.90^{ab}	18.65^{a}	0.07^{a}	0.53^{ab}	0.66^{ab}	0.03^{a}	15.06^{ab}	24.90^{b}
CDU	6.7^{a}	16.5^{a}	1.30^{a}	18.03^{a}	0.08^{a}	0.66^{a}	0.60^{b}	0.04^{a}	14.80^{ab}	36.28^{a}
FM	6.3^{a}	13.7^{bc}	0.60^{b}	11.58^{b}	0.07^{a}	0.53^{ab}	0.46^{dc}	0.04^{a}	12.66^{b}	23.50^{b}
PD	6.8^{a}	16.7^{a}	1.00^{a}	18.87^{a}	0.08^{a}	0.66^{a}	0.73^{a}	0.04^{a}	18.66^{a}	32.8^{a}
NPK	5.4^{b}	14.9^{ab}	0.70^{b}	12.75^{b}	0.08^{a}	0.60^{a}	0.59^{b}	0.03^{a}	17.53^{a}	24.60^{b}
Control	4.5^{c}	12.5^{c}	0.30^{d}	6.84^{c}	0.07^{a}	0.20^{b}	0.32^{d}	0.03^{a}	9.00^{c}	18.00^{d}
				Residual effects						
CD	5.1^{b}	17.6^{a}	0.50^{e}	12.11^{a}	0.07^{ab}	1.33^{b}	1.10^{d}	0.05^{a}	10.18^{d}	23.76^{bc}
BC	5.8^{a}	16.7^{abc}	0.60^{d}	11.86^{ab}	0.08^{a}	1.30^{b}	1.21^{d}	0.03^{c}	11.62^{abc}	27.47^{b}
CDU	5.0^{b}	16.9^{ab}	1.70^{a}	11.23^{bc}	0.08^{a}	1.40^{b}	1.61^{b}	0.04^{b}	11.93^{ab}	31.61^{a}
FM	4.7^{c}	15.0^{bcd}	1.90^{a}	10.05^{c}	0.08^{a}	0.80^{c}	1.00^{e}	0.04^{b}	10.66^{cd}	25.23^{bc}
PD	5.9^{a}	16.6^{abc}	0.80^{c}	12.34^{a}	0.08^{a}	1.60^{a}	2.03^{a}	0.04^{b}	12.47^{a}	34.43^{a}
NPK	4.5^{c}	14.3^{c}	1.00^{b}	11.12^{bc}	0.08^{a}	0.08^{c}	1.23^{d}	0.04^{b}	10.96^{bcd}	23.33^{bc}
Control	4.1^{c}	12.7^{d}	0.40^{f}	3.73^{d}	0.05^{b}	0.04^{c}	1.00^{e}	0.03^{c}	9.93^{e}	22.23^{c}

Means followed by the same letter(s) within a column are not significantly different at $p \leq 0.05$
CD - cattle dung, BC - biochar, CDU - CD plus urea, FM - fermentate, PD - poultry droppings.
NPK - NPK-15:15:15, SOM – soil organic matter, AvP - available P, CEC – cation exchange capacity

In the second crop cycle when residual effects of treatment were tested, BC and PD showed the highest soil pH, whereas there was rather a drop by 8.89 and 4.08%, respectively in potted soils amended with FM and NPK compared with the initial soil pH. This could be due to the inherently low native soil pH which perhaps was exacerbated by the addition of NPK fertilizer which often bear acid radicals. Similar results were reported by Ayeni and Adeyele (2012) and Ozlu and Kumar (2018) with application of urea and NPK, respectively. The CD, BC, CDU and PD had higher SOM compared with the others. This could be due to the curing of the fresh CD on a paved, partially shaded surface and pre-application milling which prevented nutrient leaching and facilitated decomposition and mineralisation as observed by Usman et al. (2015) and Ameeta and Ronak (2017). Total N was highest in FM-treated potted soils, while available P was higher in CD-, BC- and PD-treated potted soils compared with those that received the other amendments. All the soil amendments studied increased K^+ content of the soil relative to the control. The divalent basic cations (Ca^{2+} and Mg^{2+}) were highest in PD-amended potted soils and lowest in the control. The CEC was enhanced in potted soils treated with BD, CDU and PD, while base saturation was higher in CDU and PD compared with the rest of the treatments.

