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Response of *Corchorus olitorius* L. to cocoa pod husk powder and urea fertilizer

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Respuesta de *Corchorus olitorius* L. al polvo de cáscara de mazorca de cacao y al fertilizante químico de nitrógeno

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ABSTRACT

Keywords:
Inorganic fertilizer
Jute mallow
Recycling waste
Sustainable production

Jute mallow is a crop with versatile applications in industries and as a food source. Low yield resulting from land degradation has necessitated the use of cocoa pod husk as a nutrient source, although it may require inorganic fertilizers to enhance its efficiency. The aim was to determine the effects of Cocoa Pod Husk Powder (CPHP) and urea fertilizer on Jute mallow performance. In a repeated 3x3 factorial pot experiment, CPHP [0 (C_0), 30 (C_{30}), and 60 (C_{60}) kg N ha^{-1}] and urea fertilizer [0 (U_0), 30 (U_{30}), and 60 (U_{60}) kg N ha^{-1}] were evaluated on Jute growth, fresh and dry biomasses using a randomized complete block design with five replicates. Applying CPHP increased the growth parameters but reduced fresh and dry biomass of Jute mallow in both plantings. The plants treated with U_{60} had significantly higher fresh biomass than the control during the first planting, but were similar in the second planting. The sole CPHP and urea treatments performed better for the parameters observed. However, $C_{30}U_{60}$ had similar fresh weights (11.14 and 11.40 g per plant) with C_0U_{60} (12.76 and 15.07 g per plant) during the first and second plantings, respectively. Jute mallow dry biomass ranged from 1.64 ($C_{60}U_{30}$) to 2.12 ($C_{30}U_{60}$) g per plant and differed significantly between C_0U_{30} (1.30 g per plant) and C_0U_{60} (3.00 g per plant) during the first and second plantings, respectively. Cocoa pod husk powder at 30 kg N combined with urea at 60 kg N ha^{-1} is recommended for improving crop and soil quality.

RESUMEN

Palabras clave:
Fertilizante inorgánico
Malva de yute
Reciclaje de residuos
Producción sostenible

El jute mallow es un cultivo con aplicaciones versátiles en industrias y como fuente de alimento. El bajo rendimiento resultante de la degradación del suelo ha hecho necesario el uso de cáscaras de mazorcas de cacao como fuente de nutrientes, aunque puede requerir fertilizantes inorgánicos para mejorar su eficiencia. Este estudio determinó los efectos del polvo de cáscara de mazorca de cacao (CPHP) y el fertilizante de urea en el rendimiento del jute mallow. En un experimento repetido en macetas con un diseño factorial 3x3, se evaluaron el CPHP [0 (C_0), 30 (C_{30}) y 60 (C_{60}) kg N ha^{-1}] y el fertilizante de urea [0 (U_0), 30 (U_{30}) y 60 (U_{60}) kg N ha^{-1}] sobre el crecimiento del jute, biomasa fresca y seca utilizando un diseño de bloques completamente al azar con cinco réplicas. La aplicación de CPHP aumentó los parámetros de crecimiento, pero redujo la biomasa fresca y seca del jute mallow en ambas siembras. Las plantas tratadas con U_{60} tuvieron una biomasa fresca significativamente más alta que el control durante la primera siembra, pero fueron similares en la segunda siembra. Los tratamientos de CPHP y urea por sí solos tuvieron un mejor rendimiento en los parámetros observados. Sin embargo, $C_{30}U_{60}$ tuvo pesos frescos similares (11.14 y 11.40 g por planta) con C_0U_{60} (12.76 y 15.07 g por planta) durante las primeras y segundas siembras, respectivamente. La biomasa seca de la malva de yute varió de 1.64 ($C_{60}U_{30}$) a 2.12 ($C_{30}U_{60}$) g por planta y diferenció significativamente entre C_0U_{30} (1.30 g por planta) y C_0U_{60} (3.00 g por planta) durante las primeras y segundas siembras, respectivamente. Se recomienda el polvo de cáscara de vaina de cacao a 30 kg N combinado con urea a 60 kg N ha^{-1} para mejorar la calidad del cultivo y del suelo.

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Corchorus olitorius (L) called Jute mallow, is the most versatile natural herb of the family Malvaceae valued for its eco-friendly fiber in textile, packaging, and agriculture (Vaishnavi and Krishnaveni 2022). It is a biodegradable, low-carbon, and renewable source that offers a natural alternative to synthetic fiber (Maiti et al. 2022). The leaves and young stems can be consumed by boiling or added to soup (Rumanuzzaman et al. 2024). Economically, Jute mallow provides livelihood opportunities for millions of farmers in developing countries through cultivation, processing, and manufacturing, consequently, boosting export earnings and employment generation (Shahinur et al. 2022). Jute cultivation also enhances soil health by enriching organic matter in the soil, suppressing weed growth, and reducing pest and disease occurrence in subsequent crops through natural rotation (Shahinur et al. 2022).

Jute cultivation requires nitrogen, phosphorus, and potassium for optimal growth and yield. Nitrogen is essential for vegetative growth, phosphorus promotes root development, and potassium enhances plant vigor and disease resistance (Govindasamy et al. 2023). In addition, Jute also requires micronutrients, all of which are often deficient in tropical soils (Rumanuzzaman et al. 2024). Consequently, maintaining proper soil fertility status is crucial for sustainable Jute cultivation. Nutrient deficiencies can negatively affect Jute growth and yield, especially in tropical soils that rapidly lose nutrient status and are devoid of soil organic matter due to high rates of weathering and intensive rainfall coupled with continuous cropping (Zhao and Riaz 2024). Thus, fertilizer application is crucial for successful Jute mallow cultivation.

