RADISH RESPONSE TO COCOA POD HUSK AND UREA FERTILISER APPLICATIONS

Tajudeen B. Akinrinola*, Ayoade B. Ojo
*Department of Crop and Horticultural Sciences, Faculty of Agriculture, University of Ibadan, Ibadan, Nigeria. *Corresponding author: tb.akinrinola@gmail.com*

Abstract. Radishes are vegetables cultivated and consumed for their enlarged roots. Low yield resulting from cropping intensification requires supplementation to improve or maintain yield. The perverse effects of sole inorganic fertiliser on soil health and produce quality have necessitated integrating inorganic fertiliser with farm waste as alternatives. However, there is limited information on cocoa pod husk (CPH) powder and urea fertiliser in radish production. Therefore, this study investigated the impact of CPH and urea on radish performance. A 3×4 factorial experiment was conducted using 5 kg soil to evaluate CPH at 0, 30, and 60, and urea at 0, 15, 30, and 45 kg N/ha in a randomised complete block design with six replicates. Growth and root yield data were subjected to ANOVA and significant means were separated ($p < 0.05$). Applying CPH reduced plant height, number of leaves, dry shoot biomass, root yield, and harvest index in radish. Increasing CPH application led to a further reduction in these parameters. Urea fertiliser application enhanced the observed parameters with the highest values at 45 kg N/ha. Sole urea application at 45 kg N/ha had a significantly higher root yield than other treatments at first cropping. However, the root yield (93.50 g/plant) was similar to CPH at 30 kg N/ha × urea at 30 kg N/ha (67.50 g/plant) and CPH at 30 kg N/ha × urea at 45 kg N/ha (75.75 g/plant) during the second cropping. Therefore, CPH at 30 kg N/ha × urea at 30 kg N/ha was suggested for radish production.

Keywords: cocoa pod husk, urea, fertiliser integration, sustainable production, root yield

Abbreviations
ANOVA- analysis of variance
C_0- Cocoa pod husk powder at kg of N/ha
C_{30}- Cocoa pod husk powder at 30 kg of N/ha
C_{60}- Cocoa pod husk powder at 60 kg of N/ha
CPH- cocoa pod husk
HI- Harvest index
U_0- Urea fertiliser at 0 kg of N/ha
U_{15}- Urea fertiliser at 60 kg of N/ha
U_{30}- Urea fertiliser at 30 kg of N/ha
U_{45}- Urea fertiliser at 60 kg of N/ha
USDA- United States Department of Agriculture

INTRODUCTION

Radish (*Raphanus sativus* L.) is an annual vegetable cultivated in tropical and temperate regions for its swollen taproots, which can be rounded, tapering, or cylindrical (CABI, 2022). The edible component of the plant includes the swollen hypocotyl and primary root. The juiciness of the root system is attributed to the absence of lignification in the vascular tissue and the presence of significantly thin-walled parenchyma. Depending on the cultivar, the enlarged roots are available in various sizes, shapes, and colours (Swaamy, 2023). The whole plant is edible, but the most commonly eaten part is the fleshy taproot, while the tops are also used as leafy vegetables (Kiran et al., 2016). Both fleshy roots and tender leaves are rich in proteins, minerals, and carbohydrates (Xu et al., 2023). It is a good source of Vitamin C (ascorbic acid) and minerals such as calcium, potassium, and phosphorus (Swaamy, 2023). It has refreshing and diuretic properties. In homoeopathy, it is used for neurological issues, headaches, insomnia, and chronic diarrhoea. Radish roots can also be processed as dried or canned pickles (Manivannan et al., 2019).

The growth and yield of radishes greatly depend on soil and climatic conditions. Different varieties have varying soil and climatic requirements for their optimal performance. Among the agro-techniques, plant nutrition is one of the main factors that affect radish growth and yield. The nutritional requirements of crops vary depending on the variety, agro-climatic conditions, soil type, and soil fertility (Bakhsh et al., 2006). As a short-duration and fast-growing crop, the root growth should be rapid and uninterrupted. Hence, for producing good quality radishes, optimal fertiliser application through organic, inorganic, and bio-fertiliser is essential (Kushwah et al., 2020). The consistent reports of using inorganic fertiliser in producing root or leafy vegetables have not been encouraging. The perverse effects of inorganic fertilisers include soil degradation and low-quality produce (Krasilnikov et al., 2022). The limited amount of nutrients from organic sources has necessitated supplementation with other means to meet crop needs within the limited time of growth. Consequently, combined inorganic and organic fertilisers increase crop yield and improve quality (Titirmare et al., 2023). Therefore, farm residues are encouraged as a soil management strategy to reduce the wastage of limited available resources in the field.

After the cocoa harvest, the beans are extracted from the pods. The husks are often left to rot on the field. Unfortunately, the continued deposition of husk on the field constitutes future problems for the cocoa farm as they become potential host to cocoa black pod disease that could ravage the farm. Despite containing potassium and other nutrients, these husks are not adequately recycled (Hougni et al., 2021). Hartemink (2005) reported that for every 1000 kg of cocoa beans harvested, about 10.6-31.4 and 27.2-77.2 kg/ha of N and K, respectively, are contained in the husks. The significance of cocoa pod husk (CPH) as a fertiliser, both independently and in conjunction with other inorganic fertilisers, for enhancing crop performance and achieving high yields have been documented (Hougni et al., 2021; Osei et al., 2023; Adeleye et al., 2023). However, information on the response of radish to CPH fertiliser is limited. Cocoa pod husk in powdery form as fertiliser could serve as a promising source of plant nutrition for promoting rapid growth, high yield, and good quality. Selecting the optimal application of CPH powder with urea fertiliser is crucial to maintaining or enhancing radish production. This initiative would increase radish production, helping farmers generate more income to support their households. Therefore, this study aimed to investigate the effect of CPH, urea, and their combinations on the growth and yield of radish.