Notably, the positive effect of CDU on available P was without a residual value. Using some texturally contrasting Nigerian soils (including a sandy loam), Ayeni (2012) compared CD and CDU for their effects on key soil fertility indices after a sixty-day incubation period. Their CDU treatment had CD and urea added at rates equivalent to 5 t ha^{-1} and 100 kg ha^{-1} to the soil. Though these application rates were about half of ours, the CD-urea combining ratio in their study of 50 that was close to ours which was 40. Ayeni (2012) reported about five-fold increase in available P in CDU relative to CD for the sandy-loam soil of their study. Supporting our data for the immediate and residual effects with this one from a sixty-day incubation study, we infer that CDU is a viable utilisation option for facilitating the mineralisation of CD to release P in sandy-loam tropical soils, but that this effect is short-lived in such soils.

Unlike synthetic fertilizers, manures have most of the nutrients in them in organic forms and their rate of release is regulated by several factors including manure characteristics and soil mineralogy, temperature and moisture (Chadwick et al. 2000; Azeez and Averbeke 2010; Font-Palma 2019). The CN ratio of organic resources influences their rate of decomposition and nutrient release as well as availability of nutrients to plants (Ayeni and Adeyele 2012; Pei et al. 2019). The significant effect of PD in the present study could be as a result of its relatively low CN ratio. The drop in the CN ratio of CD when transformed to BC before use or combined with urea and so applied as CDU could explain their positive effects being comparable with those of PD. Similar positive effects of N-fortified CD on soil properties (N, P, K, Ca and Mg) and maize yield were reported by Ayoola and Makinde (2008) in Ibadan, southwestern Nigeria.

According to Gaskin et al. (2008), Blanco-Canqui (2017), Kameyama et al. (2017) and Zou et al. (2019), the ameliorating effect of biochar on soil properties depends to a large extent on the amount and type of nutrients in the feedstock and pyrolysis conditions. The inherent properties of CD from which the BC was produced might, therefore, have contributed to the outstanding effects of BC in this study compared with the other CD derivatives. Biochar is known for its large surface area and enhanced porosity, pH, CEC and nutrient content as well as presence of multiple functional groups, especially when derived from animal manure (Hanzel et al. 2013; Gul et al. 2015). For this reason, biochar upon application alters the physical and chemical properties of the soil which in turn influence soil microbial structure and activities as well as nutrient availability (Gul et al. 2015; Glab et al. 2016; Gunamantha and Widana 2018).

The high water holding capacity of biochar reduces leaching and thus enhances nutrient retention (Zheng et al. 2013). Biochar reduces leaching of N in particular and enhances its retention by adsorbing NH_4^- and NO_3^- (Xu et al. 2016; Liu et al. 2017; Sun et al. 2017). The rich supply of carbon in biochar increases its charge density, thereby enhancing CEC (Liang et al. 2006). It enhances the rate of decomposition and mineralisation by providing a microhabitat for microbes in its pores and labile carbon which serves as a substrate for them (bacteria and fungi) (Ezawa et al. 2002; Verheijen et al. 2009; Khodadad et al. 2011; Nelissen et al. 2012); this alters the microbial community structure of the soil (Xu et al. 2014) which in turn enhances N-fixation. Furthermore, the ability of biochar to supress plant diseases through the modification of soil microbial diversity and secretion of nematocidal compounds contribute to its positive effects on soil properties and plant growth (Poveda et al. 2021).

