Chilean J. Agric. Anim. Sci., ex Agro-Ciencia (2025) 41(2): 300-311.
https://doi.org/10.29393/CHJAAS41-27RETJ30027

ISSN 0719-3890 online

AMARANTHUS (*Amaranthus hybridus* L.) RESPONSE TO COCOA POD HUSK POWDER AND NITROGEN FERTILISER APPLICATIONS

Tajudeen B. Akinrinola[1a]*, Adedayo O. Salami[1b], and Samuel A. Adegoke[2]

[1a] Department of Crop and Horticultural Sciences, University of Ibadan, Ibadan, Nigeria
https://orcid.org/0000-0001-8761-3835
[1b] Department of Crop and Horticultural Sciences, University of Ibadan, Ibadan, Nigeria
https://orcid.org/0009-0006-1945-4995
[2] Department of Toxicology, Faculty of Biology, University of Duisburg-Essen, Germany
https://orcid.org//0000-0003-1007-0726
* Corresponding author: tb.akinrinola@gmail.com

ABSTRACT

Amaranthus is a fast-growing vegetable affected by inadequate soil nutrient supply due to intensive cultivation. Inorganic fertiliser application reduces vegetable quality, thus, farm waste such as Cocoa pod husk (CPH) was encouraged as organic fertiliser. However, limited information is available on CPH powder or its combination with urea on amaranthus performance. Therefore, the response of amaranthus to CPH and urea fertiliser was investigated. In a replicated 3 × 3 factorial experiment, CPH powder at 0, 30, and 60 kg N ha^{-1} and urea fertiliser at 0, 30, and 60 kg N ha^{-1} were evaluated in a randomised complete block design with five replicates using 4 kg soil. Data collected were subjected to ANOVA and significantly different means were separated at $p<0.05$. The results indicated that the control (0 kg CPH) had better growth than the CPH-treated plants at both plantings. Applying 60 kg N ha^{-1} urea significantly increased the number of leaves and shoot biomass compared to the other treatments in both plantings. The CPH × urea interactions resulted in significant variations in amaranthus height, number of leaves and shoot biomass among the treatments. The growth parameters observed at 0 kg CPH × 60 kg N ha^{-1} urea were significantly higher than other treatments but not different from CPH at 60 kg N ha^{-1} × 60 kg N ha^{-1} urea and CPH at 30 kg N ha^{-1} × 30 kg N ha^{-1} urea applications in both plantings. Consequently, CPH powder at 30 kg N ha^{-1} with urea at 30 kg N ha^{-1} was considered appropriate for sustainable amaranthus production.

Keywords: Amaranthus, cocoa pod husk, urea fertiliser, sustainable production, shoot biomass.

INTRODUCTION

Amaranthus hybridus L. is a widely cultivated leafy vegetable in Africa, with over 60 species grown for their leaves, seeds, and ornamental value (Schippers, 2000). Amaranth is recognised for its exceptional nutritional profile, characterised by high protein content, fibre, vitamins, and minerals like iron and calcium. Schippers (2000) reported its potential as an anti-inflammatory, anti-cancer, and antioxidant agent. It may also contribute to lowering blood pressure and cholesterol levels. Beyond its nutritional and agricultural benefits, amaranth holds cultural significance across various regions, particularly in South America, where it is used in religious ceremonies and festivals, underscoring its importance beyond its nutritional value (Adhikary et al., 2020). It is also used in the poultry industry to reduce the amount of cholesterol in eggs (Rodríguez-Ríos et al., 2020).

The most common amaranthus species in Nigeria is *A. hybridus* (L.), a traditional vegetable grown in tropical Africa (Ogwu, 2020). This plant

Received: January 15, 2025 Accepted: August 1, 2025

is remarkably resilient and grows very well in different soil types. However, the growth and development of amaranthus can be influenced by soil conditions such as nutrient availability, pH levels, and drainage (Sharma et al., 2023). Amaranthus requires moderate nitrogen, phosphorus, and potassium levels for optimal growth. However, the continual cultivation of the crop depletes soil nutrients and changes microbial composition resulting in low yield over time (Alami et al., 2021). Consequently, fertiliser must be applied to maintain or improve yield. Fertilisers are commonly used to improve soil fertility and crop yield. They provide essential plant nutrients such as nitrogen, phosphorus, and potassium, that are deficient in soils (Barłóg et al., 2022). However, fertilisers can also significantly impact soil quality and ecosystem health (Alami et al., 2021; Barłóg et al., 2022). The effect of fertiliser applications in amaranthus production is vital for rapid growth and high yield. The use of inorganic fertiliser for the improvement in amaranthus growth has been reported (Akamine et al., 2020; Ortikov et al., 2023). According to research by Akamine et al. (2020), Amaranthus requires moderate levels of 400 kg ha^{-1} for NPK at a ratio of 1:1:1, respectively. However, the consistent reports of the detrimental effects of inorganic fertilisers on soil health, aside from the reduction in vegetable quality call for a more sustainable approach to improve soil conditions for crop production (Krasilnikov et al., 2022). Thus, farm waste such as CPH was encouraged as organic fertiliser.

Cocoa pod husk is the by-product of cocoa after extracting the cocoa beans from the pod (Mariatti et al., 2021). The pods are used to produce soap and the like. CPHs are reported to be rich in hemicellulose (such as xylan, glucuronoxylan, arabinoxylan, glucomannan, and xyloglucan), cellulose, raw energy, potassium, and many other minerals considered useful in improving soil health (Suharyatun et al., 2024). Applying different forms of CPH as a soil amendment for improving crop performance is well documented (Adeosun et al., 2019; Oluleye et al., 2023; Suharyatun et al., 2024). However, varying recommendations have been made regarding the level of application for appreciable yield in crops. Adeosun et al. (2019) reported the application of CPH at 300 kg N ha^{-1} for a substantial response for tea [*Camellia sinensis* (L.) O. Kuntze], while Kekong (2023) recommended CPH in combination with other organic sources at 10 t ha^{-1} to optimise okra production. The recommendations for different crops also differ. The level of CPH application to soil for crop improvement depends on several factors, including the quality of the CPH as organic fertiliser to use, type of crop, soil type and the level of soil nutrient depletion (Vanlauwe et al., 2023). The differences in these factors lead to variations in the level of CPH application to effectively improve soil conditions and increase crop yield, thus meeting the demand for food. Applying organic fertilisers at the right time and amount prevents nutrient loss and ensures optimal effectiveness. However, the reported low N in CPH as fertiliser have necessitated complementing this organic source with inorganic N to improve crop nutrition (Ouattara et al., 2021). Nitrogen-based fertilisers can increase soil nitrogen levels, thus enhancing plant growth and productivity (Barłóg, 2023). However, their excessive application can also lead to nitrogen pollution, which can cause water and air pollution and negatively impact human and environmental health (Barłóg, 2023).