Inorganic and organic fertilizers applied solely have significantly contributed to Jute mallow production (Sahoo et al. 2023). However, limited attention is given to inorganic fertilizers due to their effect on crop quality reduction and adverse impact on soil quality and the ecosystem (Zhao and Riaz 2024). Organic fertilizers, including animal manure, green manure, compost, and crop residues, contribute to nutrient cycling and improve soil organic carbon, which are critical for sustaining Jute mallow yield in tropical soils (Sahoo et al. 2023). They also help lower greenhouse gas emissions than synthetic fertilizers through carbon sequestration during production and application (He et al. 2023). Organic fertilizers release nutrients slowly over time as they undergo decomposition, reducing the risk of nutrient leaching and run-off (Anas et al. 2020). The slow-release nutrients, in alignment with the plant growth requirements, minimize nutrient wastage and improve nutrient use efficiency (Anas et al. 2020). Poultry manure and cow dung applications have the problem of transporting large quantities to the farm and are often not in sufficient quantity (Liu and Wang 2020). Therefore, the need for alternative sources for improving crop performance within the farmers fields.

The use of cocoa pod husk powder (CPHP) as an organic manure for vegetable production serves as a way of recycling farm waste and reducing the build-up of black pod disease in cocoa plantations (Fidelis and Rajashekhar Rao 2017). Cocoa pod husk (CPH) is a by-product obtained after extracting cocoa beans and consists of the outer shell of cocoa pods. Its nutrient composition can vary depending on cocoa variety, pod maturity, and processing methods. Generally, CPH contains significant amounts of organic matter, nitrogen, phosphorus, potassium, and other essential nutrients (Hougni et al. 2021). Cocoa pod husk is rich in organic matter, which contributes to improving soil structure, moisture retention, and nutrient-holding capacity. Its use as compost, biochar, ash, and powdery form for crop improvement are documented (Munongo et al. 2017; Doungous et al. 2018; Tamfuh et al. 2021; Kayode and Adeoye 2021). Like many other organic fertilizer sources, reports have shown that CPH is limited in the adequate quantity of N required for proper crop growth (Hougni et al. 2021).

Consequently, combining CPHP with urea demonstrates a renewed interest in integrating nutrient management strategies to increase crop production. Urea is the preferred and predominant source of N due to relatively higher nitrogen contents and low cost (Swify et al. 2024). Urea can be applied to increase crop yields, such as cereals, vegetables, and fruit trees (Anas et al. 2020). It can be applied as a top dressing, incorporated into the soil, or used in foliar sprays, providing flexibility in application methods (Swify et al. 2024). The excessive use of sole urea in crop production reportedly causes groundwater pollution and environmental hazards. However, the combination with organic sources of fertilizer limits negative effects on the environment (Swify et al. 2024). Its combination with organic fertilizers reduces the quantity needed to achieve the desired nitrogen supply, minimizing transportation, storage, and application costs (Gheith et al. 2022). Composted CPH and urea combination improves cocoa performance (Doungous et al. 2018). The integrated application enhanced nutrient uptake and improved soil fertility, ultimately contributing to increased yield. Nevertheless, empirical evidence remains scarce regarding the effects of CPHP, either individually or in conjunction with urea, on the growth, development, and yield performance of short-duration, high-value crops such as jute (*Corchorus olitorius* L.). Accordingly, the present study sought to elucidate the impacts of CPHP, urea, and their interaction on the growth dynamics of jute.

MATERIALS AND METHODS

Experimental site

The experiments for the first and second studies were carried out in the screenhouse between April to June and June to August 2023 for the first and second plantings, respectively, at the Department of Crop and Horticultural Sciences, University of Ibadan, Ibadan, Nigeria. The coordinates of the screenhouse are latitude 7°27′6″ N and longitude 3°53′46″ E.

Experimental design and treatments

Cocoa Pod Husk Powder (CPHP) at 0, 30, and 60 kg of N ha^{-1} and urea at 0, 30, and 60 kg of N ha^{-1} were evaluated in a 3×3 factorial experiment. The experimental design was a randomized complete block design and each treatment was replicated five times. Treatments include 0 CPHP × 0 urea (control), 0 CPHP × 30 urea, 0 CPHP × 60 urea, 30 CPHP × 0 urea, 30 CPHP × 30 urea, 30 CPHP × 60 urea, 60 CPHP × 0 urea, 60 CPHP × 30 urea, and 60 CPHP × 60 urea. The treatments were the same for the second planting. By implication, the CPHP was applied at 0, 7.13, and 14.27 g per pot of 4 kg soil, which were equivalent to 0, 3,567.18, and 7,134.36 kg ha^{-1}, respectively. The urea levels were applied at 0, 0.13, and 0.26 g per pot of 4 kg soil, which amounted to 0, 65.22, and 130.44 kg ha^{-1}.

Soil sample collection and analysis

Topsoil was collected from the Department of Crop and Horticultural Sciences research field, University of Ibadan, Ibadan, Nigeria. The collected soil was thoroughly mixed for homogeneity, sieved with a 2 mm mesh, and air-dried. A soil sample from the mixed treatment was analyzed at the Soil Service Laboratory, Department of Soil Resources Management, University of Ibadan, to determine its routine chemical and physical properties. Soil pH was measured using a glass electrode pH meter, while soil organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Poudel 2020). Macro-kjeldhal and Bray P-1 methods were used to determine the soil total N and available P contents, respectively (FAO 2021). The Ca and Mg were determined using the EDTA titration method (FAO 2020). Exchangeable K and Na were determined using an EEL flame photometer. The hydrometer method was used in determining the soil textural classification (Hossain et al. 2022).