Experiments carried out with CD-derived extracts suggest that the resultant extracts increase nutrient availability (Capulin-Grande et al. 2000, 2011). This could explain the similarity in effects of FM and NPK, given that the nutrients are already in solution and in forms readily available for plant uptake. For instance, Asadu and Igboka (2014), while assessing the effects of the application of liquid extracts from cattle dung, piggery dung and poultry droppings on maize grown in an Ultisol southeastern Nigeria, found a general improvement in some soil fertility indices (SOM, available phosphorus, CEC and exchangeable bases) and maize performance compared with the solid forms of these animal manures. The release of nutrients from organic amendments is a slow and gradual process; therefore, they are bound to have higher residual effects compared to FM and inorganic fertilizers (NPK) whose nutrients are in readily available forms (Adeniyan et al. 2011; Usman et al. 2015; Ameeta and Ronak 2017; Damiyal et al. 2017).

Effects of cattle dung and its derivatives on maize growth parameters

The immediate and residual effects of treatments on plant height, number of leaves per plant and leaf area are presented in Tables 4, 5 and 6, respectively. Generally, growth parameters were significantly enhanced by treatment across the first and second crop cycles. In the first crop cycle, BC, PD and NPK recorded the tallest plants and the control the shortest at 2 WAS (Table 4). However, all the treatments apart from CDU showed taller plants compared to the control at 3 and 4 WAS. The BC showed similar plant height as the control at 5 and 6 WAS. The data presented show, therefore, that CD, FM and PD always showed taller plants compared to the control, while BC and PD were always similar during the sampling period (2-8 WAS).

There was a gradual increase in the number of leaves per the maize plant from 2 to 8 WAS, with variable effects among treatments (Table 5).

However, all the treatments showed significantly more leaves per plant compared to the control at 6 and 7 WAS, whereas treatment FM and the control had the fewest leaves at 8 WAS. The results for the leaf area show that, apart from FM and NPK whose effects were variable, all the treatments showed broader leaves compared to the control, with CDU and PD showing the broadest leaves at 8 WAS (Table 6).

Table 4 Immediate and residual effects of treatments involving cattle dung and its derivatives and conventional organic and inorganic fertilizers on maize height (cm) at different growth stages

Amendment	**2 WAS**	**3 WAS**	**4 WAS**	**5 WAS**	**6 WAS**	**7 WAS**	**8 WAS**
			Immediate effects				
CD	29.60^{b}	43.96^{a}	55.40^{a}	73.70^{a}	95.53^{a}	99.83^{a}	104.06^{a}
BC	33.46^{ab}	43.90^{a}	56.26^{a}	66.30^{ab}	81.13^{abc}	95.73^{a}	109.40^{a}
CDU	26.00^{b}	34.66^{b}	44.83^{b}	78.73^{a}	84.30^{abc}	91.06^{a}	109.33^{a}
FM	28.90^{b}	47.43^{a}	50.70^{a}	71.23^{a}	92.00^{a}	94.10^{a}	95.00^{b}
PD	41.33^{a}	44.56^{a}	55.20^{a}	76.52^{a}	98.16^{a}	104.26^{a}	116.83^{a}
NPK	35.73^{ab}	44.10^{a}	52.00^{a}	67.50^{ab}	76.03^{bc}	88.13^{ab}	99.83^{b}
Control	22.13^{c}	33.70^{b}	47.66^{b}	62.23^{b}	72.56^{c}	81.63^{b}	91.33^{c}
				Residual effects			
CD	14.36^{c}	40.93^{ab}	42.56^{bc}	67.76^{a}	77.33^{bc}	99.00^{ab}	102.66^{b}
BC	24.36^{ab}	41.00^{ab}	61.96^{a}	69.46^{a}	84.66^{b}	101.33^{ab}	104.33^{b}
CDU	22.60^{ab}	43.16^{a}	59.13^{a}	71.86^{a}	88.66^{a}	100.66^{ab}	112.66^{a}
FM	19.63^{b}	32.00^{bc}	44.06^{b}	47.33^{b}	65.66^{d}	89.00^{bc}	98.66^{b}
PD	26.53^{a}	46.10^{a}	62.13^{a}	78.06^{a}	92.66^{a}	107.00^{a}	118.33^{a}
NPK	21.03^{ab}	31.16^{bc}	33.50^{bc}	47.53^{b}	68.66^{cd}	79.33^{c}	103.00^{b}
Control	8.26^{d}	28.80^{d}	31.66^{d}	36.00^{d}	51.33^{e}	63.66^{d}	68.66^{c}

Means followed by the same letter(s) within a column are not significantly different at $p \leq 0.05$. CD - cattle dung, BC - biochar, CDU - CD plus urea, FM - fermentate, PD - poultry droppings, NPK - NPK-15:15:15.
WAS - weeks after sowing.