MATERIALS AND METHODS

Experimental site. The experiment was conducted from April to August 2023 in the screenhouse at the Department of Agronomy, University of Ibadan in Ibadan, Oyo State, Nigeria. The experimental field was at 7° 27’ 6” North latitude and 3° 53’ 46” East longitude with an altitude of 210 metres above sea level.

Experimental design and treatment. The experiment was a 3 × 4 factorial experiment involving CPH powder at 0 (C_0), 30 (C_{30}) and 60 (C_{60}) kg N/ha and urea at 0 (U_0), 15 (U_{15}), 30 (U_{30}) and 45 (U_{60}) kg N/ha. The treatment interactions were; control (C_0×U_0), 0 kg of CPH × urea at 15 kg N/ha (C_0×U_{15}), 0 kg of CPH × urea at 30 kg N/ha (C_0×U_{30}), 0 kg of CPH × 45 urea (C_0×U_{45}), CPH at 30 kg N/ha × urea at 0 kg N/ha (C_{30}×U_0), CPH at 30 kg N/ha × urea at 15 kg N/ha (C_{30}×U_{15}), CPH at 30 kg N/ha × urea at 30 kg N/ha (C_{30}×U_{30}), CPH at 30 kg N/ha × urea at 45 kg N/ha (C_{30}×U_{45}), CPH at 60 kg N/ha × urea at 0 kg N/ha (C_{60}×U_0), CPH at 60 kg N/ha × urea at 15 kg N/ha (C_{60}×U_{15}) CPH at 60 kg N/ha × urea at 30 kg N/ha (C_{60}×U_{30}), CPH at 60 kg N/ha × urea at 45 kg N/ha (C_{60}×U_{45}). The experiment was conducted in a randomised complete block design with six replicates.

The total N concentrations in the fertiliser expressed in kg/ha were used to calculate the levels of N application based on the weight of the pot (5/2,000,000 ha). All the treatments were incorporated into the 5 kg of soil each. The polythene bags were labelled according to the type and rate of application to be added to the soil. The labelled polythene bags consisted of 12 treatments replicated six times. The levels of CPH and urea fertilisers to be applied varied from each other to achieve satisfactory results. The treatments were measured using a sensitive electronic scale (Camry, model EK5500, manufactured in China) to ensure the appropriate amount of fertiliser was added to the soil. Cocoa pod husk was added to the soil two weeks before sowing in all the designated pots for CPH treatments. Two weeks after planting, urea was applied 5 cm away from the radish plants in the experimental pots. The pots were randomly arranged on iron benches in the screenhouse. The pots were spaced 25 cm apart before sowing the seeds.

Materials and soil sample analysis. The materials used were seeds collected from the National Horticultural Research Institute (NIHORT), CPH powder collected from the Department of Agronomy at the University of Ibadan, and urea sourced from an agricultural enterprise in Bodija, Ibadan. The perforated black polythene bags were from the Department of Agronomy's store.

Soil samples were collected from the experimental field of the Department of Agronomy at the University of Ibadan, Nigeria, and analysed for chemical and physical properties. The soil sample was air-dried, crushed, and sieved with a 2 mm mesh before analysis. Soil pH was measured using a glass electrode pH metre, while soil organic carbon was estimated using the dichromate wet oxidation method described by Walkley and Black (1934). Total N and available P were determined using the macro-kjeldhal and Bray P-1 methods, respectively (Bray and Kurtz, 1945). The K, Na, Ca and Mg were determined using a flame photometer (Sherwood Classic Model 410) (Page, 1982). Particle size fractions were determined using the hydrometer method (Bouyoucous, 1951). The properties of the soil used in the study are presented in Table 1.

Table 1. Physiochemical properties of the experimental soil used for the study

Parameters	Values
Physical properties (g/kg)	
Sand	808
Silt	130

Clay	62
Textural classification (USDA)	Loamy sand
Chemical properties	
pH (H_2O)	7.09
Organic C (g/kg)	30.08
Total N (g/kg)	3.30
Available P (mg/kg)	16.10
Exchangeable bases (cmol/kg)	
K	0.36
Mg	0.83
Na	0.29
Ca	2.71
Exchangeable acidity	0.40
Extractable micronutrients (mg/kg)	
Mn	76.00
Fe	92.00
Cu	1.35
Zn	1.86

Cocoa pod husk powder properties

The organic carbon of the cocoa husk powder was determined using the modified Walkley and Black method that involved dichromate wet oxidation as described by Singh and Praharaj (2017). Distillation and titration were employed in total nitrogen determination through micro-Kjeldahl digestion. Analysis of other nutrients such as phosphorus, potassium, calcium, and magnesium was done from the wet digestion method. Phosphorus was determined by the molybdate blue method in an auto-analyser in which the absorbance was read calorimetrically, potassium by flame photometry. Calcium, magnesium and other micronutrients were determined by atomic absorption spectrophotometer. The concentration of nutrients in the CPH used for this experiment indicated a moderately high C:N ratio (Table 2).

Table 2. The nutrient compositions of the cocoa pod husk powder used for the study

Parameters	Value	Unit
Organic C	14.804	%
Total N	0.841	%
C:N ratio	17.60	
Total P	0.143	%
Ca	0.531	%
Mg	0.227	%
K	2.058	%
Na	0.398	%
Mn	48.65	mg/kg
Fe	1467.25	mg/kg
Cu	11.00	mg/kg
Zn	64.55	mg/kg

Planting and maintenance. Soil for planting was collected from the experimental field of the Department of Crop and Horticultural Sciences. The polythene bags were filled with 5 kg of soil per pot for radish cultivation. Pots were carefully weighed using a top-loading spring dial balance (Camry, model N55) to measure the weight of the soil. The bags were perforated at the sides to allow for easy drainage of excess water upon watering; however, this was avoided to minimise the loss of nutrients from the soil. The bags were labelled according to the treatments for the experiment.

