


ORIGINAL RESEARCH ARTICLE

Effect of Row Arrangement, Stand Density, and Phosphorus Fertilizer on Yield and Yield Components of Cowpea (*Vigna unguiculata* L. walp) in Sudan Savannah, Nigeria

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ABSTRACT

Cowpea (*Vigna unguiculata* L. Walp) is an important grain legume widely cultivated in the Sudan savanna of West Africa, where it contributes significantly to food security, soil fertility improvement, and farmers' income. However, its productivity in the region remains low due to poor soil fertility, particularly phosphorus deficiency, and suboptimal crop management practices such as improper plant population and spatial arrangement. This study was therefore conducted to evaluate the influence of row arrangement, stand density, and phosphorus fertilizer application rate on cowpea yield and yield components in the Sudan savanna agro-ecology. A field experiment was conducted during the 2023 rainy season at Federal University Dutsin-Ma, teaching and research farm and Umar Musa Yar'adua University Katsina teaching and research farm in Katsina State, Nigeria. The treatments consisted of two row arrangements (single row and double rows), three stand densities (one, two, and three plants per stand), and four phosphorus fertilizer levels (0, 13.2, 26.4, and 39.6 kg P ha⁻¹). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Data were collected on shoot dry weight, number of pods per plant, number of seeds per pod, 100 seed weight, grain yield, harvest index, and shelling percentage. Results indicated that row arrangement did not significantly influence grain yield at either location, although it significantly affected harvest index and shelling percentage at Dutsin-Ma, where the double-row arrangement produced superior performance. Stand density significantly affected harvest index, with variable responses across locations. Phosphorus fertilizer application significantly improved grain yield, harvest index, and shelling percentage at both locations. The study demonstrates that adequate phosphorus fertilization combined with appropriate row arrangement and stand density can enhance cowpea productivity in the Sudan savanna agro-ecology. These management practices offer a practical strategy for improving cowpea yield and resource use efficiency in the region.

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INTRODUCTION

Cowpea (*Vigna unguiculata* L) is an important leguminous crop grown for its tasty leaves and seeds. It serves as a staple meal and a vital source of protein for millions of people, particularly in sub-Saharan Africa, Asia, and certain regions of the Americas (Mateva *et al.*, 2024). It is cultivated across various agro-ecological zones. The crop's significance in sustainable agricultural systems stems from its adaptability to different soil types and its ability to fix atmospheric nitrogen (Phiri *et al.*, 2023).

Cowpea production is fraught with difficulties despite its significance, such as inconsistent yields, vulnerability to pests and diseases, and the effects of climate change on

production conditions (Mekonnen *et al.*, 2022). There is a clear need to increase cowpea production given the rising demand for nutrient-dense food sources worldwide and the mounting strain on agricultural systems to provide food security. Cultivated in the Sudan Savanna and other areas, this adaptable and essential legume is an essential part of the agricultural environment. To increase cowpea output, farmers and researchers are constantly investigating novel agronomic approaches.

Cowpea growth, development, and yield are significantly influenced by a number of parameters, including phosphorus levels, planting technique, and the number of

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plants per hill (Traore *et al.*, 2014). Because of its unique climatic conditions and soil properties, the Sudan Savanna offers a unique location for examining the relationship between these agronomic parameters and cowpea performance (Traore *et al.*, 2014).

Cowpea is a vital legume crop that is important to global agriculture, particularly in Africa. According to data from the Food and Agriculture Organization (FAO), Abebe and Alemayehu (2022), the global production of cowpeas in 2020 was approximately 8.9 million tons. A large amount of this production comes from Africa; Nigeria and Niger together account for more than 66% of global cowpea production. Nigeria is the world's largest producer of cowpeas, with an estimated 2.6 million tons produced in 2020. The crop's significance to Nigerian food and agricultural systems is shown by its noteworthy position. Nigeria's significant contribution to global cowpea production demonstrates the significance of cowpeas for both domestic consumption and regional trade (Canton 2021).