Table 5 Immediate and residual effects of treatments involving cattle dung and its derivatives and conventional organic and inorganic fertilizers on number of leaves per plant of maize

Amendment	**2 WAS**	**3 WAS**	**4 WAS**	**5 WAS**	**6 WAS**	**7 WAS**	**8 WAS**
Immediate effects							
CD	6.00^{a}	8.33^{a}	10.00^{a}	10.66^{ab}	12.66^{a}	14.00^{a}	16.00^{a}
BC	6.33^{a}	8.00^{ab}	10.00^{a}	10.33^{abc}	12.00^{ab}	13.33^{ab}	15.33^{ab}
CDU	6.00^{a}	8.00^{ab}	9.33^{ab}	10.33^{abc}	13.33^{a}	14.66^{a}	16.66^{a}
FM	5.33^{a}	7.66a^{bc}	9.66^{ab}	8.66^{cd}	11.66^{ab}	12.66^{ab}	14.66^{bc}
PD	5.66^{a}	8.00^{ab}	10.00^{a}	12.00^{a}	12.00^{ab}	13.66^{a}	15.00^{ab}
NPK	5.33^{a}	7.00^{cd}	8.66bc	10.00^{bc}	12.00^{ab}	13.33^{ab}	15.33^{ab}
Control	5.33^{a}	6.66^{cd}	7.66^{d}	8.00^{d}	10.33^{b}	11.33^{b}	12.33^{c}
Residual effects							
CD	4.33^{bc}	7.00^{a}	7.66^{b}	8.33^{de}	11.33^{c}	13.33^{cd}	18.66^{bc}
BC	5.00^{a}	7.00^{a}	8.66^{a}	9.66^{bc}	12.33^{bc}	16.00^{a}	19.33^{ab}
CDU	4.00^{c}	6.33^{ab}	9.00^{a}	10.66^{ab}	13.66^{ab}	16.00^{a}	21.00^{a}
FM	4.00^{c}	5.66^{b}	7.66^{b}	9.33^{cd}	11.66^{c}	13.33^{cd}	16.66^{d}
PD	4.66^{ab}	7.00^{a}	9.00^{a}	11.66^{a}	14.00^{a}	15.66^{ab}	21.00^{a}
NPK	4.00^{c}	6.00^{ab}	7.66^{b}	8.33^{de}	11.66^{c}	13.66^{ab}	17.33^{cd}
Control	4.00^{c}	5.33^{b}	6.33^{c}	7.33^{e}	9.66^{d}	11.00^{c}	12.33^{e}

Means followed by the same letter(s) within a column are not significantly different at $p \leq 0.05$.
CD - cattle dung, BC - biochar, CDU - CD plus urea, FM - fermentate, PD - poultry droppings, NPK - NPK-15:15:15.
WAS - weeks after sowing.

In the test of the residual effects, although FM and NPK showed variable and lower effects on plant growth parameters compared to the other amendments, they performed significantly better than the control (Tables 4-6). The apparent lack of residual effect of FM is attributed to the low level of N in this treatment (Zhang et al. 2006), as the fermentation of CD recovered only a small proportion of N in it (see Table 2). The PD and CDU showed the tallest plants across the sampling stages. Treatment effects on the number of leaves per plant were variable; however, PD, BC and CD consistently showed the most leaves. The residual effect of PD was remarkable in that it consistently gave broader leaves of maize than the other treatments during 4-8 WAS. The immediate and residual effects of the treatments on above-soil dry matter of maize as tested, respectively, in the first and second crop cycles of the study are shown in Fig. 1a, b.