The radish seeds were sown at a rate of two seeds per pot, at a depth of 2 cm in each pot. The seeds for the first and second crops were sown on the 25th of April 2023 and the 18th of August 2023, respectively. Thinning the plants in each pot to one was conducted after one week of planting to minimise competition for space, light, nutrients, and water. The most vigorous plant stands were selected for the experiment. Watering the pots was done every evening until the experiment was concluded. Also, weeding was carried out promptly based on visual assessment to prevent noxious and unwanted plants from competing with radishes. Weeding was carefully done to reduce injury to the growing radish stems and leaves. Weeds were hand-picked manually, and no chemical weed control method was employed.

Data collection

At harvest, plant height was measured from the base of the plant using a flexible metre ruler, while the number of leaves per plant was counted through visual observation. The total fresh biomass weight of radishes was determined at harvest using an electronic scale (Qun Ze High Precision Portable scale). The radish shoot was separated from the root to determine the dry shoot biomass, and the root yield was measured per treatment to assess the yield. A flexible metre ruler and Vernier caliper were used in measuring the length of the roots and their diameters, respectively. The harvest index (HI) was determined as the ratio of harvestable biomass to the total biomass.

Statistical analysis

Data on growth, yield, and yield components were subjected to analysis of variance (ANOVA) using GenStat version 8.1 software. The significantly different means were separated using Duncan's Multiple Range Test at the 0.05 significance level.

RESULTS AND DISCUSSION

Soil and CPH powder properties

Crop response to soil amendments varies depending on the primary inherent limitation to good crop performance. The high sand content of the soil indicated either a highly weathered condition or under intensive cultivation with low organic matter content and limited ability to adsorb soil nutrients. Consequently, improving soil conditions through organic means will likely increase crop performance. Cocoa pod husk has improved soil conditions for enhanced crop yield (Hougni et al., 2021; Osei et al., 2023; Adeleye et al., 2023). The chemical properties showed low nutrient status that could adequately support good radish growth and development, thus requiring an amendment with adequate N and K nutrients. Therefore, for sustainable radish production, the amendment should meet the nutrient demand of the radish. Aside from the nutrient composition in the CPH, the C:N ratio was moderate but relatively above the recommended ratio expected of 10:1 for dynamic equilibrium conditions that facilitate good soil health for crop production. The CPH is likely to support more bacteria than fungal populations.

Effects of CPH and urea fertiliser on the height of radish at harvest

Cocoa pod husk powder application on plant height at harvest was significantly higher at 30 kg N/ha than 60 kg N/ha but was comparable to the control in the first cropping (Table 3). In the second cropping, the effect of CPH on radish height was not appreciable among the treatments. The response of radish to urea fertiliser application was not significant for plant height, however, the tallest plants were observed under urea at 15 kg N/ha during both cropping. The interactions of CPH and urea fertiliser applications significantly increased radish height by $C_{30}\times U_{15}$ than the control and $C_{60}\times U_{30}$, while the other treatments were similar in the first cropping. The variations among treatments in the second cropping were not significant. However, the height of the radish ranged from 31.00 (control and $C_{60}\times U_{30}$) to 34.50 cm ($C_0\times U_{30}$).

Height in crops is an essential morphological component in assessing growth over time (Hilty et al., 2021). The height of plants also reflects the capacity to capture light and a strategy to utilise C (Quan et al., 2024). The increase in the height of radish at harvest by CPH application at 30 kg N/ha indicated better crop nutrition than the control. Nutrient availability through CPH application helped to improve the soil's physical condition and the supply of soil-limited nutrients (Kekong, 2023). This study affirmed the report of Komariah et al. (2021) that organic fertiliser application increased rice height. However, raising CPH application to 60 kg N/ha resulted in a decrease in radish height. This may imply that the applied level is excessive for ameliorating the soil condition for improved crop growth. The negative response of crops to higher levels of organic fertiliser application has also been reported (Wang, 2024). The reason could be due to unfavourable soil conditions that hamper the ability of the plant root to acquire nutrients under very high N levels.

The difference in radish height due to urea fertiliser application was not substantial among treatments. However, the increase in height could be due to the improvement in N required for development. Urea supplies mainly N, which is required for cell multiplication, expansion and elongation (Hilty et al., 2021). Sileshi et al. (2022) also reported limited response to urea fertiliser. This response also indicated that the level of urea application beyond 15 kg N/ha did not correspond to an increase in plant height.

Effects of fertiliser on radish number of leaves at harvest

The number of leaves per plant significantly increased in plants treated with CPH at 30 kg N/ha compared to CPH at 60 kg N/ha in the first cropping (Table 3). However, the effect of CPH application was not significant in the second cropping but the variation between the treatments was not significant in the second cropping. Urea treatments at 15, 30 and 45 kg N/ha significantly increased the radish number of leaves compared to the control in both cropping. The $C_0\times U_{30}$ and $C_{30}\times U_{30}$ treated plants were similar in the number of leaves/plant at harvest but varied significantly from the other treatments, except $C_0\times U_{15}$, $C_0\times U_{45}$, $C_{30}\times U_{15}$ and $C_{60}\times U_{45}$ in the first cropping. The interactions of CPH with urea fertiliser significantly affected the radish number of leaves at harvest at varying levels in the second cropping. The highest and lowest values of 20.75 and 15.25 were observed in the CPH at 30 with urea at 30 kg N/ha and the control, respectively.

The leaves of plants are the photosynthetic apparatus to capture infrared light rays for photosynthesis activity (Kochetova et al., 2022). These enable the plant to accumulate the required energy for growth. The increase in the number of leaves through CPH application compared to the control affirms the contribution of CPH in leaf initiation through the P contained in the powder. The improvement in P nutrition in crops reportedly enhances the number of leaves (Tekeste et al., 2018). The CPH applied at 30 kg N/ha improved the number of leaves in radish. The higher number of leaves observed with CPH application at 30 kg N/ha indicated the optimum level required for improved leaf production. However, the higher application level did not translate to a further increase in number of leaves.