The influence of inorganic or organic fertilisers on the soil and its microbial community is complex and depends on many factors like fertiliser type, application rate, and soil properties (Vanlauwe et al., 2023). Vanlauwe et al. (2023) reported that careful fertiliser management practices considering soil nutrient status, crop nutrient requirements, and environmental impacts are essential to ensure sustainable cotton production while maintaining soil health and ecosystem functioning. Some studies have shown that excessive fertiliser use can reduce soil microbial diversity and abundance, leading to changes in soil nutrient cycling and reduced plant growth (Dincă et al., 2022; Bhattacharyya and Furtak, 2023). Nevertheless, appropriate fertiliser application can enhance soil microbial activity and diversity, improving soil health and ecosystem functioning. However, limited information on CPH powder application or its combination with urea on the performance of short-duration crops like amaranthus is available. This is important in obtaining high crop yield without compromising the nutrient composition of amaranthus or soil health. Consequently, this will boost amaranthus production, manage cocoa production waist and improve the small-scale farmer's income. Therefore, this study aimed to determine the effects of CPH powder and urea on the performance of amaranthus.

MATERIALS AND METHODS

Experimental site

The experimental setup occurred within the screen house at the Department of Agronomy, Faculty of Agriculture, University of Ibadan, Oyo State, Nigeria. The specific coordinates of the experimental field are latitude 7°27′6″ N and longitude 3°53′46″ E, at an elevation of 210 m above sea level.

Experimental design and treatments

The experiment was a 3 × 3 factorial arrangement in a randomised complete block design with five replicates. The treatments involved the application of CPH powder) at 0, 30, and 60 kg N ha^{-1} and urea fertiliser at 0, 30, and 60 kg N ha^{-1}. The treatment interactions were 0 CPH × 0 urea (C_0U_0), 0 CPH × 30 kg N ha^{-1} urea (C_0U_{30}), 0 CPH × 60 kg N ha^{-1} urea (C_0U_{60}), CPH at 30 kg N ha^{-1} × 0 urea ($C_{30}U_0$), CPH at 30 kg N ha^{-1} × urea at 30 kg N ha^{-1} ($C_{30}U_{30}$), CPH at 30 kg N ha^{-1} × urea at 60 kg N ha^{-1} ($C_{30}U_{60}$), CPH at 60 kg N ha^{-1} × 0 urea ($C_{60}U_0$), CPH at 60 kg N ha^{-1} × urea at 30 kg N ha^{-1} ($C_{60}U_{30}$) and CPH at 60 kg N ha^{-1} × urea at 60 kg N ha^{-1} ($C_{60}U_{60}$).

Materials sources and collection

The National Horticultural Research Institute, Ibadan, Nigeria, supplied the amaranthus seeds, while the Department of Agronomy provided the dried CPH and black polythene bags. Additionally, the urea fertiliser used in the study was purchased from a retailer in Ibadan.

Planting and establishment in pots

The soil used for planting was obtained from the Agronomy experimental field at the University of Ibadan, Ibadan, Nigeria. Perforated polythene bags were filled with 4 kg of soil using a Camry dial scale. Amaranthus seeds were sowed in each pot at a depth of 2 cm at the centre of each pot on April 25 and July 14, 2023, for the first and second sowing, respectively. A light irrigation with water followed the sowing. The pots were subsequently irrigated every fortnight in the evening to ensure enough moisture for the healthy emergence and development of the amaranthus plant. Each pot received an equal amount of water from the watering can when watering. The polythene bags that contained the different treatments were labelled accordingly and positioned on iron benches within the screenhouse. For optimum plant growth and ease of data collection, the pots were spaced properly before the sowing of seeds.

Treatment applications

The CPH and urea fertiliser treatments were weighed with an electronically sensitive scale in the soil laboratory of the Department of Soil Resources Management, University of Ibadan, Ibadan, Nigeria. In all the selected pots for the CPH treatments, the powder was mixed into the soil one week before planting, while urea was applied to the side of the plants after two weeks of planting where needed. The properties of the CPH used in the study includes 14.80% of organic carbon, 0.84% total N and 0.14% total P. The Ca, Mg, K and Na were 0.53, 0.23, 2.06 and 0.40, respectively.

Maintenance

A week after planting, thinning was carried out to reduce competition among the amaranthus plants for resources such as space, light, nutrients, and water. The healthiest and most vigorous plant stands were selected to remain in the experimental pots, ensuring optimal growth and development. Regular manual weed removal was conducted weekly to eliminate unwanted plants that could compete with the amaranthus plants for available resources.

Data collection

Throughout the experiment, regular observations were made at 2, 3, 4 and 5 weeks after sowing (WAS) to assess various growth characteristics of the plants. The observations included plant height, stem diameter, number of leaves per plant, and the fresh and dry biomass of the plants. A flexible metre ruler was used to measure plant height, while a Vernier calliper measured stem diameter. At maturity, the plants were harvested for fresh weight. Subsequently, the harvested plants were oven-dried, and their dry biomass was measured using a precision scale.

Statistical analysis

Data for the qualitative and quantitative observations were analysed using GenStat 8.1 and MS-Excel 2016. The means of significantly varied agronomic parameters were separated using Duncan's Multiple Range Test at a 5% probability level.

RESULTS

Chemical and particle size analysis of the soil

The chemical properties of the soil indicated a neutral pH of 7.09. The total nitrogen content, potassium and available phosphorus levels in the soil were 3.3 g kg^{-1}, 0.29 cmol kg^{-1} and 16.10 mg kg^{-1}, respectively (Table 1). The values of the exchangeable bases in the soil were 0.36, 0.83, 0.29 and 2.71 cmol kg^{-1} for K, Mg, Na and Ca, respectively. The values for the soil physical parameters present in the soil were as indicated in Table 1, and the textural classification was loamy sand.

Effects of CPH and urea fertiliser on amaranthus plant height

The height of amaranthus plants was not significantly affected by the different levels of CPH powder throughout the observation period in the first cropping (Table 2). However,

Table 1. Chemical and physical properties of the experimental soil.