The highest amounts of dry matter in both crop cycles were obtained from potted soils treated with CDU. This CDU was similar to BC only for the residual effects. Notably, the best option of CDU for the immediate effects and CDU/BC for the residual effects produced as much as dry matter as PD in each case. The CDU represents supplementing CD with mineral N in order to increase the former's CN ratio. Tanimu et al. (2013) similarly reported that fortifying cattle dung with urea (N-fertilizer) consistently increased maize grain yield compared with all other cattle dung management practices evaluated in the two farms of their field study in Zaria, north-western Nigeria.

Apart from nutrient imbalances, Al-toxicity alters the physiological (root elongation, shoot growth and biomass production) and metabolic (photosynthesis, respiration) processes in plants especially in acidic soils. Through mechanisms such as complexation, cation exchange, adsorption and absorption, organic amendments have been shown to ameliorate the toxic effect of Al (Shetty and Prakash 2020). With an increase in soil pH, the physical, chemical and biological processes in the soil were enhanced and thus nutrients were decomposed and released. This could be responsible for the observed increases in plant height, number of leaves and leaf area of the maize plant in the treatments where these increases prevailed. Such increases imply greater surface area for light interception and hence higher rates of photosynthesis and overall plant productivity (Koester et al. 2014).

Generally, the FM showed not to be a promising option of utilising cattle dung as soil amendment in the present study. This observation is attributed partly to its high CN ratio which was second to CD itself, and partly to an inference that four weeks was not adequate to completely ferment the cattle dung and to have most of the mineralisable nutrients in it extracted. Supported by the increases in maize dry matter with increasing duration of fermentation of cattle dung reported by Asadu and Igboka (2014), we propose fermentation of cattle dung for a duration longer than four weeks for greater agronomic value of FM.

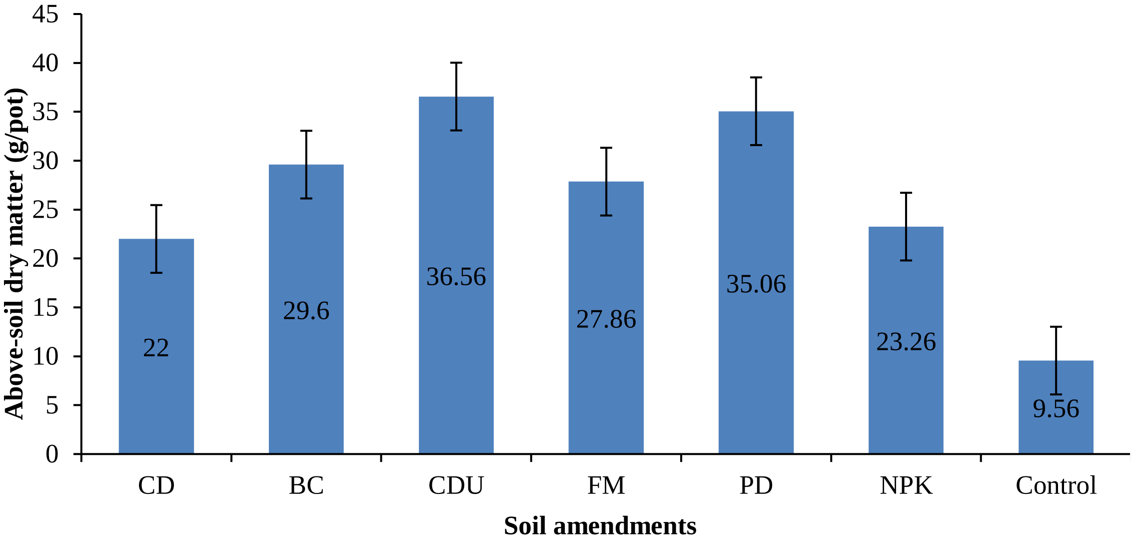
Table 6 Immediate and residual effects of treatments involving cattle dung and its derivatives and conventional organic and inorganic fertilizers on leaf area (cm^2) of maize