All levels of urea application significantly enhanced the number of leaves observed at harvest. These signify the importance of the early release of N and the spontaneous response from radish. Under soil N enrichment, the responses of crops are generally drastic when soil N is a major limiting factor (Pasley et al., 2019). The availability of N is essential for cell differentiation in plants (Ariraman et al., 2020). Consequently, the increase in urea application resulted in the enhancement of the number of leaves in the study. However, the highest level of urea application (45 kg N/ha) had fewer leaves than the 30 kg N/ha. This indicated a limit to the application of urea to improve the number of leaves in radish.

The higher plant height observed from the interactions of CPH at 30 kg N/ha and urea at 15 kg N/ha during the two cropping substantiated the importance of combining organic and inorganic fertiliser to improve plant height. Idowu-Agida and Olaniyi (2019) also reported that CPH and urea fertiliser combinations increased amaranthus height. Integrating fertiliser improved the soil's physical and chemical parameters, thus enhancing radish nutrition. The improvement in the plant environment increased the crop nutrient use efficiency. Consequently, this results in an increase in plant height.

Inorganic and organic fertiliser combinations indicated that the sole application of urea ($C_0 \times U_{30}$) was comparable to $C_{30} \times U_{30}$ for leaves/plant observed. Also, across the levels of CPH application, the highest increase in the number of leaves in radish was observed by applying urea at 30 and 45 kg N/ha for the 30 and 60 kg N/ha of CPH, the enrichment of soil with CPH and urea integration did par the best result from sole urea application in both cropping.

The influences of fertiliser on fresh shoot biomass at harvest

Significantly higher fresh shoot biomass was observed in the control and CPH at kg N/ha compared to the CPH at 60 kg N/ha treatments during the first and second cropping (Table 3). However, the control had the highest values during both cropping. Increasing the levels of urea application increased radish fresh shoot biomass, with significantly higher fresh shoot biomass observed at 60 kg N/ha compared to the control and 15 kg N/ha treated plants in both cropping. Even though the plants treated with 30 and 45 kg N/ha were similar, urea application at 45 kg N/ha treatment had 9.51 and 3.53% higher fresh shoot biomass than 30 kg N/ha during the first and second cropping, respectively. The $C_0 \times U_{45}$ treated plants had significantly higher fresh shoot biomass than the other treatments but were comparable to $C_{30} \times U_{30}$ and $C_0 \times U_{30}$ treatments.

Biomass production in crops is generally affected by environmental situations, which involve the nutrient status and physical condition of the soil and the ability of the crop to convert photosynthates to assimilate. Organic materials are a good source of improving the soil's water-holding capacity and allowing nutrients to be available to plants (Shah et al., 2023). Fresh shoot biomass is also affected by the moisture content in the plant at the time of measurement. The fresh biomass of a crop is appreciated in fruits and vegetables, as bigger fruits tend to command higher prices in the market (Kiran et al., 2016). The applied CPH can increase the soil organic carbon content, despite its relatively moderate C:N ratio and promote macro and micronutrients in the soil. However, the highest fresh biomass was observed in the control rather than the CPH-treated plants during both cropping. The CPH at 30 kg N/ha also outperformed the 60 kg N/ha. This indicates that the increase in CPH application further limits the performance of radish. Thus, higher CPH introduction delimited nutrient availability by microbial activities that locked up nutrients in their tissues. Therefore, the plant's roots were limited in acquiring the applied nutrients for biomass accumulation within the time of the study. The nutrient release pattern of CPH may not synchronise with the crop's nutrient requirements.

Soil nutrient enrichment through urea application at 60 kg N/ha resulted in a significant increase in fresh biomass accumulation at harvest compared to the control and urea at 15 kg N/ha. The responses of crops to urea application are related to promoting plant height, number of leaves and water use efficiency (Ariraman et al., 2020). The level of application that resulted in an appreciable difference among the treatments was 45 kg N/ha.

The integration of CPH and urea fertiliser application showed that the highest fresh biomass accumulation was observed when applying $C_0 \times U_{45}$. Even though the level was at par with $C_{30} \times U_{30}$, the magnitude of the difference was appreciable. Consequently, N substitution in CPH through urea application was not better than sole urea application in both cropping. The increased urea application at 30 kg N/ha of CPH further reduced fresh shoot biomass, indicating poor nutrient use efficiency.

Dry shoot biomass of radish as affected by CPH and urea fertiliser applications

Response of radish to CPH application was significantly higher under the control and CPH at 30 kg N/ha compared to the CPH at 60 kg N/ha treatments for dry shoot biomass (Table 3). The plants under the control also had significantly higher dry shoot biomass than CPH at 60 kg N/ha. However, the control had 2.08 and 4.17% higher values than CPH at 30 kg N/ha treatment in the first and second cropping, respectively. Dry shoot biomass significantly increased with urea application during both cropping. The highest dry shoot biomass in the first and second cropping were observed when applying urea at 45 and 30 kg N/ha, respectively. The $C_0 \times U_{30}$ and $C_0 \times U_{45}$ treated plants had significantly higher dry shoot biomass than the plants under the other treatments, except $C_0 \times U_{30}$. Comparatively, the interactions involving CPH at 30 kg N/ha had higher values than the 60 kg N/ha interactions. The highest values for dry biomass for CPH combination with urea fertiliser were observed under $C_{30} \times U_{30}$ and $C_{30} \times U_{15}$ for first and second cropping, respectively.

Dry shoot biomass indicates the ability of the crops to mobilise the photosynthate for biomass production (Lima et al., 2017). The dry biomass of radish accumulated at harvest is associated with the cumulative processes concerning the plant's ability to balance carbohydrates assimilated through photosynthesis and the losses of the photosynthate by respiration and leaf shedding (Hilty et al., 2020). The significantly lower dry biomass acquisition within the growth period in plants treated with CPH at 60 kg N/ha compared to CPH at 30 kg N/ha and control indicated the treatment did not encourage nutrient uptake by the rooting system. Consequently, the plants treated with CPH at 60 kg N/ha had limited assimilated carbohydrates for biomass accumulation. These results were corroborated by the responses observed from the plant height and number of leaves at harvest.