Parameters	Value
Organic C (g kg^{-1})	30.08
Total N (g kg^{-1})	3.3
Available P (mg kg^{-1})	16.1
pH (H_2O)	7.09
Exchangeable bases (cmol kg^{-1})	
K	0.36
Mg	0.83
Na	0.289
Ca	2.71
Exchangeable acidity (cmol kg^{-1})	0.4
Physical properties (g kg^{-1})	
Sand	800
Silt	130
Clay	70
Textural class	Loamy sand

Table 2. Influence of cocoa pod husk, urea and their interactions on amaranthus plant height (cm) at different observation periods.

	First planting (WAP)				Second planting (WAP)			
Treatment	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**
CPH (kg N ha^{-1})								
0	16.53	27.53	30.73	38.53	16.78	27.89	31.22	37.22
30	16.27	27.73	29.93	37.20	16.67	27.89	28.89	37.44
60	15.20	25.87	30.27	36.93	15.33	27.00	30.33	36.44
SE	0.56	1.22	1.72	1.89	0.71	1.80	2.73	2.80
Urea (kg N ha^{-1})								
0	15.33	23.00b	25.93b	32.60b	16.11	23.67b	26.44	33.67
30	16.93	29.40a	31.80a	38.53a	16.89	30.56a	32.00	38.22
60	15.73	28.73a	33.20a	41.53a	15.78	28.56ab	32.00	39.22
SE	0.56	1.22	1.72	1.89	0.71	1.80	2.73	2.80
Interactions								
C_0U_0	16.40ab	24.80b-d	27.67ab	33.00bc	18.33ab	27.00a-c	29.00	34.33
C_0U3_0	16.20ab	26.80a-d	31.80ab	38.00a-c	15.33b	26.00a-c	30.67	34.33
C_0U_{60}	17.00ab	31.00ab	32.80a	44.67a	16.67ab	30.67ab	34.00	43.00
$C_{30}U_0$	15.00b	23.67cd	27.67ab	36.00a-c	14.67b	23.67bc	27.33	37.00
$C_{30}U_{30}$	18.67a	32.67a	31.00ab	38.67a-c	20.00a	33.33a	31.00	41.00
$C_{30}U_{60}$	15.20b	27.00a-d	31.20ab	37.00a-c	15.33b	26.67bc	28.33	34.33
$C_{60}U_0$	14.67b	20.67d	22.67b	28.80c	15.33b	20.33c	23.00	29.67
$C_{60}U_{30}$	16.00ab	28.80a-c	32.67a	39.00a-c	15.33b	32.33ab	34.33	39.33
$C_{60}U_{60}$	15.00b	28.20a-c	35.60a	43.00ab	15.33b	28.33a-c	33.67	40.33
SE	0.97	2.12	2.99	3.28	1.23	3.13	4.72	4.85

CPH = Cocoa Pod Husk, WAP: Weeks After Planting; C_0 = CPH at 0 kg N ha^{-1}; C_{30} = CPH at 30 kg N ha^{-1}; C_{60} = CPH at 60 kg N ha^{-1}; U_0 = Urea at 0 kg N ha^{-1}; U_{30} = Urea at 30 kg N ha^{-1}; U_{60} = Urea at 60 kg N ha^{-1}; Mean values within the same column and with similar letter(s) are not significantly different at probability level of 0.05, as determined by Duncan`s Multiple Range Test.

the plants under the control treatment had the highest height at 2, 4 and 5 WAP, while CPH at 60 kg N ha^{-1} treatment had the lowest plant heights at 2, 3 and 5 WAP. In the second planting, the height of amaranthus plants was similar for all the treatments across the observation periods. However, the CPH at 60 kg N ha^{-1} treated plants were consistently taller than the other treatments, except at 4 WAP, while the control had taller plants at 2 and 4 WAP.

Plant height under urea fertiliser application was similar for all the treatments at 2 WAP in the first planting (Table 2). However, urea fertiliser application significantly increased amaranthus heights at 3, 4 and 5 WAP compared to the control, with the CPH at 60 kg N ha^{-1} having the tallest plants at 4 and 5 WAP. A similar trend was observed for plant height in the second planting, except that the heights were not significantly different throughout the observation periods.

The interactions of CPH and urea fertiliser further improved the height of amaranthus in the first and second plantings (Table 2). In the first planting, plants treated with $C_{30}U_{30}$ had significantly taller plants at 2 and 3 WAS, while the $C_{60}U_0$ treatment had the shortest plants. At 4 WAS, the C_0U_{60}, $C_{60}U_{60}$ and $C_{60}U_{60}$ treated plants had significantly taller plants than $C_{60}U_0$, while the other treatments were similar. The plant height observed for the control (C_0U_0) and $C_{60}U_0$ were significantly shorter than the C_0U_{60} treated plants at 5 WAS. Plants treated with $C_{30}U_{30}$ were significantly taller than those treated with $C_{30}U_0$ and $C_{30}U_{60}$ at 2 WAS in the second planting. At 3 WAS C_0U_{60} and $C_{30}U_{30}$ treatments significantly increased amaranthus heights compared to $C_{30}U_0$ and $C_{60}U_0$ but similar with the other treatments. Amaranthus heights were not significantly different at 4 and 5 WAS, however, the heights ranged from 34.33 ($C_{60}U_{30}$) to 23.00 ($C_{60}U_0$) and ($C_{30}U_{30}$) to ($C_{30}U_{30}$), respectively.

Effect of fertiliser on amaranthus stem diameter

The influence of CPH on the stem diameter of amaranthus varies among treatments in the two plantings (Table 3). The plants under control treatment had a significantly higher stem diameter value than the CPH applied at 30 kg N ha^{-1} at 2 WAS in the first planting. At 3, 4 and 5 WAS, no significant difference was observed among the treatments but the plants under the control had higher stem diameters. In contrast, CPH application at 60 kg N ha^{-1} had the lowest stem diameter. In the second planting, no significant variation was observed among the treatments for stem diameter throughout the observation period. However, the control (CPH at 0 kg) had a higher stem diameter across the observation period than the other treatments.

Amaranthus plants treated with urea (0, 30 and 60 kg N ha^{-1}) displayed a significant variation among treatments for stem diameter in the first plantings (Table 3). The influence of urea fertiliser was not significant at 2 WAS but varied significantly at 3, 4 and 5 WAS. The higher the level of urea application, the higher the stem diameter values. Applying urea fertiliser at 30 and 60 kg N ha^{-1} significantly increased the stem diameter of amaranthus compared to the control. The application of urea fertiliser did not significantly increase amaranthus stem diameter across the observation period but increased with the application level, except at 3 WAS.