Amendment	**2 WAS**	**3 WAS**	**4 WAS**	**5 WAS**	**6 WAS**	**7 WAS**	**8 WAS**
				Immediate effects			
CD	102.61^{a}	232.65^{a}	308.59^{ab}	483.70^{abc}	376.26^{a}	426.37^{ab}	475.62^{bc}
BC	82.85^{b}	223.24^{a}	306.13^{ab}	399.00^{ab}	307.24^{ab}	340.00^{ab}	460.73^{bc}
CDU	91.25^{ab}	188.64^{ab}	308.83^{ab}	220.08^{de}	364.83^{a}	468.19^{a}	631.10^{a}
FM	70.90^{bc}	144.20^{bc}	246.72^{bc}	294.93^{bcd}	158.10^{b}	330.41^{ab}	435.60^{bc}
PD	98.35^{a}	213.75^{a}	346.06^{a}	363.44^{abc}	293.78^{ab}	426.84^{ab}	566.83^{ab}
NPK	83.36^{b}	145.12^{bc}	138.19^{ab}	247.28^{cde}	255.26^{ab}	344.33^{ab}	465.81^{bc}
Control	69.58^{c}	116.98^{d}	207.40^{c}	166.06^{e}	211.17^{b}	283.76^{b}	343.86^{c}
				Residual effects			
	2 WAS	3 WAS	4 WAS	5 WAS	6 WAS	7 WAS	8 WAS
CD	43.35^{c}	100.97^{c}	116.0^{bc}	114.23^{bc}	145.66^{c}	160.20^{c}	171.3^{d}
BC	51.20^{ab}	125.87^{ab}	126.35^{bc}	112.58^{bc}	151.06^{bc}	168.30^{bc}	190.96^{bc}
CDU	65.06^{a}	119.04^{b}	139.78^{ab}	140.40^{ab}	177.66^{ab}	188.03^{ab}	201.66^{ab}
FM	43.60^{c}	98.91^{c}	102.40^{c}	114.52^{bc}	139.76^{c}	149.06^{cd}	182.93^{cd}
PD	60.53^{ab}	133.54^{a}	153.60^{a}	171.97^{a}	182.80^{a}	198.33^{a}	210.23^{a}
NPK	53.67^{b}	99.02^{c}	104.53^{c}	113.50^{bc}	122.23^{cd}	132.66^{de}	173.06^{d}
Control	25.82^{d}	$68.75d^{d}$	77.13^{d}	95.80^{c}	99.66^{d}	102.00^{e}	112.66^{c}

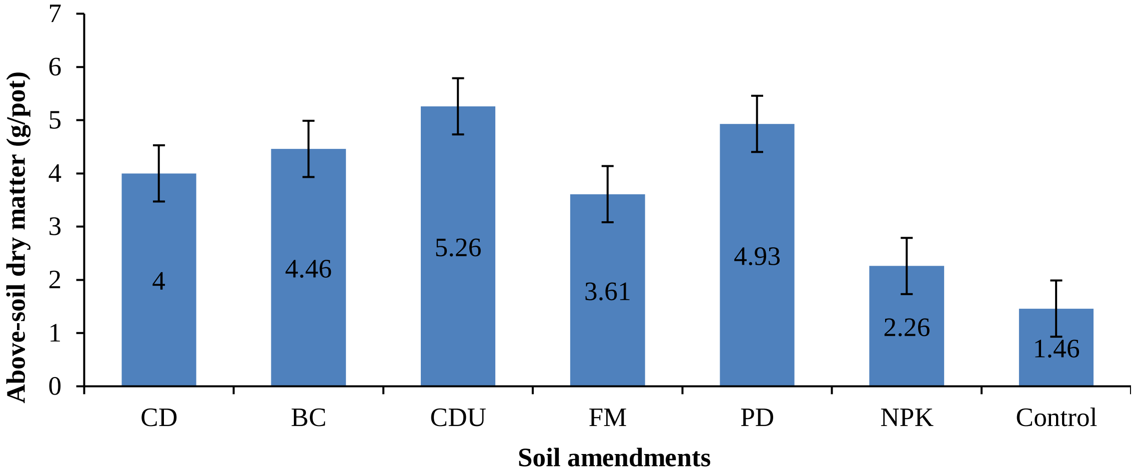
Means followed by the same letter(s) within a column are not significantly different at $p \leq 0.05$.
CD - cattle dung, BC - biochar, CDU - CD plus urea, FM - fermentate, PD - poultry droppings, NPK - NPK-15:15:15.
WAS - weeks after sowing.