Urea application at 30 during the first cropping and 45 kg N/ha during the second cropping significantly enhances dry biomass accumulation at harvest. Since N is the nutrient supplied by urea fertiliser, its application must have increased the N uptake in the plant, consequently promoting the interception of available radiance for photosynthetic activities (Lima et al., 2017). Promoting photosynthesis encourages the plant root system to acquire more nutrients, favouring the balance between assimilate acquisition and catabolism. Subsequently, this action facilitates dry biomass accumulation in the plant.

Cocoa pod husk and urea fertiliser interaction were not comparable, with the sole urea applications at 15 and 30 kg N/ha during the two cropping. The effect could be due to the forced response of radish after urea application. This tended to trigger quick physiological activities in the plant that enhance photosynthesis and the subsequent accumulation of assimilates rather than assimilate breakdown (Pasley et al., 2019). The forced response from the urea application outperformed the CPH treatment in which nutrients were initially locked up by soil microbes before release.

Influence of fertiliser application on the root yield of radish at harvest

Radish root weight is significantly higher in plants treated with CPH at 30 kg N/ha and the control compared to the plants under CPH at 60 kg N/ha (Table 4). The plants under the control had 19.35% higher root yield than the CPH at 30 kg N/ha. During the second cropping, root yields differed significantly among the treatments with the lowest observed under CPH application at 60 kg N/ha, while the highest root yield was under the control. The root yield under urea application at 45 kg N/ha was significantly higher than the control and urea application at 15 kg N/ha during the first cropping. The variation in the second cropping was compared to the control treatment. However, the urea at 30 kg N/ha had 17.05 and 7.66% lower root yield than the urea at 45 kg N/ha during the first and second cropping, respectively. The $C_0 \times U_{45}$ treatment had a significantly higher root yield than the other treatments during the first cropping. However, the $C_{30} \times U_{45}$ treatment had the highest value among the CPH and urea interactions. The trend was similar during the second cropping, but $C_{30} \times U_{30}$ and $C_{30} \times U_{45}$ were comparable to $C_0 \times U_{45}$ for root yield.

Crop yield is determined by the entire spectrum of attributes like the plant height, number of leaves and biomass accumulation throughout the growing period (Bakhsh et al., 2006). The yield of radish under the control treatment was higher than the CPH applications. In the absence of unknown limitations in sink capacity, this suggests that the applied CPH did not promote the accumulation of photosynthate in the taproot, thus failing to maintain the balance between assimilate accumulation and metabolism. Despite the expected contribution of CPH as an organic fertiliser in improving soil conditions for increased crop yield, the observed yield was comparatively lower than the control.

Table 3. Effect of cocoa pod husk, urea and their interactions fresh biomass and dry biomass at harvest

	Plant height (cm)		Number of leaves		Fresh shoot biomass (g/plant)		Dry shoot biomass (g/plant)	
	1st cropping	2nd cropping	1st cropping	2nd cropping	1st cropping	2nd cropping	1st cropping	2nd cropping
CPH								
0	32.17ab	32.81	18.67ab	18.13	113.13a	121.13a	5.90a	6.00a
30	33.25a	33.75	19.08a	18.81	101.38a	107.38a	5.78a	5.76a
60	31.29b	31.88	17.29b	18.00	75.46b	79.25b	4.35b	4.34b
SE	0.55	0.66	0.57	0.47	5.60	6.31	0.09	0.12
Urea								
0	32.06	32.33	16.06b	16.08b	75.50c	83.17c	4.93b	4.92b
15	32.61	33.67	18.61a	18.33a	93.00bc	95.67bc	5.38a	5.46a
30	32.28	33.00	19.94a	19.75a	103.61ab	113.67ab	5.51a	5.59a
45	32.00	32.25	18.78a	19.08a	114.50a	117.83a	5.56a	5.51a
SE	0.63	0.76	0.66	0.54	6.47	7.29	0.11	0.14
Interactions								

$C_0 \times U_0$	31.17b	31.00	15.33c	15.25e	85.33b-e	96.50b-f	4.28cd	4.30c
$C_0 \times U_{15}$	32.00ab	33.75	19.00ab	17.50b-e	106.83bc	114.50a-e	6.20ab	6.23ab
$C_0 \times U_{30}$	33.50ab	34.50	21.50a	20.25a	116.50ab	131.75ab	6.53a	6.78a
$C_0 \times U_{45}$	32.00ab	32.00	18.83ab	19.50ab	143.83a	141.75a	6.60a	6.70a
$C_{30} \times U_0$	33.50ab	34.25	17.33bc	16.75c-r	82.17c-e	91.50c-f	5.68b	5.68b
$C_{30} \times U_{15}$	34.33a	34.25	19.33ab	19.00a-c	102.00bc	91.50c-f	5.83b	5.95b
$C_{30} \times U_{30}$	32.67ab	33.50	21.50a	20.75a	114.83ab	122.50a-d	5.85b	5.80b
$C_{30} \times U_{45}$	32.50ab	33.00	18.17bc	18.75a-d	106.50bc	124.00a-c	5.75b	5.63b
$C_{60} \times U_0$	31.50ab	31.75	15.50c	16.25de	59.00e	61.50f	4.82c	4.78c
$C_{60} \times U_{15}$	31.50ab	33.00	17.50bc	18.50a-d	70.17de	81.00ef	4.10d	4.20c
$C_{60} \times U_{30}$	30.67b	31.00	16.83bc	18.25a-d	79.50c-e	86.75d-f	4.15d	4.20c
$C_{60} \times U_{45}$	31.50ab	31.75	19.33ab	19.00a-c	93.17b-d	87.75c-f	4.32cd	4.20c
SE	1.10	1.33	1.05	0.94	11.21	12.62	0.19	0.25