Analysis of cocoa pod husk powder

The cocoa husk ash was analyzed for nutrient content. Total nitrogen was measured using the Micro-Kjeldahl method. The other nutrients were assessed using a wet digestion technique (AOAC 1990). After digestion, the same methods applied to soil were used to evaluate P, K, Ca, and Mg.

Material sources and collection

The materials used in the experiment included seeds obtained from the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. The CPHP was collected from the Department of Crop and Horticultural Sciences. Additionally, the urea used in the study was sourced from an agricultural enterprise in Bodija, Ibadan. The Department of Crop and Horticultural Sciences provided the black polyethylene bags of 45 pieces filled with 4 kg of soil, as a larger soil weight may offer more nutrients and obscure the true impact of experimental treatments. The polyethylene bags were labeled properly, based on the type and rate of treatment to be given to the soil sample for the experiment. There were nine treatments.

To ensure accurate measurement of all treatments, an electronic sensitive scale (Qun Ze High Precision Portable scale) was used. In the case of the CPHP treatments, it was added to the soil one week before the planting process in all the designated pots. After two weeks of planting, urea was added to the experimental pots where required, based on the treatment specifications. This sequential application of CPHP and urea allowed for proper nutrient management and ensured that the desired experimental conditions were achieved.

Planting and establishment

Before sowing, the pots were appropriately spaced to ensure proper plant growth and development. In all treatment pots, Jute seeds treated with hot water were sown on the soil surface. Two seedlings were initially raised, then thinned to one each per pot 10 days after sowing (WAS). The sowing of seeds took place on 25th April 2023 and was followed by light irrigation to provide initial moisture. To ensure adequate moisture for the proper emergence and development of Jute roots, the pots were watered in the morning and evening every day. A measuring cylinder was used for watering, and an equal amount of water was provided to each pot. At the initial stage, 20 mm of water is added per day to ensure the surface of the soil is not dry and the volume increases to 100 mL with plant size increase. The consistent watering regimens were aimed at facilitating optimal moisture uptake and promoting the healthy growth of the Jute plants.

Maintenance

One week after planting, thinning was conducted to minimize competition among the Jute plants for space, light, nutrients, and water. The most vigorous and healthy plant stands were carefully selected to remain in the experimental pots. Thinning was done in all pots to ensure optimal plant growth and development. Similarly, weed removal was performed to prevent the growth of unwanted and harmful plants that could compete with the Jute. Careful attention was given during the weeding process to minimize potential damage to the growing Jute stems and leaves. Weeds were hand-picked, and no chemical weed control methods were used.

Data collection

Throughout the experiment, observations on plant height and stem diameter were measured, and the number of leaves was counted at 2, 3, 4, and 5 weeks after sowing (WAS). To obtain accurate measurements, a Vernier caliper was used to measure the stem diameter, and a flexible meter ruler was used to measure the height of the plants. At 6 WAS, the plant was harvested, and its fresh weights were taken using a sensitive scale. This was done before the plants start partitioning assimilates for flower and seed formation. Additionally, the harvested plants were oven-dried and the dry biomass weights were taken.

Statistical analysis

The agronomic data collected were analyzed using GenStat version 8.1. Means that showed significant differences were separated using Duncan`s Multiple Range Test at a probability level of 0.05

RESULTS AND DISCUSSION

Chemical and particle size analysis of the soil at the experimental site

Chemical analysis of the soil at the experimental site showed that the soil was neutral with a pH of 7.09 (Table 1). However, the total nitrogen content in the soil was 3.3 g kg^{-1}. The potassium value was determined to be 0.36 cmol kg^{-1}, while the available phosphorus content was 16.1 mg kg^{-1}. The particle size result indicated the soil textural class was loamy sand. The study site soil has a nitrogen level below the critical level for Jute production (Huat et al. 2017). Considering the soil texture with a low soil organic matter content. Therefore, there is an urgent need to increase the available nitrogen in the soil to ensure the establishment and production of Jute. Organic fertilizers are well-known for their beneficial effect on crop growth and development (Anas et al. 2020).

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

Parameters	Values
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	0.29
Ca	2.71
Exchangeable acidity	0.4
Extractable micronutrients (mg kg^{-1})	
Fe	92
Cu	1.35
Mn	76
Zn	1.86
Textural class (g kg^{-1})	
Sand	800
Silt	130
Clay	62
Textural class	Loamy sand

Cocoa pod Husk powder properties

The chemical properties of the CPHP used revealed that the C: N ratio was 17.60, indicating an organic material with a low C: N ratio (Table 2). Health-conscious individuals often prefer to consume farm produce cultivated using organic materials. These organic materials serve as valuable sources of nutrients for plants, enhancing the soil's water-holding capacity and improving nutrient availability, thus creating favorable conditions for Jute root growth and nutrient uptake (Fidelis and Rajashekhar Rao 2017).

Table 2. Chemical properties of the cocoa pod husk powder used in the study.

Total N (%)	Organic C (%)	Total P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})
0.841	14.804	0.143	0.531	0.227	2.058	0.398	48.65	1467.25	64.55

Effects of fertilizers on the height of Jute mallow plants

The CPHP application resulted in significant (P<0.05) variations among treatments in the height of the Jute plants during the first and second cropping (Table 3). In the first planting, the CPH-treated plants at 30 kg of N ha^{-1} had significantly higher height than the control at 2 and 3 WAS. At 4 WAS, the CPHP application at 60 kg of N ha^{-1} had significantly taller plants than the control, while the difference was not significant at 5 WAS. In the second planting, CPHP at 30 kg of N ha^{-1} had significantly taller plants than the other treatments at 2 and 3 WAS, while the difference was not significant at 4 WAS. The control treatment had the lowest height throughout the observation periods. These results suggest that CPHP at 30 kg N ha^{-1} is effective for early growth, while higher rates (60 kg N ha^{-1}) may be better for later stages. The taller the plants, the better the access to light, leading to more developed root systems for nutrient and water absorption (Rumanuzzaman et al. 2024). The results of the CPHP application demonstrated improvements in the plant height over the control. The nutrient composition of cocoa pod husk includes nitrogen, phosphorus, and potassium, which serve as a source of plant-available nutrients, supporting crop growth, development, and productivity (Munongo et al. 2017). These results were consistent with earlier reports that organic soil amendments improved crop growth parameters (Bai et al. 2023).