The influence of CPH and urea fertiliser interactions were similar for stem diameter in the first planting (Table 3). The C_0U_{60} and C_0U_{30} interactions significantly increased the stem diameter of amaranthus compared to sole CPH treatments ($C_{30}U_0$ and $C_{60}U_0$), while other treatment interactions were at par at 3 WAS. At 4 WAS, $C_{60}U_{60}$-treated plants had significantly higher stem diameters than $C_{60}U_0$-treated plants, while the others were similar.

At 5 WAS, the $C_{60}U_0$ treated plants had significantly lower stem diameter than other treatments, except C_0U_0, $C_{30}U_0$ and $C_{30}U_{60}$. In the second planting, the $C_{60}U_0$ treated plants had significantly higher stem diameters than $C_{30}U_{60}$ and $C_{30}U_0$ but at par with the other treatments at 2 WAS. The C_0U_{60} and $C_{30}U_{30}$ interactions significantly improved amaranthus stem diameter than $C_{60}U_0$, while others were similar at 3 WAS. Stem diameters of amaranthus at 4 and 5 WAS were not significantly different but ranged from 0.55 ($C_{30}U_0$) to 0.68 cm (C_0U_{60}) and 0.70 ($C_{60}U_0$) to 0.89 cm (C_0U_{60}), respectively.

Number of amaranthus leaves affected by cocoa pod husk and urea fertiliser

The application of CPH reduces the number of leaves produced with the increase in application level across the observation period, except at 5 WAS (Table 4). The control treatment (CPH at 0 kg) differed significantly from the response observed for CPH at 60 kg N ha^{-1} in the number of leaves at 2 WAS. The number of leaves at 3 and 4 WAS were not significantly different but ranged from 11.93 (CPH at 60 kg N ha^{-1}) to 12.73 (control) and 13.13 (CPH at 30 kg N ha^{-1}) to 13.40 (control), respectively. At 5 WAS, the number of leaves was similar for all treatments. The influence of CPH on the amaranthus number of leaves in the second planting was comparable to the trends observed in the first planting. However, the control treatments had the highest values at 2, 3 and 4 WAS, while CPH at 30 kg N ha^{-1} had

Table 3. Influence of cocoa pod husk, urea and their interactions on the amaranthus stem diameter (cm).

	First planting (WAP)				Second planting			
Treatments	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**
CPH (kg N ha^{-1})								
0	0.34a	0.48	0.63	0.84	0.34	0.48	0.63	0.82
30	0.31b	0.47	0.60	0.83	0.30	0.47	0.58	0.81
60	0.32ab	0.44	0.62	0.81	0.32	0.45	0.61	0.81
SE	0.01	0.02	0.02	0.02	0.01	0.03	0.04	0.03
Urea (kg N ha^{-1})								
0	0.33	0.39b	0.55b	0.77b	0.33	0.40	0.55	0.76
30	0.32	0.50a	0.63a	0.84a	0.31	0.51	0.64	0.83
60	0.31	0.50a	0.65a	0.87a	0.31	0.49	0.64	0.84
SE	0.07	0.01	0.02	0.02	0.01	0.03	0.04	0.03
Interactions								
C_0U_0	0.35a	0.44a-c	0.59ab	0.78ab	0.37a	0.47ab	0.59	0.77
C_0U_{30}	0.32a	0.45ab	0.64ab	0.84a	0.31ab	0.44ab	0.64	0.80
C_0U_{60}	0.34a	0.54a	0.65ab	0.90a	0.33ab	0.53a	0.68	0.89
$C_{30}U_0$	0.30a	0.40bc	0.56ab	0.82ab	0.29b	0.40ab	0.55	0.81
$C_{30}U_{30}$	0.32a	0.56a	0.61ab	0.84a	0.31ab	0.58a	0.62	0.85
$C_{30}U_{60}$	0.30a	0.46ab	0.62ab	0.82ab	0.29b	0.44ab	0.57	0.78
$C_{60}U_0$	0.33a	0.33c	0.51b	0.71b	0.34a	0.34b	0.51	0.70
$C_{60}U_{30}$	0.32a	0.5ab	0.64ab	0.85a	0.31ab	0.50ab	0.67	0.86
$C_{60}U_{60}$	0.30a	0.50ab	0.70a	0.88a	0.31ab	0.50ab	0.66	0.85
SE	0.01	0.03	0.04	0.03	0.02	0.06	0.07	0.06

CPH = Cocoa Pod Husk, WAP: Weeks After Planting; C_0 = CPH at 0 kg N ha^{-1}; C_{30} = CPH at 30 kg N ha^{-1}; C_{60} = CPH at 60 kg N ha^{-1}; U_0 = Urea at 0 kg N ha^{-1}; U_{30} = Urea at 30 kg N ha^{-1}; U_{60} = Urea at 60 kg N ha^{-1}; Mean values within the same column and with similar letter(s) are not significantly different at probability level of 0.05, as determined by Duncan`s Multiple Range Test.

the highest value at 5 WAS. The CPH at 60 kg N ha^{-1} had the lowest number of leaves at 2, 3 and 4 WAS, while the lowest value at 5 WAS was in the control.

The effect of urea fertiliser application did not significantly improve the amaranthus number of leaves at 2 WAS but increased with the application level in the first planting (Table 4). At 3 and 4 WAS, the effects of urea fertiliser at 30 and 60 kg N ha^{-1}, respectively, increased the amaranthus number of leaves compared to the controls. At 5 WAS, 30 and 60 kg N ha^{-1} treated plants had a significantly higher number of leaves than the control. In the second planting, no significant variation was observed among the treatments, except at 3 WAS, where the 30 kg N ha^{-1} treated plants varied significantly from the control.