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

The high amount of Fe in the CPH could be responsible for the poor root yield. However, the judicious application of Fe promotes chlorophyll synthesis and increases photosynthesis when supplied in high quantity leading to catalysation of oxidative stress causing low yield (Ahmed et al., 2023). This condition increases polyphenol oxidase activity, causing a reduction in root oxidation power and limited root development (Ning et al., 2023). The lower root yield observed under CPH at 60 kg N/ha compared to CPH at 30 kg N/ha substantiated that the introduction of CPH into the soil could have disrupted the balance in the ecosystem. The disruption was further heightened with the increase in the level of CPH application, thereby reducing the ability to support radish production.The increase in urea application improved the deposition of acquired carbohydrates in the root of the radish with significant variation observed from the control by applying urea at 45 kg N/ha. The impact of urea on the growth parameters must have influenced the magnitude of the differences in assimilate deposition in radish. This corroborates Fathi (2022) report that the increase in N application further improves chlorophyll content in the leaves, and enhances chloroplast activity. Consequently, the photosynthetic productivity of the plant is increased, resulting in higher yield.

The observed root yield was significantly higher under the urea at 45 kg N/ha treatment compared to the other treatments, except plants treated with CPH at 30 kg N/ha x urea at 30 kg N/ha and CPH at 30 kg N/ha x urea at 45 kg N/ha during the second cropping. The higher response to urea application may be due to the quick supply of N that facilitated an early increase in plant height, and number of leaves (Ghimire et al., 2023). The increase in growth parameters enhances shoot biomass accumulation improving metabolite accruement and better yield. However, in the CPH treatments, the increase in soil carbon content must have enhanced soil microbial activities and temporary nutrient fixation that could have been made available to the crop. The C:N ratio was above 10:1 recommended for a stable level during which there is a spontaneous release of nutrients after the breakdown of carbon in organic material and the release of N and other nutrients for crop uptake (USDA, 2022). These processes prolong the availability of resources for an early increase in photosynthetic processes that encourage carbohydrate accumulation and increase crop yield. However, the C_{30}×U_{30} and C_{30}×U_{45} treatments had relatively comparable yields.

Table 4. Effect of cocoa pod husk, urea and their interactions with fresh biomass, dry biomass and fruit diameter at harvest

	Root yield (g/plant)		Harvest index	
	1st cropping	2nd cropping	1st cropping	2nd cropping
CPH				
0	67.17a	78.44a	0.59a	0.64a
30	54.17a	59.19b	0.53ab	0.53b
60	37.08b	37.75c	0.49b	0.44b

SE	5.16	5.80	0.03	0.03
Urea				
0	40.00b	47.75b	0.53	0.54
15	49.17b	52.08ab	0.53	0.51
30	55.33ab	64.33ab	0.53	0.55
45	66.72a	69.67a	0.58	0.55
SE	5.96	6.78	0.04	0.03
Interactions				
$C_0 \times U_0$	48.67b-d	61.75a-e	0.57ab	0.64a
$C_0 \times U_{15}$	62.67b	77.75a-c	0.59ab	0.67a
$C_0 \times U_{30}$	63.67b	80.75ab	0.55ab	0.61ab
$C_0 \times U_{45}$	93.67a	93.50a	0.65a	0.66a
$C_{30} \times U_0$	42.00b-d	52.00b-e	0.51ab	0.55a-d
$C_{30} \times U_{15}$	54.00b-d	41.50de	0.53ab	0.42cd
$C_{30} \times U_{30}$	59.17bc	67.50a-d	0.52ab	0.55a-d
$C_{30} \times U_{45}$	61.50b	75.75a-c	0.58ab	0.60a-c
$C_{60} \times U_0$	29.33d	29.50e	0.50ab	0.45b-d
$C_{60} \times U_{15}$	30.83cd	37.00de	0.44b	0.44b-d
$C_{60} \times U_{30}$	43.17b-d	44.75c-e	0.54ab	0.49a-d
$C_{60} \times U_{45}$	45.00b-d	39.75de	0.48b	0.39d
SE	10.32	11.74	0.06	0.06

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

The harvest index of radish as affected by fertiliser applications

The plants under the control treatment had a significantly higher harvest index than CPH at 60 kg N/ha during the first cropping (Table 4). The plants under the control treatment differ considerably from the CPH applications at 30 and 60 kg N/ha during the second cropping, the variation in HI for plants under urea application was not significant during both cropping. However, the plants treated with urea at 45 kg N/ha had 8.62% higher HI than the other treatments during the first cropping. During the second cropping, the HI for urea at 30 and 45 kg N/ha were the same but had 1.82 and 7.27% higher HI than the control and urea at 15 kg N/ha, respectively. During the first cropping, HI for CPH and urea interactions ranged from 0.44 (C_{60}×U_{15}) to 0.65 (C_0×U_{45}). However, the highest HI involving CPH and urea application was observed at C_{30}×U_{45}. Variations in HI among treatments were significant for CPH and urea fertiliser interaction during second cropping. The highest and lowest HI in radish were observed under C_0×U_{15} and C_{60}×U_{45}, respectively. However, the HI for C_{30}×U_{45} was the highest among CPH and urea fertiliser applications.

The HI indicates the partitioning of the assimilated photosynthate in crops. It reveals that competition exists for available assimilates for structural growth (biological yield) and storage (economic yield) (Hilty et al., 2021). The lower HI observed for CPH in the two cropping ascertained poor nutrient release possibly caused by nutrient immobilisation through soil microbial activities. Adding CPH increases the soil's organic carbon which promotes microbial growth, leading to the negative response observed in radish. Therefore, the higher level of CPH application resulted in poorer HI. Therefore, the higher the CPH application the lesser the ability and physiological efficiency of radish to convert total dry matter into economic yield. The lower HI observed from the CPH application (despite the high K in the material) suggests impeded metabolite accumulation.