Table 3. Effect of Cocoa pod husk, urea, and their interactions on Jute plant height (cm).

	First planting (WAS)				Second planting (WAS)			
	2	3	4	5	2	3	4	5
CPHP (kg of N ha^{-1})								
0	8.13^{b}	15.97^{b}	24.13^{b}	37.40	8.67^{b}	16.44^{c}	25.44	39.56
30	11.23^{a}	21.86^{a}	29.53^{ab}	38.07	11.56^{a}	22.98^{a}	29.78	39.44
60	9.90^{a}	20.99^{a}	30.87^{a}	43.13	9.78^{ab}	19.83^{b}	29.44	42.33
SE	0.58	0.81	1.98	2.70	0.72	0.93	2.80	3.86
Urea (kg of N ha^{-1})								
0	8.57^{b}	18.56^{b}	26.33	38.07	8.61^{b}	19.22^{ab}	27.89	39.33
30	11.17^{a}	22.10^{a}	29.80	39.67	11.56^{a}	21.94^{a}	29.56	41.56
60	9.53^{ab}	18.16^{b}	28.40	40.87	9.83^{ab}	18.09^{b}	27.22	40.44
SE	0.58	0.81	1.98	2.70	0.72	0.93	2.80	3.87
Interactions								
C_0U_0	9.80^{a-c}	17.80^{cd}	24.60^{ab}	36.20	10.33^{ab}	17.67^{cd}	23.00	36.33
C_0U_{30}	6.20^{d}	13.70e	22.20^{b}	34.40	6.33^{c}	14.50^{d}	25.33	34.67
C_0U_{60}	8.40^{cd}	16.40^{de}	25.60^{ab}	41.60	9.33^{a-c}	17.17^{cd}	28.00	47.67
$C_{30}U_0$	11.90^{a}	25.30^{a}	31.40^{ab}	37.80	12.00^{a}	25.50^{a}	30.33	39.00
$C_{30}U_{30}$	10.30^{a-c}	21.30^{a-c}	25.20^{ab}	35.00	9.83^{a-c}	23.17^{ab}	28.00	40.00

Table 3

	First planting (WAS)				Second planting (WAS)			
	2	3	4	5	2	3	4	5
Interactions								
$C_{30}U_{60}$	11.50^{ab}	18.98^{cd}	32.00^{ab}	41.40	12.83^{a}	20.27^{bc}	31.00	39.33
$C_{60}U_{0}$	11.80^{a}	23.20^{ab}	33.40^{a}	45.00	12.33^{a}	22.67^{ab}	35.33	49.33
$C_{60}U_{30}$	9.20^{a-c}	20.68^{bc}	31.60^{ab}	44.80	9.67^{a-c}	20.00^{bc}	30.33	43.33
$C_{60}U_{60}$	8.70^{b-d}	19.10^{cd}	27.60^{ab}	39.60	7.33^{bc}	16.83^{cd}	22.67	34.33
SE	1.00	1.41	3.43	4.68	1.25	1.61	4.85	6.69

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

Urea application at 30 kg of N ha^{-1} resulted in significantly (P<0.05) higher plant height than the control in the second week of sowing in the first planting. At 3 WAS, the other treatments had significantly lower height than the effect of urea at 30 kg of N ha^{-1}. The variations in plant height at 4 and 5 WAS were similar for the treatments. However, urea at 30 and 60 kg of N ha^{-1} had the tallest plants at 4 and 5 WAS, respectively, while the control treatment had the shortest plants. At 2 and 3 WAS in the second planting, plants treated with urea at 30 kg of N ha^{-1} were significantly taller than plants under the control and urea at 60 kg of N ha^{-1}, respectively. Plant heights at 4 and 5 WAS were not significantly different but ranged from 27.22 (60 kg of N ha^{-1}) to 29.56 cm (30 kg of N ha^{-1}) and 39.33 (control) to 41.56 cm (30 kg of N ha^{-1}), respectively. Urea fertilizer application at varying levels led to a significant increase in the observed growth parameters of Jute mallow, but the effect may be more pronounced early in growth. This is due to its high solubility in water, which allows for easy uptake by plant roots (Gheith et al. 2022). Urea fertilizer effectively ameliorates the nitrogen status in N-deficient soils, thereby increasing the available nitrogen required for cell mitosis at the meristem, causing stem height increase (Govindasamy et al. 2023; Swify et al. 2024). This conforms with Luo et al. (2020) report that improved N availability for crop uptake promotes plant height increase.