Variation in number of leaves was significant for the CPH x urea fertiliser interactions in the first planting (Table 4). At 2 WAS, the $C_{30}U_{30}$-treated plants had a significantly higher number of leaves than plants treated with $C_{30}U_0$, $C_{60}U_0$ and $C_{60}U_{60}$. Plants treated with C_0U_{30} had a significantly higher number of leaves than C_0U_0, $C_{30}U_0$ and $C_{60}U_0$ at 3 WAS. The number of leaves observed at $C_{60}U_{60}$ was significantly higher than $C_{60}U_0$ at 4 WAS. Similarly, at 5 WAS, the $C_{60}U_{60}$ treated plants had a significantly higher number of leaves than C_0U_0 and $C_{60}U_0$. In the second planting, the interaction of $C_{30}U_{30}$ significantly increased the number of amaranthus leaves compared to the other treatments at 2 WAS except the control. The C_0U_{30} treatment significantly increased the number of leaves in amaranthus compared to $C_{30}U_0$, $C_{60}U_{60}$ and $C_{60}U_0$ applications at 3 WAS. No significant variation was observed for the number of leaves at 4 and 5 WAS. However, the number of leaves of amaranthus ranged from 10.67 ($C_{60}U_0$) to 15.00 (C_0U_{60}) and 10.33 ($C_{60}U_0$) to 14.33 ($C_{30}U_{30}$) at 4 and 5 WAS, respectively.

Table 4. Number of leaves of amaranthus as affected by cocoa pod husk, urea fertiliser and their interactions.

	First planting (WAP)				Second planting (WAP)			
Treatment	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**
CPH (kg N ha^{-1})								
0	8.27a	12.73	13.40	12.27	8.33a	13.22	13.78	11.89
30	8.00ab	12.47	13.13	12.73	8.44ab	12.44	13.00	12.78
60	7.20b	11.93	13.33	12.67	7.22b	11.78	12.89	12.56
SE	0.36	0.35	0.58	0.54	0.40	0.49	0.88	0.83
Urea (kg N ha^{-1})								
0	7.33	11.27b	12.20b	11.40b	7.89	11.44b	12.11	11.33
30	8.53	13.33a	13.47ab	13.20a	8.44	13.56a	13.56	13.22
60	7.60	12.53ab	14.20a	13.07a	7.67	12.44ab	14.00	12.67
SE	0.36	0.35	0.58	0.54	0.40	0.49	0.88	0.83
Interactions								
C_0U_0	8.40ab	11.40cd	12.40ab	11.80bc	9.67ab	12.00a-c	12.67	11.67
C_0U_{30}	8.00ab	13.60a	13.80ab	13.00a-c	7.33c	14.33a	13.67	12.00
C_0U_{60}	8.40ab	13.20ab	14.00ab	12.00a-c	8.00bc	13.33ab	15.00	12.00
$C_{30}U_0$	7.00b	11.80b-d	12.80ab	12.00a-c	7.00c	11.67bc	13.00	12.00
$C_{30}U_{30}$	9.60a	13.40ab	13.00ab	13.60ab	10.67a	14.00ab	13.33	14.33
$C_{30}U_{60}$	7.40b	12.20a-d	13.60ab	12.60a-c	7.67bc	11.67bc	12.67	12.00
$C_{60}U_0$	6.60b	10.60d	11.40b	10.40c	7.00c	10.67c	10.67	10.33
$C_{60}U_{30}$	8.00ab	13.00a-c	13.60ab	13.00a-c	7.33c	12.33a-c	13.67	13.33
$C_{60}U_{60}$	7.00b	12.20a-d	15.00a	14.60a	7.33c	12.33a-c	14.33	14.00
SE	0.62	0.61	1.01	0.94	0.70	0.85	1.53	1.44

CPH = Cocoa Pod Husk, WAP: Weeks After Planting; C_0 = CPH at 0 kg N ha^{-1}; C_{30} = CPH at 30 kg N ha^{-1}; C_{60} = CPH at 60 kg N ha^{-1}; U_0 = Urea at 0 kg N ha^{-1}; U_{30} = Urea at 30 kg N ha^{-1}; U_{60} = Urea at 60 kg N ha^{-1}; Mean values within the same column and with similar letter(s) are not significantly different at probability level of 0.05, as determined by Duncan`s Multiple Range Test.

Effect of fertiliser on fresh biomass and dry biomass at harvest

The first and second plantings indicated significant variations among the CPH treatments for fresh biomass accumulation in amaranthus (Table 5). Application of CPH at 30 and 60 kg N ha^{-1} resulted in a significant reduction in fresh biomass in both plantings. However, applying CPH at 60 kg N ha^{-1} increased the fresh biomass of amaranthus by 19.77 and 25.75% compared to 30 kg N ha^{-1} in the first and second plantings, respectively. Urea fertiliser application significantly increased the fresh biomass of amaranthus with an increase in the application level in the first planting. During the second planting, the variation was insignificant (Table 5). However, 60 kg N ha^{-1} improved fresh biomass by 13.21% compared to the 30 kg N ha^{-1}.

The results of the interactions between CPH and urea fertiliser indicated significant variations among the treatments in the first planting (Table 5). The fresh biomass observed in the plants treated with C_0U_{60} was significantly higher than in the other treatments. However, the $C_{60}U_{60}$ application was at par with the C_0U_{30} for fresh biomass. In the second planting, the C_0U_{60} and C_0U_{30} treatments gave significantly higher fresh biomass than the others but were comparable to $C_{60}U_{30}$ and $C_{60}U_{60}$.

During the first planting, the control treatment had significantly higher dry biomass weight than the CPH treatment at 60 kg N ha^{-1} (Table 5). In the second planting, the differences among the treatments were not significant. However, the highest and lowest dry biomass weight values were 3.00 and 2.04 for the control and CPH at 60 kg N ha^{-1}, respectively.

Urea applications at 30 and 60 kg N ha^{-1} significantly increased dry biomass weight in amaranthus compared to the control in the first planting (Table 5). Applying 60 kg N ha^{-1} increased amaranthus dry biomass weight by

Table 5. Effect of cocoa pod husk, urea fertiliser and their interactions on amaranthus fresh and dry biomass (g plant^{-1}).