The partitioning of assimilate under urea application was insignificant in the two cropping. This implied that improvement in N nutrition did not affect the partitioning of assimilate in the study. Therefore, urea application had no significant impact on improving the conversion of total dry matter into economic yield in radish. A similar HI in the fertiliser levels could imply no remobilisation of metabolites in radish.

The highest HI measured under sole urea application was at par with C30×U45. The C30×U30 was similar to C30×U45 for HI. This corroborated the improvements in the growth parameters and yield observed. Lower HI was observed for the interactions of CPH at 60 kg N/ha, while the interactions of CPH at 0 and 30 kg N/ha with urea fertiliser were similar. They further establish the reduced effect of higher CPH application on radish performance. The interaction reduced the diversion of acquired assimilates into economic yield.

CONCLUSION

The results of this study revealed that applying cocoa pod husk powder reduced plant height, number of leaves, fresh and dry shoot biomass, fruit yield and harvest index in radish. The increase in CPH application from 30 kg N/ha to 60 kg N/ha leads to a further reduction in the parameters observed. The response of radish to urea fertiliser application increased with the increase in the level of urea application for the observed parameters. The interactions of CPH and urea fertiliser applications indicated that sole urea resulted in the highest values for the various parameters. However, the response by interacting CPH at 30 kg N/ha × urea at 30 kg N/ha and CPH at 30 kg N/ha × urea at 45 kg N/ha were comparable to the urea at 45 kg N/ha treatment for the growth and yield attributes considered. Therefore, considering the impact of sole urea application on soil health and crop yield quality, CPH at 30 kg N/ha × urea at 30 kg N/ha was suggested for radish production.

REFERENCES

1. Adeleye AA, Shittu OS, Ilori AOA, Adeleye EO. Evaluation of soil chemical properties and carrot performance as influenced by integrated application of poultry manure and cocoa pod husk in the rainforest agroecological zone of Nigeria. FUDMA Journal of Agriculture and Agricultural Technology 2023; 9(2):136-145 https://doi.org/10.33003/jaat.2023.0902.18
2. Ahmed N, Zhang B, Chachar Z, Li J, Xiao G, Wang Q, Hayat F, Deng L, Narejo M, Bozdar B, Tu P. Micronutrients and their effects on Horticultural crop quality, productivity and sustainability. Scientia Horticulturae 2023; 323:112512. https://doi.org/10.1016/j.scienta.2023.112512
3. Ariraman R, Prabhaharan J, Selvakumar S, Sowmya S, Mansingh MDI. Effect of nitrogen levels on growth parameters, yield parameters, yield, quality and economics of maize: A review. Journal of Pharmacognosy and Phytochemistry 2020; 9(6):1558-1563. https://doi.org/10.22271/phyto.2020.v9.i6w.13169
4. Bakhsh K, Ahmad B, Gill ZA, Hassan SA. Estimating indicators of higher yield in radish cultivation. International Journal of Agriculture and Biology 2006; 8(6):783-787. https://api.fspublishers.org/downloadPaper/16101_..pdf
5. Bouyoucous GH. A recalibration of the hydrometer method for making mechanical analysis of soils. Agronomy Journal 1951; 43:434-443. https://doi.org/10.2134/agronj1951.00021962004300090005x
6. Bray FRH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soils. Soil Science 1945; 59:39-45. http://dx.doi.org/10.1097/00010694-194501000-00006
7. CABI. cabicompendium.46796, CABI Compendium, CABI International, *Raphanus sativus* (radish), (2022) https://doi.org/10.1079/cabicompendium.46796
8. Fathi A. Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review. Agrisost 2022; 28:1-8. https://doi.org/10.5281/zenodo.7143588
9. Ghimire S, Poudel Chhetri B, Shrestha J. Efficacy of different organic and inorganic nutrient sources on the growth and yield of bitter gourd (*Momordica charantia* L.). Heliyon 2023; 9(11):e22135. https://doi.org/10.1016/j.heliyon.2023.e22135
10. Hartemink AE. Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystems: a review. Adv Agron 2005; 86:227-253. https://doi.org/10.1016/s0065-2113(05)86005-5
11. Hilty J, Muller B, Pantin F, Leuzinger S. Plant growth: the What, the How, and the Why. New Phytol 2021; 232:25-41. https://doi.org/10.1111/nph.17610
12. Hougni DG, Schut AGT, Woittiez LS, Vanlauwe B, Giller KE. How nutrient rich are decaying cocoa pod husks? The kinetics of nutrient leaching. Plant Soil 2021; 463:155-170. https://doi.org/10.1007/s11104-021-04885-1
13. Idowu-Agida OO, Olaniyi JO. Effects of nitrogen sources on vegetative growth of grain amaranth accessions in two Agro-Ecological Zones of Oyo State, Nigeria. Journal of Agricultural Studies 2019; 7(4):256-271. https://doi.org/10.5296/jas.v7i4.15588
14. Kekong MA. Integrated cocoa pod compost affect soil physical and chemical properties and yield of okra in a derived savanna of Obubra Nigeria. Nigerian Agricultural Journal 2023; 54(2):162-170. https://www.ajol.info/index.php/naj/article/view/267481 Accessed 20.10.24.
15. Kiran M, Jilani MS, Waseem K, Sohail M. Effect of organic manures and inorganic fertiliser on growth and yield of radish (*Raphanus sativus* L). Pakistan Journal of Agricultural Sciences 2016; 29(4):363-372. https://www.abrinternationaljournal.org/articles/effect-of-organic-and-inorganic-