Cocoa pod husk powder and urea applications resulted in significantly (P<0.05) different Jute mallow heights in the first and second plantings (Table 3). The $C_{60}U_{30}$ interaction resulted in the highest plant height at 2 and 3 WAS in the first planting. Also, $C_{60}U_{30}$ significantly increased Jute height compared to C_0U_{30} at 4 WAS, while the treatments were all similar at 5 WAS. During the second planting, the $C_{30}U_{60}$ and $C_{30}U_0$ had the tallest plants at 2 and 3 WAS, respectively, while C_0U_{30} had the shortest plants. This indicated that soil physical property improvement through CPHP application was a major factor for height increase. The CPHP and urea interactions did not significantly influence variation among the treatments at 4 and 5 WAS. However, the heights ranged from 23.00 (C_0U_{30}) to 35.33 cm ($C_{60}U_0$) and 34.33 ($C_{60}U_{60}$) to 49.33 cm ($C_{60}U_0$) at 4 and 5 WAS, respectively. Integrating organic and inorganic fertilizers is a strategy to promote plant growth and maintain soil health (Bai et al. 2023; Akinrinola and Ojo 2024). However, the finding in this study did not conform to this assertion, in that the sole CPHP treatments had taller plants with the increase in application levels. These results suggest CPHP is more effective than urea in promoting Jute height, which could be due to improved nutrient supply and soil physical condition, as supported by Doungous et al. (2018).

Effects of fertilizers on the stem diameter of Jute

The effects of CPH, urea fertilizers, and their combinations on Jute stem diameter showed similar responses during the first and second plantings (Table 4). At 2 and 3 WAS, CPHP applications at 30 kg of N ha^{-1} and 60 kg of N ha^{-1} significantly (P<0.05) increased Jute mallow stem diameter compared to the 0 kg of N ha^{-1} during the first planting. There was no significant difference in stem diameter at 4 WAS, while CPHP at 60 kg of N ha^{-1} significantly improved stem diameter compared to the other treatments at 5 WAS.

During the second planting, CPHP applications at 30 and 60 kg of N ha^{-1} significantly increased Jute stem diameter at 2 and 5 WAS, respectively, compared to the control. However, the variations among treatments at 3 and 4 WAS were nonsignificant. This finding conformed with Tamfuh et al. (2021) that applying CPH resulted in the stem diameter increase in okra. The influence of CPH powder could be attributed to the availability of assimilates that encourage an increase in cell division or enlargement of the lateral meristematic tissue, thus resulting in the thickness of plants' stems.

Jute plants treated with urea were not significantly (P<0.05) different throughout the observation periods during both plantings (Table 4). This observation suggests that urea has a weak influence on stem diameter. However, urea treatment at 30 kg of N ha^{-1} had relatively higher stem diameters during observation periods. These results implied that urea application at 30 kg N ha^{-1} is sufficient to promote stem diameter, but increasing the level to 60 kg N ha^{-1} offers little additional benefit, possibly due to nutrient saturation or allocation to other growth parameters. This assertion supported Luo et al. (2020) report that the response to nitrogen increase is minimal after the optimum plant requirement.

At 2, 3, and 5 WAS during the first planting, there were significant differences among fertilizer combinations. The plants treated with $C_{30}U_0$ had the highest stem diameter at 2 WAS, while $C_{30}U_{30}$, $C_{60}U_{30}$, and $C_{60}U_0$ treatments had higher values at 3 WAS. At 5 WAS, $C_{60}U_{60}$-treated plants had the highest stem diameter. During the second planting,

Table 4. Effect of cocoa pod husk and urea applications on Jute stem diameter (cm).

	First planting (WAS)				Second planting (WAS)			
	2	3	4	5	2	3	4	5
CPHP (kg of N ha^{-1})								
0	0.18^{b}	0.25^{b}	0.24	0.32^{b}	0.18^{b}	0.26	0.26	0.33^{b}
30	0.22^{a}	0.27^{a}	0.27	0.35^{b}	0.22^{a}	0.27	0.27	0.35^{ab}
60	0.21^{a}	0.27^{a}	0.28	0.41^{a}	0.20^{ab}	0.27	0.27	0.40^{a}
SE	0.01	0.01	1.14	0.02	0.01	0.01	0.01	0.02
Urea (kg of N ha^{-1})								
0	0.19	0.27	0.25	0.34	0.19	0.27	0.27	0.35
30	0.21	0.27	0.27	0.37	0.22	0.27	0.27	0.40
60	0.19	0.26	0.26	0.36	0.20	0.26	0.26	0.33
SE	0.01	0.01	1.14	0.01	0.01	0.01	0.01	0.02
Interactions								
C_0U_0	0.19^{b-e}	0.26^{ab}	0.21	0.35^{a-c}	0.19^{a-c}	0.27	0.27	0.38^{a-c}
C_0U_{30}	0.15^{e}	0.25^{b}	0.25	0.28^{c}	0.15^{c}	0.25	0.25	0.28^{c}
C_0U_{60}	0.19^{c-e}	0.25^{b}	0.26	0.34^{a-c}	0.21^{ab}	0.27	0.27	0.33^{a-c}
$C_{30}U_0$	0.23^{a}	0.27^{ab}	0.27	0.37^{ab}	0.23^{a}	0.27	0.27	0.39^{a-c}
$C_{30}U_{30}$	0.21^{a-d}	0.28^{a}	0.28	0.35^{a-c}	0.20^{ab}	0.28	0.28	0.36^{a-c}
$C_{30}U_{60}$	0.22^{a-c}	0.26^{ab}	0.26	0.32^{bc}	0.23^{a}	0.26	0.26	0.31^{bc}
$C_{60}U_0$	0.22^{ab}	0.28^{a}	0.28	0.40^{ab}	0.23^{a}	0.29	0.29	0.43^{a}
$C_{60}U_{30}$	0.21^{a-d}	0.28^{a}	0.28	0.41^{a}	0.21^{ab}	0.28	0.28	0.40^{ab}
$C_{60}U_{60}$	0.18^{de}	0.26^{ab}	0.27	0.42^{a}	0.17^{bc}	0.24	0.25	0.36^{a-c}
SE	0.01	0.01	1.98	0.03	0.01	0.01	0.01	0.04

CPHP = Cocoa Pod Husk Powder; WAS = Weeks After Sowing; CPHP at 0 (C_0), 30 (C_{30}) and 60 (C_{60}) kg of N ha^{-1}; Urea fertilizer at 0 (U_0), 30 (U_{30}) and 60 (U_{60}) kg of N ha^{-1}; Mean values within the same column and with a similar letter(s) are not significantly (P<0.05), as determined by Duncan`s Multiple Range Test.