Maize dry matter in relation to treatment-induced variations in soil properties

Combining the data for the immediate and residual effects ($n = 14$), maize dry matter was found to vary with soil pH, exchangeable Mg (Mg^{2+}) and base saturation (BS). The regression, dry matter = –28.755 + 5.633pH – 19.719Mg^{2+} + 1.151BS, shows a very high R^2 of 0.927, with all the predictors (including the constant) significantly contributing to the variations. The role of retention of basic cations in maize growth is evident here. Considering the small sample size, however, the regression is not for predictive purposes, the very high R^2 notwithstanding. When the step-wise multiple linear regression was repeated separately for each of the immediate and residual effects, the only regressors selected were available P and exchangeable Ca (Ca^{2+}), respectively.Exploring further the relationships showed that the best regressions of dry matter on available P and Ca^{2+} were of the logarithmic and linear forms, respectively (Fig. 2).



Immediate effects

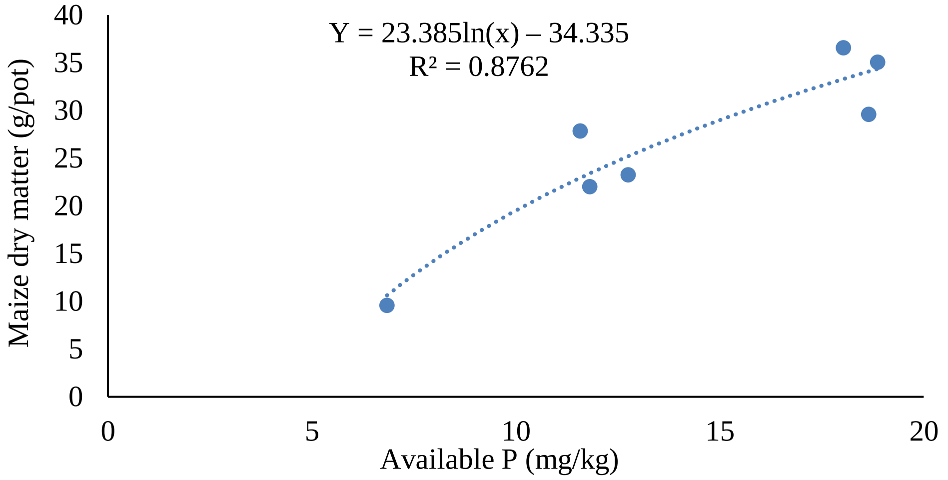


Residual effect

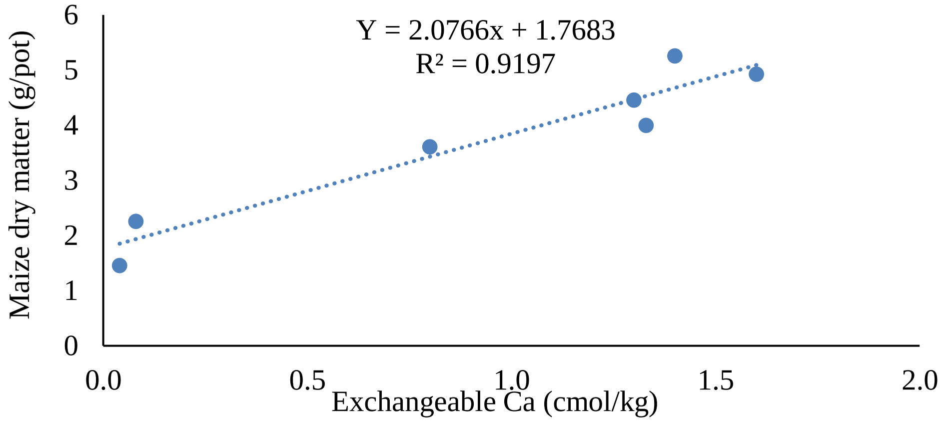
Fig. 1 Immediate (a) and residual (b) effects of treatments involving cattle dung and its derivatives and conventional organic and inorganic fertilizers on above-soil dry matter of maize assessed at 9 weeks after sowing