manures-on-growth-yield-and-economic-return-of-radish-iraphanus-sativusi-l.pdf Accessed 20.10.24.
16. Kochetova GV, Avercheva OV, Bassarskaya EM, Zhigalova TV. Light quality as a driver of photosynthetic apparatus development. Biophysical Reviews 2022; 14(4):779-803. https://doi.org/10.1007/s12551-022-00985-z
17. Komariah UM, Sumani DPA, Setyawati A. Effects of high temperature and organic fertiliser on growth of several varieties of rice (*Oryza sativa* L) during the flowering stage. 6th International Conference on Climate Change 2021. Institute of Physics (IOP) Conference Series: Earth and Environmental Science. 2021; 824:012063 https://doi.org/10.1088/1755-1315/824/1/012063
18. Krasilnikov P, Taboada MA. Fertiliser Use, Soil Health and Agricultural Sustainability. Agriculture 2022; 12:462. https://doi.org/10.3390/agriculture12040462
19. Kushwah L, Sharma RK, Kushwah SS, Singh OP. Influence of organic manures and inorganic fertiliser on growth, yield and profitability of radish (*Raphanus sativus* L.). Annals of Plant and Soil Research 2020; 22(1):14-18. https://www.gkvsociety.com/control/uploads/4729243.pdf Accessed 20.10.24.
20. Lima MDF, Eloy NB, Siqueira JABD, Inzé D, Hemerly AS, Ferreira PCG. Molecular mechanisms of biomass increase in plants. Biotechnology Research and Innovation, 2017; 1(1):14-25. https://doi.org/10.1016/j.biori.2017.08.001
21. Manivannan A, Kim J-H, Kim D-S, Lee E-S, Lee H-E. Deciphering the nutraceutical potential of *Raphanus sativus*—a comprehensive overview. Nutrients 2019; 11:402. https://doi.org/10.3390/nu11020402
22. Osei I, Addo A, Kemausuor F. Optimal evaluation of crop residues for gasification in Ghana using integrated multi-criterial decision-making techniques. Heliyon (2023); *9*(10):e20553. https://doi.org/10.1016/j.heliyon.2023.e20553
23. Page AL. Methods of soil analysis: Part 2 Chemical and microbiological properties. Agronomy Monograph 9, second edition. American Society of Agronomy, Inc., Soil Science Society of America, Inc. 1982; 1159. https://doi.org/10.2134/agronmonogr9.2.2ed
24. Pasley HR, Cairns JE, Camberato JJ, Vyn TJ. Nitrogen fertiliser rate increases plant uptake and soil availability of essential nutrients in continuous maize production in Kenya and Zimbabwe. Nutr Cycl Agroecosyst 2019; 115:373-389. https://doi.org/10.1007/s10705-019-10016-1
25. Quan Q, He N, Zhang R, Wang J, Luo Y, Ma F, Pan J, Wang R, Liu C, Zhang J, Wang Y, Song B, Li Z, Zhou Q, Yu G. Plant height as an indicator for alpine carbon sequestration and ecosystem response to warming. nature plants 2024; 10:890-900. https://doi.org/10.1038/s41477-024-01705-z
26. Shah MN, Wright DL, Hussain S, Koutroubas SD, Seepaul R, George S, Ali S, Naveed M, Khan M, Tanveer Altaf M, Ghaffor K, Dawar K, Syed A, Eswaramoorthy R. Organic fertiliser sources improve the yield and quality attributes of maize (*Zea mays* L.) hybrids by improving soil properties and nutrient uptake under drought stress. Journal of King Saud University - Science, 2023; 35(4):102570. https://doi.org/10.1016/j.jksus.2023.102570
27. Sileshi GW, Kihara J, Tamene L, Vanlauwe B, Phiri E, Jama B. Unravelling causes of poor crop response to applied N and P fertiliser on African soils. Experimental Agriculture 2022; 58(e7):1-17. https://doi.org/10.1017/S0014479721000247
28. Singh U, Praharaj CS. Practical manual-chemical analysis of soil and plant samples, ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh- 208 024, India. 2017. pp. 58.
29. Swaamy KRM. Origin, distribution, genetic diversity and breeding of radish (*Raphanus sativus* L.), International Journal of Development Research 2023; 13(02):61657-61673. https://doi.org/10.37118/ijdr.26289.02.2023

30. Tekeste N, Dechassa N, Woldetsadik K, Dessalegne L, Takele A. Influence of nitrogen and phosphorus application on bulb yield and yield components of onion (*Allium cepa* L.). The Open Agriculture Journal 2018; 12:194-206. https://doi.org/10.2174/1874331501812010194
31. Titirmare NS, Ranshur NJ, Patil AH, Patil SR, Margal PB. Effect of inorganic fertiliser and organic manures on physical properties of soil: A review. International Journal of Plant and Soil Science 2023; 35(19):1015-1023. https://doi.org/10.9734/ijpss/2023/v35i19363
32. USDA. Carbon: Nitrogen ratio (C:N). Soil Tech Notes. Natural Resources Conservation Service. 23A. (2022). https://www.nrcs.usda.gov/sites/default/files/2022-09/SoilTechNote23A.pdf Accessed 20.10.24.
33. Wang M, Zhu T, Wang J, Wang H, Bai Q, Wang F, Zeng Q, Peng H. Effects of fertiliser application on the growth of *Stranvaesia davidiana* D. Seedlings. PeerJ 2024; 12:e16721 https://doi.org/10.7717/peerj.16721
34. Xu L, Wang Y, Dong J, Zhang W, Tang M, Zhang W, Wang K, Chen Y, Zhang X, He Q, Zhang X, Wang K, Wang L, Ma Y, Xia K, Liu L. A chromosome-level genome assembly of radish (*Raphanus sativus* L.) reveals insights into genome adaptation and differential bolting regulation. Plant Biotechnology Journal 2023; 21(5):990-1004. https://doi.org/10.1111/pbi.14011
35. Ning X, Lin M, Huang G, Mao J, Gao Z and Wang X (2023) Research progress on iron absorption, transport, and molecular regulation strategy in plants. Front. Plant Sci. 14:1190768. doi: https://doi.org/10.3389/fpls.2023.1190768