CPHP and urea interactions significantly improved Jute stem diameter at 2 and 5 WAS, with $C_{30}U_{60}$ having the highest value among the interactions. The C_0U_{30} consistently had the lowest values during the observation period. These findings at the last observation before harvest were inconsistent with Kayode and Adeoye's (2021) report that CPHP combined with NPK fertilizer further increased okra stem diameter. While the first planting supported Kayode and Adeoye's (2021) report, the second planting was against it, though the readings were similar. It can be inferred that the attributes of CPHP as fertilizer were sufficient to supply the required Jute mallow stem increase. The low responses from urea application as compared to its combination with CPHP may reflect the absence of complementary nutrients in urea compared to CPHP.

Effects of fertilizers on the number of leaves

During the first planting, the CPHP application at 30 kg of N ha^{-1} significantly (P<0.05) increased the number of leaves in Jute mallow compared to the control at 2 and 3 WAS (Table 5). At 4 WAS, 60 kg of N ha^{-1} of CPHP had a significantly higher number of leaves than the control, while the variation among treatments was not significantly different at 5 WAS. A similar trend of observations was made in the second planting, except that the variations at 4 WAS were not significantly different. The number of leaves produced by a plant indicates its light interception ability and the net carbon gain it can achieve (Luo et al. 2020). It is an indicator often used interchangeably with leaf area to monitor a plant's growth rate. During the two plantings, CPHP-treated plants had more numbers of leaves than the control treatment.

Table 5. Influence of Cocoa pod husk, urea, and interactions on Jute number of leaves.

	First planting (WAS)				Second planting (WAS)			
	2	3	4	5	2	3	4	5
CPHP (kg of N ha^{-1})								
0	7.93^{b}	13.07^{b}	12.20^{b}	15.40	8.11^{b}	12.44^{b}	11.56	14.56
30	9.00^{a}	14.60^{a}	13.20^{ab}	16.80	9.11^{a}	14.56^{a}	12.89	16.22
60	8.60^{ab}	14.13^{ab}	14.27^{a}	16.87	8.67^{ab}	13.44^{ab}	13.56	15.67
SE	0.35	0.41	0.45	0.59	0.37	0.48	0.58	0.79
Urea (kg of N ha^{-1})								
0	8.00	13.27	13.07	16.07	8.00	12.78	12.56	15.22
30	8.93	14.13	13.33	16.13	9.11	14.00	12.78	15.22
60	8.60	14.40	13.27	16.87	8.78	13.67	12.67	16.00
SE	0.35	0.41	0.45	0.60	0.38	0.48	0.58	0.79
Interactions								
C_0U_0	8.60^{ab}	14.00^{ab}	12.60^{a-c}	15.20^{b}	8.67^{a-d}	13.00^{ab}	11.33	13.00
C_0U_{30}	7.20^{b}	12.40^{b}	12.20^{bc}	15.40^{ab}	7.00^{d}	12.33^{b}	12.33	15.67
C_0U_{60}	8.00^{ab}	12.80^{b}	11.80^{c}	15.60^{ab}	8.67^{a-d}	12.00^{b}	11.00	15.00
$C_{30}U_0$	9.20^{a}	15.00^{a}	13.60^{a-c}	17.40^{ab}	9.00^{a-c}	15.33^{ab}	13.33	17.00
$C_{30}U_{30}$	8.40^{ab}	13.40^{ab}	12.40^{a-c}	16.20^{ab}	8.00^{b-d}	13.00^{ab}	11.67	15.00
$C_{30}U_{60}$	9.40^{a}	15.40^{a}	13.60^{a-c}	16.80^{ab}	10.33^{a}	15.33^{a}	13.67	16.67
$C_{60}U_0$	9.00^{a}	13.40^{b}	13.80^{a-c}	15.80^{ab}	9.67^{ab}	13.67^{ab}	13.67	15.67
$C_{60}U_{30}$	8.40^{ab}	14.00^{ab}	14.60^{a}	16.60^{ab}	9.00^{a-c}	13.00^{ab}	13.67	15.00
$C_{60}U_{60}$	8.40^{ab}	15.00^{a}	14.40^{ab}	18.20^{a}	7.33^{cd}	13.67^{ab}	13.33	16.33
SE	0.60	0.71	0.78	1.03	0.65	0.83	1.01	1.37

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

All urea fertilizer treatments showed a nonsignificant difference in the number of leaves throughout the observation period in both plants (Table 5). However, plants treated with urea fertilizer at 30 kg of N ha^{-1} and 60 kg of N ha^{-1} relatively had higher values in the first planting. The differences among treatments were not significant during the second planting. However, urea-treated plants at 30 kg of N ha^{-1} had a relatively higher number of leaves at 2, 3, and 4 WAS, while the control had the lowest values. This observation possibly suggests nutrient allocation to other traits. The results did not justify the cost of increasing soil nitrogen from urea fertilizer, to support the increase in the number of leaves in Jute mallow as reported by Gheith et al. (2022).