These highlight the importance of cowpeas, especially in West and Central Africa, in promoting agricultural economies and food security. Due to its high nutritional content and capacity to adapt to many climates, the crop is a mainstay in many African diets and a focus of agronomic study and improvement (Wu *et al.*, 2023).

In Nigeria, cowpea cultivation is predominantly carried out by smallholder farmers using traditional and improved agronomic practices. The major production areas are in the Sudan and Sahel savanna zones, including states such as Kano, Kaduna, Sokoto, Borno, and Zamfara (Yabo *et al.*, 2025). Farmers employ different planting methods (broadcasting, drilling, or row planting) and maintain variable plant populations depending on available inputs and local preferences (Adesoji *et al.*, 2020). Its production is constrained by factors such as inappropriate row arrangement, inadequate stand density, poor soil fertility management, insect pests (aphids, thrips, and pod borers), diseases (fungal, viral, and bacterial infections), and parasitic weeds like *Striga gesnerioides*. To mitigate these challenges, farmers adopt integrated pest management (IPM) strategies, including resistant varieties, biological control, and appropriate chemical applications (Begna, 2020).

Cowpea is also commonly planted in traditional single-row arrangements, which may limit the efficient use of light, water, and soil nutrients. Evidence indicates that alternative configurations, such as double-row arrangement, can improve canopy development, suppress weed growth, and enhance resource-use efficiency (Traoré *et al.*, 2023). In addition, the common practice of sowing two seeds per stand does not always ensure optimal plant population and may lead to competition among plants. Stand density has been shown to significantly influence biomass accumulation, growth dynamics, and grain yield in cowpea (Traoré *et al.*, 2023), highlighting the need to determine appropriate stand density.

Fertilization with phosphorus is also essential for maximizing development and yield, especially in soils lacking nutrients. One of the most crucial minerals for cowpea growth is phosphorus (P), which influences nodulation, root development, and yield. However, phosphorus deficit is a significant constraint that significantly lowers crop yield in many Sudan Savanna soils (Mekonnen *et al.*, 2022). Optimizing plant density through optimal planting practices and appropriate plant stands per hill is also necessary for improved light interception, nitrogen uptake, and overall yield performance (Feng *et al.*, 2023). Few researches have examined how these traits combine to impact cowpea productivity in the Sudan Savanna, even though they have been the focus of numerous investigations.

Cowpea is well adapted to warm climates and performs best in regions with an annual temperature range of 25 - 35°C. It is a drought-tolerant crop, requiring 300 - 700 mm of rainfall per growing season, though excessive moisture can lead to poor germination and disease susceptibility. It thrives in well-drained sandy loam to loamy soils with a pH range of 5.5 - 6.5. It is highly sensitive to waterlogging but exhibits remarkable resilience under nutrient-deficient conditions, benefiting from its symbiotic nitrogen-fixing capability (Nair *et al.*, 2021). It is a multipurpose crop valued for its grains, leaves, and haulms. The dried seeds are consumed as a protein-rich staple, often prepared as soups, stews, and porridge. The young leaves, pods, and shoots serve as vegetables, while the haulms provide nutritious fodder for livestock (Ombaka 2021).

Furthermore, by fixing atmospheric nitrogen, cowpeas help to improve soil fertility and lessen the demand for synthetic fertilizers (Ombaka 2021). Cowpeas are a significant revenue crop for Nigerian smallholder farmers, who make money from both local and export markets. The crop helps with agro-industrial processes including making flour, making animal feed, and making processed foods like snacks made from cowpeas. Due to population expansion and the growing need for plant-based protein sources, its demand is continuously rising (Purewal *et al.*, 2023).

With a particular focus on row arrangement, stand density and phosphorus rates, the aim of this study is to clarify the complex linkages influencing cowpea production in the Sudan Savanna.

MATERIALS AND METHOD

This experiment was conducted simultaneously during the 2023 rainy season at the Faculty of Agriculture, Teaching and Research Farm, Federal University Dutsin-Ma (Permanent Site), (Latitude $\approx 12^{\circ} 17' 44''$ N, and Longitude $\approx 07^{\circ} 27' 39''$ E and 605m above sea level) and at University Farm, Umaru Musa Yar'adua University, Katsina (Latitude $\approx 12^{\circ} 53' 24''$ N and Longitude $\approx 7^{\circ} 34' 24''$ E), both sites are situated at Sudan Savannah of Nigeria.