Error bars in the Fig.1 represent standard errors.
Means bearing by the same letter(s) in each graph are not significantly different at $p \leq 0.05$. CD - cattle dung, BC - biochar, CDU - CD plus urea, FM - fermentate, PD - poultry droppings, NPK - NPK-15:15:15.

Thus, of the three primary plant nutrients (N, P and K), treatment affected N and P contents, but only P influenced maize dry matter. This supports the report that P was a more critical nutrient than N for maize in similar Ghanaian soils (Okebalama et al. 2019). In the residual effects, Ca^{2+} alone defined dry matter, reflecting the afore-stated role of basic cations in maize growth. For an insight into the mechanisms involved in these results, we correlated soil pH with each of available P and Ca^{2+} and found similar relationships (r = 0.82 and 0.80, respectively) for the immediate effects, but a rather weaker relationship between soil pH and available P (r = 0.74) than between soil pH and Ca^{2+} (r = 0.86) for the residual effects. These observations which buttress further the role of P for maize suggest that (i) this role is due to a suppressive effect of available P on Ca^{2+} in defining maize dry matter even with its overall dependence on basic cations in this study, and (ii) that soil pH has underlying influence on this suppressive effect.



Immediate effects



Residual effects

Fig. 2 Regression of maize dry matter on soil fertility indices, showing logarithmic relationship with available P in the first crop cycle representing immediate effects (a) and linear relationship with exchangeable Ca in the second crop cycle representing residual effects (b)

Conclusion

The data attained show that all the cattle dung (CD) utilisation options of this study compared favourably with poultry droppings (PD) and NPK-15:15:15 (NPK) as they enhanced the soil fertility properties of the sandy-loam Ultisols and shoot growth of maize. The CD-derived biochar (BC) and CD supplemented with urea (CDU) were generally more efficacious in enhancing soil pH, soil organic matter, and available phosphorus and cation exchange properties of the soil as well as maize growth parameters compared to the other options. The BC enhanced soil pH in similar degrees as PD (the conventional manure) did, whereas the CDU’s superiority over CD with respect to available phosphorus content of the soil was a fleeting one. The immediate effects of BC and residual effects of CDU on maize growth were similar to the enhanced values of PD. However, the BC, unlike CDU, showed enhanced dry matter of maize as much as PD did only for the residual effects. Given the limitations advanced against using CD in its natural form, it should be used as BC or CDU in low-fertility, coarse-textured tropical soils for prolonged liming and/or biomass productivity-enhancing effects in the soils, comparable to those obtainable with the conventional PD. The BC may be suitable for poorly buffered acid soils; CDU is a better option for on-farm procurement and use of the CD ‘waste’. These treatments promote maize growth through their related positive effects on soil pH, available P and basic cations.

In the future, the CDU that has shown to be a promising option needs to be ‘standardised’, such that the added urea brings the CN ratio of the CDU mixture to a desired value. There may also be a need to modify this treatment into mixing CD and urea, and adding same to the soil at once preferably before planting. The use of CD fermentate (FM) which generally had similar effects as NPK is suggested for growing short-duration crops, but repeated application in field crops may be required due to its low residual effect. In this regard, research should explore the organo-fertigation potential of FM as well as fermented ‘standardised’ CD-urea mixture, just as longer durations of fermentation of cured CD could be tried out.

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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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