The interactions between CPHP and urea indicated significant differences among treatments for the number of leaves during the first planting (Table 5). The highest number of leaves at 2 and 3 WAS were observed in plants treated with $C_{30}U_{60}$, while $C_{60}U_{30}$ and $C_{30}U_{0}$ had the highest values at 4 and 5 WAS, respectively. During the second planting, the plants treated with $C_{30}U_{60}$ had a significantly higher number of leaves than $C_{0}U_{30}$ at 2 and 3 WAS. However, the differences at 4 and 5 WAS were nonsignificant. The consistency and similarity in the values observed for combined CPHP and urea fertilizers during the two plantings consolidated the reports of earlier studies (Doungous et al. 2018; Kayode and Adeoye 2021). However, the consistent low response from $C_{0}U_{30}$ aligns with Table 1, substantiating that urea was inefficient without CPHP, probably due to poor uptake. The combined CPHP and urea fertilizer application during the two plantings promoted the Jute mallow plant's growth rate and soil health condition more than the control. These findings suggest moderate CPHP levels optimize this parameter, but high urea levels may not justify additional costs, given their minimal influence.

Effects of fertilizers on the fresh biomass and dry biomass at harvest

The responses observed for plant height, stem diameter, and number of leaves in Jute mallow plants were similar for CPHP, urea, and their interactions, except for slight variations during observation periods. These responses result from variations in soil health, cumulated to determine the fresh and dry biomasses accumulated during growth periods. The effect of CPHP treatments on Jute mallow fresh weight at harvest was nonsignificant during the two plantings (Table 6). However, the fresh weight ranges from 9.76 g (30 kg of N ha^{-1}) to 11.16 g (0 kg of N ha^{-1}) and from 10.03 g (30 kg of N ha^{-1}) to 11.81 g (0 kg of N ha^{-1}) during the first and second plantings, respectively. Similarly, the plants under the control treatment had significantly higher dry biomass yields than those under CPHP at 30 and 60 kg N ha^{-1} during the first planting (Table 6). The reduced biomass seen at higher CPHP levels (30 and 60 kg N ha^{-1}) may indicate nutrient imbalances or toxicity, especially because of the high Fe content in the material. Rout and Sahoo (2015) reported that organic manure could be a source through which heavy metals are deposited in the soil, thereby leading to nutrient imbalance.

Table 6. Effect of Cocoa pod husk and urea on fresh and dry biomass at harvest.

	First planting (g per plant)		Second planting (g per plant)	
	Fresh weight	Dry weight	Fresh weight	Dry weight
CPHP (kg of N ha^{-1})				
0	11.16	2.62^{a}	11.81	2.73^{a}
30	9.79	1.86^{b}	10.03	1.70^{b}
60	9.96	1.93^{b}	10.36	1.88^{ab}
SE	0.71	0.22	0.84	0.31
Urea (kg of N ha^{-1})				
0	9.45^{b}	2.03	9.86	1.98
30	9.86^{ab}	2.16	10.36	2.09
60	11.60^{a}	2.23	11.99	2.24
SE	0.72	0.22	0.84	0.32

Table 6

	First planting (g per plant)		Second planting (g per plant)	
	Fresh weight	Dry weight	Fresh weight	Dry weight
Interactions				
C_0U_0	11.32^{ab}	2.56	10.90$^{a\text{-}c}$	2.27^{ab}
C_0U_{30}	9.40$^{a\text{-}c}$	2.68	9.47^{bc}	2.93^{ab}
C_0U_{60}	12.76^{a}	2.62	15.07^{a}	3.00^{a}
$C_{30}U_0$	7.36^{c}	1.70	7.87^{c}	1.70^{ab}
$C_{30}U_{30}$	10.88$^{a\text{-}c}$	1.76	10.83$^{a\text{-}c}$	1.30^{b}
$C_{30}U_{60}$	11.14^{ab}	2.12	11.40$^{a\text{-}c}$	2.10^{ab}
$C_{60}U_0$	10.90$^{a\text{-}c}$	2.22	12.30^{ab}	2.30^{ab}
$C_{60}U_{30}$	8.08^{bc}	1.64	9.27^{bc}	1.70^{ab}
$C_{60}U_{60}$	10.90$^{a\text{-}c}$	1.94	9.50^{bc}	1.63^{ab}
SE	1.24	0.38	1.45	0.54

CPHP = Cocoa Pod Husk Powder; CPHP at 0 (C_0), 30 (C_{30}) and 60 (C_{60}) kg of N ha^{-1}; Urea fertilizer at 0 (U_0), 30 (U_{30}) and 60 (U_{60}) kg of N ha^{-1}; Mean values within the same column and with similar letter(s) are not significantly (P<0.05) different, as determined by Duncan`s Multiple Range Test.

During the second planting, however, the control treatment had significantly higher dry biomass than the CPHP treatment at 30 kg of N ha^{-1} but was comparable with the 60 kg of ha^{-1} treated plants. The results of the CPHP application demonstrated through the improvements in the plant height, stem diameter, and number of leaves over the control, consolidated the accumulation of photosynthates for growth and development. The nutrient-rich profile of CPHP supported their growth, development, and productivity (Munongo et al. 2017). These results were consistent with earlier reports that organic soil amendments improved crop growth parameters (Kayode and Adeoye 2021; Bai et al. 2023). The contribution of CPHP as an organic amendment in crop growth enhancement is achieved through the improvement in soil structure, crop nutrition, and an increase in microbial diversity and activities (Hougni et al. 2021). The results showed that CPHP at 30 kg of N ha^{-1} supported early growth (2 and 4 WAS), while 60 kg of N ha^{-1} was better at 4 and 5 WAS. Songsong et al. (2019) suggest that at the early stage of development, the higher level promoted higher microbial diversity that led to the immobilization of available nutrients for plant growth. At the lower level of the CPHP application, soil microbes were less active, thus causing minimal nutrient immobilization, thereby promoting growth (Songsong et al. 2019). This must have accounted for the improvement in the observed growth parameters after 3 WAS. The higher nitrogen from CPHP resulted in reduced biomass accumulation, possibly due to excessive microbial activities promoted rather than at the expense of biomass increase. This outcome warrants further investigation into soil dynamics or plant uptake efficiency. High Fe could have limited the plant's ability to accumulate assimilates, leading to lowered fresh and dry biomass yields (Rout and Sahoo 2015).