	First planting		Second planting	
	Fresh biomass	**Dry biomass**	**Fresh biomass**	**Dry biomass**
CPH (kg N ha^{-1})				
0	24.28a	3.10a	23.18a	3.00
30	15.07b	2.32ab	13.63b	2.40
60	18.05b	2.22b	17.14b	2.04
SE	1.34	0.28	1.98	0.33
Urea (kg N ha^{-1})				
0	13.45c	1.51b	12.14	1.48b
30	19.41b	2.85a	19.61	3.21a
60	24.54a	3.27a	22.20	2.76a
SE	1.34	0.28	1.98	0.33
Interactions				
C_0U_0	14.06cd	1.48c	13.57bc	1.63c
C_0U_{30}	25.88b	3.28ab	26.87a	3.40ab
C_0U_{60}	32.90a	4.54a	29.10a	3.97a
$C_{30}U_0$	15.22cd	1.74bc	12.77bc	1.40c
$C_{30}U_{30}$	13.32cd	3.14ab	12.07bc	4.03a
$C_{30}U_{60}$	16.66cd	2.08bc	16.07bc	1.77bc
$C_{60}U_0$	11.06d	1.32c	10.10c	1.40c
$C_{60}U_{30}$	19.04bc	2.14bc	19.90a-c	2.20bc
$C_{60}U_{60}$	24.06b	3.20ab	21.43ab	2.53a-c
SE	2.33	0.48	3.43	0.58

CPH = Cocoa Pod Husk, WAP: Weeks After Planting; C_0 = CPH at 0 kg N ha^{-1}; C_{30} = CPH at 30 kg N ha^{-1}; C_{60} = CPH at 60 kg N ha^{-1}; U_0 = Urea at 0 kg N ha^{-1}; U_{30} = Urea at 30 kg N ha^{-1}; U_{60} = Urea at 60 kg N ha^{-1}; Mean values within the same column and with similar letter(s) are not significantly different at probability level of 0.05, as determined by Duncan`s Multiple Range Test.

14.74% compared to the response observed at 30 kg N ha^{-1} of urea. A similar response to urea fertiliser application was observed in the second planting for dry biomass weight. The 30 and 60 kg N ha^{-1} treated plants had significantly higher dry biomass than the control. However, the urea treatment at 30 kg N ha^{-1} had 16.30% higher dry biomass than the 60 kg N ha^{-1} treated plants.

Dry biomass weight in amaranthus varied significantly among the treatments for CPH and urea interactions in both plantings (Table 5). The C_0U_{60} treated plants had significantly higher dry biomass than other treatments, but were comparable to $C_{30}U_{30}$ and $C_{60}U_{60}$. The C_0U_0 and $C_{60}U_0$ treated plants had significantly lower dry biomass among the treatments. In the second planting, the interaction of $C_{30}U_{30}$ was comparable to the C_0U_{80} application rate but had significantly higher dry biomass than other treatments.

DISCUSSION

The nutrient composition in the soil indicated a low fertility status as Ahmed et al. (2021) recommended for optimum crop performance. The total nitrogen in the soil falls below the critical range of 4-5 g kg^{-1} recommended for optimal amaranth production. This implies that a positive response from amaranthus plants could be obtained by applying either inorganic or organic fertilisers (such as cocoa farm waste). Crop growth is related to the extent of nutrient availability in the soil for plant root uptake. Crop performance, however, is affected by the adequacy of all required essential nutrients, without which crop growth is limited (Ahmed et al., 2023). The results of this study revealed similar trends for the growth parameters throughout the observation periods in the first and second plantings, except for the magnitude of variations. Crop growth and development are related to the magnitude of available nutrients in the soil and the synchrony of nutrient release with crop needs (Ayamba et al., 2023). The contribution of different forms of CPH in improving soil conditions for enhanced crop performance is supported by Oluleye et al. (2023) and Suharyatun et al. (2024). The responses observed in the two plantings for the plant height, stem diameter, and number of leaves revealed a similar pattern as the control treatments (0 kg N ha^{-1} CPH) performed better than the other CPH treatments. Despite the low initial soil nutrient status, the continued better performances from the control over the CPH treatments at 2, 3 and 4 WAS suggest the inability of the crop to acquire nutrients from the soil. This may be due to the slow nutrient release rate of CPH in the soil, which limited the availability of nutrients for rapid growth in short-duration crops like amaranthus (Ouattara et al., 2021; Barłóg, 2023).

Furthermore, the reduction in the growth parameters observed at the higher CPH application could be the effect of further decomposition of CPH powder or excessive application. Even though the applied CPH could release the nutrients available in the material, the continued decomposition process may restrict the release of nutrients (Rodríguez-Espinosa et al., 2023). They reported that the increase in microbial activities resulting from organic manure addition immobilises the availability of nutrients during the degradation of organic materials. This was attributed to the energy required for rebuilding the soil microbial community before commencing nutrient release to the plant root. This is probably because the CPH was applied in powder form after the pods were dried before decomposition. Although the CPH powder was applied before planting, the material could require further decomposition to synchronise nutrient release with the plant's nutrient needs. This assertion is true in that after 4 weeks of sowing, the CPH treatments improve the parameters observed compared to the control. Moreover, the CPH powder is a better source of K than N nutrient (Kone et al., 2020), consequently, the ability of the amendment to supply N that was also limiting is restricted. The results for fresh and dry biomass weights are the outcome of the plant's ability to acquire nutrients for the development and moisture content of the plant at the final stage. In both planting periods, the higher CPH application produced higher fresh biomass but lower dry biomass. The higher application of organic materials promotes soil water-holding capacity, thus increasing soil moisture for plant root uptake (Wang et al., 2023). This affirms that the higher values for fresh biomass at 60 kg N ha^{-1} CPH were most likely due to higher moisture content rather than assimilate accumulation. This result confirmed that the CPH at 30 kg N ha^{-1} had higher dry biomass than the higher application level. However, the positive effect of CPH powder application at 5 WAS suggested an improvement in the plant's nutrition and, thus the growth parameters compared to the control. However, the delay in the supply of nutrients to the plants at an earlier stage of development through CPH application could not match the nutrients accumulated over time in the control treatment. Consequently, the sudden increase through CPH did not result in higher biomass accumulation.

There was consistency in the trends observed for plant height, stem diameter, and number of leaves, which showed that the application of urea fertiliser improved the growth and yield of amaranthus. The soil used for the study was deficient in N, consequently, the supply of N through urea favoured the development of amaranthus in both plantings. Similar observation was reported on radish response to urea application (Akinrinola and Ojo, 2024). Swify et al. (2024) reported that urea fertiliser application supplies the required N and enhances crop nutrient use efficiency, consequently improving crop growth and development. In amaranth, as with other crops, an adequate nitrogen supply is essential for cell initiation and multiplication (Westerik et al., 2023). The response observed at 60 kg N ha^{-1} indicated that the level is not higher than the crop can tolerate. The improved nutrition and water uptake at higher N levels of urea increased the accumulation of dry matter through the enhanced photosynthetic ability of the plant. Thus, increased fresh and dry biomass at 60 kg N ha^{-1}.