The response of Jute mallow to urea application at 60 kg of N ha^{-1} significantly (P<0.05) increased the fresh weight in Jute mallow compared to the control during the first planting. Jute mallow fresh weight ranged from 9.86 to 11.99 g per plant for plants treated under the control and urea at 60 kg of N ha^{-1}, respectively. However, the variation was not significantly different during the second planting. Also, the variations in dry biomass among plants treated with urea fertilizer were not significantly different during the first and second plantings. However, it ranged from 2.03 to 2.23 g per plant and 1.98 to 2.24 g per plant for the control and urea application at 60 kg of N ha^{-1} during the first and second plantings, respectively. Applying urea fertilizer encourages biomass accumulation due to its high solubility in water, which allows for easy uptake by plant roots (Gheith et al. 2022). Urea fertilizer effectively ameliorates the nitrogen status in N-deficient soils, thereby increasing the available nitrogen to improve crop performance (Govindasamy et al. 2023; Swify et al. 2024). Urea is a concentrated source of nitrogen, an essential nutrient for plant growth, chlorophyll synthesis, and protein production. Therefore, adequate nitrogen supply from urea increases shoot and root growth, resulting in enhanced plant biomass production (Huat et al. 2017; Akinrinola and Ojo 2024). This report is substantiated when a higher level of urea fertilizer application (60 kg of N ha^{-1}) did not further increase the response of Jute than the (30 kg of N ha^{-1}), except for plant height. This suggests that excessive nitrogen application through urea may have caused nutrient imbalance or toxicity, thereby reducing photoassimilate accumulation. These findings are consistent with the report of Swify et al. (2024), which indicated that higher rates of urea fertilization can further enhance maize yield.

The plants treated with C_0U_{60} had significantly higher fresh weight compared to $C_{30}U_0$ and $C_{60}U_{30}$ treatments during the first planting. However, C_0U_{60} treatment significantly increased Jute mallow fresh weight more than C_0U_{30}, $C_{30}U_0$, $C_{60}U_{30}$, and $C_{60}U_{60}$ during the second planting. Furthermore, the improvement in dry biomass at harvest for CPHP and urea was not significant during the first planting but ranged from 1.64 ($C_{60}U_{30}$) to 2.68 g per plant (C_0U_{30}). During the second planting, $C_{30}U_{30}$-treated plants had significantly lower dry biomass than C_0U_{60}, while other treatments were similar. Among the interactions, the plants treated with individual applications of CPHP and urea indicated better growth. However, this tended to be at par with the combined CPHP and urea during the first and second plantings in the study. This study conforms to Govindasamy et al. (2023) and He et al. (2023), who report that the use of sole organic or inorganic sources is being less recognized because of their environmental impact on climate change and socio-economic implications. Combining CPHP at 60 kg of N ha^{-1} × urea at 30 kg of N ha^{-1} yielded the highest, surpassing the other treatments. This may be due to CPHP, an organic fertilizer that slowly mineralizes nutrients in the soil, promoting rapid growth. As a result, the development of short-duration crops like Jute mallow may be at a disadvantage. Proper application level and concise timing are crucial to maximize crop response and achieve optimal yields (Dhakal and Lange 2021). The relatively reduced response from the other CPHP and urea interactions demonstrated that the release of nutrients immobilized by microbes did not coincide with the need for crops for nutrients to increase growth. In contrast, longer-duration crops like maize may benefit more from CPHP as a fertilizer. Additionally, the microbes found in the soil must have prioritized the mineralization of nutrients in CPHP, thereby influencing the mineralization rate of existing mineral nutrients in the soil. This ultimately leads to the reduced effectiveness of the CPHP treatments. However, the low dry weight with high CPHP levels may indicate nutrient imbalance, luxury consumption, or water retention rather than productive growth. The response of Jute mallow to $C_{30}U_{60}$ indicated the level at which there was a balance in the spontaneous supply of the available nutrients for Jute growth and the microbial nutrient demand. The substitution of N in the CPHP at 30 kg of N ha^{-1} with urea fertilizer must have encouraged better Jute performance than the other interactions. This result is supported by He et al. (2023) report, that maize and wheat performed better when N in organic and inorganic fertilizers was substituted. Also, Doungous et al. (2018) reported improved *Theobroma cacao* seedlings performance due to CPH compost and urea fertilizer application. This substitution of inorganic N with organic sources would minimize the pressurized growth induced by chemical fertilizers and mitigate their negative effects on the environment, which causes global warming. Similarly, the challenges of CPHP that limit crop growth and development are overcome, thus creating an avenue to manage the waste from cocoa production.

CONCLUSION

Applying cocoa pod husk powder increased the growth parameters but reduced Jute mallow fresh and dry biomass during the first and second plantings. Response of Jute mallow plants to urea fertilizer was highest at 60 kg of N ha^{-1}. Although the individual applications of cocoa pod husk powder and urea treatments performed better for the parameters observed, their combinations were comparable. The treatment of cocoa pod husk powder at 30 kg of N ha^{-1} × urea at 60 kg of N ha^{-1} performed better in terms of growth and yield parameters. Consequently, cocoa pod husk powder at 30 kg of N ha^{-1} with urea at 60 kg of N ha^{-1} was suggested for promoting Jute mallow performance. For further research, the nutrient release dynamics of cocoa pod husk powder and its effects on soil physical, chemical, and biological properties could explain the variations observed and should be considered.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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