The effectiveness of combining organic (CPH) and inorganic (urea) fertilisers in promoting amaranthus productivity over their sole application is well documented. The application of the two fertilisers often referred to as IPNM (Integrated Plant Nutrient Management) militates the deficiencies in each, thus providing a more efficient nutrient management strategy for improving yield (Mariyono, 2020; Paramesh et al., 2023; Kushwah et al., 2023). The organic component reduces soil bulk density, improves soil porosity, enhances water-holding capacity and raises microbial diversity. The inorganic fertiliser ensures the adequate availability of nutrients to the plant root. The amaranthus plants treated with the combination of CPH at 60 kg N ha^{-1} with urea at 30 kg N ha^{-1} and CPH at 60 kg N ha^{-1} with urea at 60 kg N ha^{-1} exhibited better growth characteristics. These treatments were not different from the CPH at 30 kg N ha^{-1}

with urea at 30 kg N ha^{-1} for height, leaf numbers, stem diameter, and fresh and dry biomass. Although these applications were comparable to the observed responses for the sole 60 kg N ha^{-1} urea, the aftermath effects of urea on soil and crop quality did not make it a better choice. Furthermore, the higher levels of CPH powder at 60 kg N ha^{-1} with urea at 60 kg N ha^{-1} or CPH powder at 60 kg N ha^{-1} with urea at 30 kg N ha^{-1} did not support the IPNM strategy in that the judicious management of resources for increase yield and improve soil health for long term sustainability (Kushwah et al., 2023). According to Swify et al. (2024), CPH application in combination with urea could have controlled the release process, thus synchronising the nutrient release with the crop need. The CPH powder at 30 kg N ha^{-1} with urea at 30 kg N ha^{-1} treatment gave comparatively higher dry biomass weight than the other combinations in both plantings. Also, despite the lower growth observed for sole CPH application, its combination with urea enhanced amaranthus performance.

CONCLUSIONS

The study revealed that applying CPH powder as a soil amendment reduced amaranthus growth at the early stage of development. Subsequently, the CPH application led to enhanced amaranthus performance. Plants treated with urea at 60 kg N ha^{-1} performed better across all growth parameters than 30 kg N ha^{-1} urea. For CPH and urea fertiliser interactions, plants treated to both CPH at 60 kg N ha^{-1} with urea at 60 kg N ha^{-1} showed better performance. However, similar observations were made for CPH at 60 kg N ha^{-1} with urea at 30 kg N ha^{-1} and CPH at 30 kg N ha^{-1} with urea at 30 kg N ha^{-1}.

Considering the cost of additional urea fertilisers and the difference in yield, it was concluded that intergrating CPH at 30 kg N ha^{-1} with urea at 30 kg N ha^{-1} was the most effective approach for sustaining amaranthus production.

Conflict of interest

The authors do not have any actual or potential conflict of interest to declare.

Authors' collaboration

Tajudeen Akinrinola: active participation in the development of the methodology and discussion of the results. Adedayo Salami: actively participated in the development of the methodology and data collection. Samuel Adegoke, participated in the bibliographic review. All authors contributed equally and approved of the final version of the article.

LITERATURE CITED

Adeosun, S.A., A.O. Togun, S.A. Adejumo, and A.O. Famaye. 2019. The effect of cocoa pod husk as organic fertilizer on the growth of tea (*Camellia sinensis* (L.) O. Kuntze) under varying light intensities in Ibadan – South West Nigeria. Journal of Global Biosciences 8(2):5925-5935. Available at https://www.mutagens.co.in/jgb/vol.08/02/Journal%20of%20Global%20Biosciences%20080202.pdf (Accessed 17 October 2024).

Adhikary, D., U. Khatri-Chhetri, and J. Slaski 2020. Amaranth: An ancient and high-quality wholesome crop. In: Waisundara V.Y. (ed.). Nutritional value of amaranth. IntechOpen. Available at http://dx.doi.org/10.5772/intechopen.88093 (Accessed 17 October 2024)

Ahmed, N., B. Zhang, Z. Chachar, J. Li, G. Xiao, Q. Wang, F. Hayat, L. Deng, M. Narejo, B. Bozdar, and P. Tu. 2023. Micronutrients and their effects on horticultural crop quality, productivity and sustainability. Scientia Horticulturae 323:112512. https://doi.org/10.1016/j.scienta.2023.112512

Ahmed, U., J.C.W. Lin, G. Srivastava, and Y. Djenouri. 2021. A nutrient recommendation system for soil fertilization based on evolutionary computation. Computers and Electronics in Agriculture 189:106407. https://doi.org/10.1016/j.compag.2021.106407

Akamine, H., M. Ohshiro, and M.A. Hossain 2020. Fertilizer management for amaranth (*Amaranthus* spp.) cultivation on dark-red soil in Okinawa, Japan. Applied Ecology and Environmental Research 18(6):8145-8158. Available at https://www.aloki.hu/pdf/1806_81458158.pdf (Accessed 17 October 2024)

Akinrinola, T.B. and A.B. Ojo 2024. Radish response to cocoa pod husk and urea fertiliser applications. Agricultura 131(3-4):106-122.

Alami, M.M., Q. Pang, Z. Gong, T. Yang, D. Tu, O. Zhen, W. Yu, M.J. Alami, and X. Wang. 2021. Continuous cropping changes the composition and diversity of bacterial communities: A meta-analysis in nine different fields with different plant cultivation. Agriculture 11:1224. https://doi.org/10.3390/agriculture11121224

Ayamba, B.E., R.C. Abaidoo, A. Opoku, and N. Ewusi-Mensah. 2023. Mechanisms for nutrient interactions from organic amendments and mineral fertilizer inputs under cropping systems: A review. PeerJ 11:e15135 http://doi.org/10.7717/peerj.15135

Barłóg, P. 2023. Improving fertilizer use efficiency—methods and strategies for the future. Plants 12(20):3658. https://doi.org/10.3390/plants12203658

Barłóg, P., W. Grzebisz, and R. Łukowiak. 2022. Fertilizers and fertilization strategies mitigating soil factors constraining efficiency of nitrogen in plant production. Plants 11(14):1855. https://doi.org/10.3390/plants11141855

Bhattacharyya, S.S., K. Furtak, 2023. Soil–plant–microbe interactions determine soil biological fertility by altering rhizospheric nutrient cycling and biocrust formation. Sustainability 15(1):625. https://doi.org/10.3390/su15010625

Dincă, L.C., P., Grenni, C., Onet, and A. Onet. 2022. Fertilization and soil microbial community: A review. Applied Sciences 12(3):1198. https://doi.org/10.3390/app12031198

Kekong, M.A. 2023. Integrated cocoa pod compost affect soil physical and chemical properties and yield of okra in a derived savanna of Obubra Nigeria. Nigeria Agricultural Journal 54(2):162-170. Available at: https://www.ajol.info/index.php/naj/article/view/267481 (Accessed 17 October 2024)

Kone, K., K. Akueson, and G. Norval 2020. On the production of potassium carbonate from cocoa pod husks. Recycling 5(3):23. https://doi.org/10.3390/recycling5030023

Krasilnikov, P., and M.A. Taboada. 2022. Fertilizer use, soil health and agricultural sustainability. Agriculture 12(4):462. https://doi.org/10.3390/agriculture12040462

Kushwah, N., V. Billore, O.P. Sharma, D. Singh, and A.P.S. Chauhan. 2023. Integrated nutrient management for optimal plant health and crop yield. Plant Science Archives 8(2):10-12. http://dx.doi.org/10.5281/zenodo.10399479

Mariatti, F., V. Gunjević, L. Boffa, and G. Cravotto. 2021. Process intensification technologies for the recovery of valuable compounds from cocoa by-products. Innovative Food Science and Emerging Technologies 68:102601. https://doi.org/10.1016/j.ifset.2021.102601

Mariyono, J. 2020. Improvement of economic and sustainability performance of agribusiness management using ecological technologies in Indonesia. International Journal of Productivity and Performance Management 69 (5): 989-1008. https://doi.org/10.1108/ijppm-01-2019-0036

Ogwu, M.C. 2020. Value of *Amaranthus* [L.] Species in Nigeria. In: Waisundara, V.Y. (Ed.). Nutritional value of amaranth. IntechOpen. https://doi.org/10.5772/intechopen.86990

Oluleye, A.K., M.O. Ogunlade, and O.B. Adewoyin. 2023. Response of okra, *Abelmoschus esculentus* (L.) Moench, to biochar derived from cocoa pod husk and NPK fertiliser. Tropical Agriculture (Trinidad) 100(1):11-19. Available at https://journals.sta.uwi.edu/ojs/index.php/ta/article/view/8174 (Accessed 17 October 2024)

Ortikov, T., B. Shoniyozov, A. Makhmatmurodov, and M. Mashrabov. 2023. Influence of mineral and organic fertilizers on the properties of serozem-meadow soils, nutritional dynamics and productivity of amaranth. E3S Web of Conferences. 462:02017. https://doi.org/10.1051/e3sconf/202346202017

Ouattara, L.Y., E.K.A. Kouassi, D. Soro, Y. Soro, K. Yao, K. Adouby, A.P. Drogui, D.R. Tyagi, and P.M. Aina. 2021. Cocoa pod husks as potential sources of renewable high-value-added products: A review of current valorizations and future prospects. BioResources 16(1):1988-2020. https://doi.org/10.15376/BIORES.16.1.OUATTARA

Paramesh, V., K.R. Mohan, G.A. Rajanna, S. Gowda, A.J. Nath, Y. Madiva, D. Jinger, S. Bhat, and S. Toraskar. 2023. Integrated nutrient management for improving crop yields, soil properties, and reducing greenhouse gas emissions. Frontiers Sustainable Food System 7:1173258. https://doi.org/10.3389/fsufs.2023.1173258

Rodríguez-Espinosa, T., J. Navarro-Pedreño, L.I. Gómez, M.B.A. Cande, A.P. Gimeno, and A.A. Zorpas. 2023. Soluble elements released from organic wastes to increase available nutrients for soil and crops. Applied Science 13:1151. https://doi.org/10.3390/app13021151

Rodríguez-Ríos, H., J. Campos-Parra, R. Astudillo-Neira, J. Grande-Cano, S. Carrillo-Domínguez, and F. Pérez Gil- Romo. 2020. *Amaranthus cruentus* L. as a food alternative in laying hens to reduce cholesterol in eggs. Chilean Journal of Agricultural and Animal Sciences 36(1):78-85. Retrieved from https://revistas.udec.cl/index.php/chjaas/article/view/1959 (Accessed 10 January 2025)

Schippers, R.R. 2000. African indigenous vegetables: An overview of the cultivated species. Chatham, UK: Natural Resources Institute /ACP-EU Technical Centre for Agricultural and Rural Cooperation. University of Greenwich, Natural Resources Institute, Chatham, Great Britain. 214 pp http://gala.gre.ac.uk/id/eprint/12060

Sharma, S., B. Lishika, H. Shubham, and S. Kaushal. 2023. Soil quality indicators: A comprehensive review. International Journal of Plant and Soil Science 35:315-325. https://doi.org/10.9734/ijpss/2023/v35i224139

Suharyatun, S., A. Haryanto, M.D.W. Wardhana, S. Triyono, O.T. Purwadi, and F.K. Wisnu. 2024. Improving the growth and yield of pak choy (*Brassica chinensis* L.) using cacao pod husk biochar. International journal on Advancement Science Engineering Information Technology 14(2):77-785. https://doi.org/10.18517/ijaseit.14.2.19536

Swify, S., R. Mažeika, J. Baltrusaitis, E.D. Drapanauskait, and E.K. Barˇcauskait. 2024. Review: Modified urea fertilizers and their effects on improving nitrogen use efficiency (NUE). Sustainability 16:188. https://doi.org/10.3390/su16010188

Vanlauwe, B., T. Amede, A. Bationo, P. Bindraban, et al. 2023. Fertilizer and soil health in Africa: The role of fertilizer in building soil health to sustain farming and address climate change. International Fertilizer Development Center (IFDC). USA. 76 pp. Available at https://ifdc.org/resources/fertilizer-and-soil-health-in-africa-the-role-of-fertilizer-in-building-soil-health-to-sustain-farming-and-address-climate-change/ [Accessed 17 October 2024]

Wang, X., L. Wang, and T. Wang. 2023. Effect of replacing mineral fertilizer with manure on soil water retention capacity in a Semi-Arid Region. Agronomy 13(9): 2272. https://doi.org/10.3390/agronomy13092272

Westerik, D., E. Holand, and R. Hijbeek. 2023. Nitrogen fertilizer replacement values of organic amendments: determination and prediction. Nutrient Cycling in Agroecosystems 129:445–458. https://doi.org/10.1007/s10705-023-10316-7