Before the establishment of each trial, soil samples were randomly taken from multiple locations at soil depths

ranging from 0 to 30 cm. The composite sample's physical and chemical characteristics were examined using a standard procedure (Wu *et al.*, 2023).

The treatments of this research consisted of two row arrangements (single row and double rows), three levels of stand density (one, two, and three stands), and four phosphorus (P) rates (0, 13.2, 26.4 and 39.6kg P ha⁻¹). The experiment was laid out in a 2 × 3 × 4 factorial combinations using a randomized complete block design (RCBD) and replicated three times.

The plot consisted of four ridges (3m) which are 0.75m apart and 4m long given a gross plot area of 4 m × 3 m (12 m²). While the net plot consists of 4 m × 1.5 m (6 m²). The pace between plots was 0.5 m and 0.75 m between the replications.

The experimental field was ploughed, harrowed and followed by ridging where 75 cm inter-row spacing was maintained (Kumar *et al.*, 2023). The plot size is 4 × 3 m and 0.75 m intervals between replications, and 0.5m intervals between plots. The total size of the experimental area was 23 × 54 m (1,242 m²). This gave rise to 24 plots per replication and a total of 72 plots for three replications.

The cowpea seed used in this research was SAMPEA 14. It is an improved variety that was sourced from the Institute for Agricultural Research (I.A.R.), Zaria, prior to the 2023 rainy season. SAMPEA-14 also known as IT99K-573-1-1; National Code: NGVU-11-29. It is a cowpea variety developed for improved performance in Nigerian agricultural systems. The seeds are medium-sized with a rough texture, a white coat, and a brown eye. SAMPEA-14 is an early-maturing variety, reaching physiological maturity within 60 - 100 days after sowing.

Weeds were controlled through the application of herbicides, manual use of hoes, and hand-pulling. The first weed control was performed using glyphosate at each location, at a rate of 3.5 kg a.i. ha⁻¹, using a knapsack sprayer as prescribed on the container label at sowing. The second weeding was conducted five (5) weeks after sowing, using hoes and hand-pulling (Shen *et al.*, 2024). Single Super Phosphate (SSP 20%) fertilizer was used as the source of phosphorus and was applied after land preparation and plots layout, by side placement at sowing, which was according to the specified rates of this research as follows: 0, 13.2, 26.4, and 39.6 kg P ha⁻¹. Magic Force insecticide containing active ingredients (a.i) (Lambda-Cyhalotrin 15g/L + Dimethoate 300g/L) was used for the control of insect pest and disease incidence during growth, flowering, and fruiting stages (7th, 9th, 11th and 13th WAS) at the rate of 1L ha⁻¹. Crop yield was harvested separately for each experimental plot to determine grain yield. It was harvested manually by hand-picking at 11th to 14th WAS, when the leaves turned brown, showing physiological maturity. It was harvested from the net plot, threshed, cleaned, weighed, and recorded.

To assess various yield characters, data were collected from 10 randomly selected plants within each plot and the following characters were taken and recorded.

1. Total dry matter (g): The plant biomass was determined at 10 WAS. Four cowpea plant samples were cut along the soil surface level from the outer ridges of each gross plot. Then it was put in labeled envelopes and dried up at room temperature to constant weight and its dry weight was determined using a top loading Mettler balance (Model P.120) and recorded as reported by Shen *et al.*, (2024).

2. Number of seeds pod⁻¹: This is determined by counting the number of seeds pod⁻¹ from ten pods of the harvested pods from the five randomly tagged plants and the mean will be taken and recorded according to procedures explained by An *et al.*, (2023).

3. Number of pods plant⁻¹: The number of pods plant⁻¹ was also determined by counting the number of pods of the five randomly tagged plants from each of the net plots and the average was recorded according to Nair *et al.*, (2021).

4. Pod yield plot⁻¹ (g): The pod yield plot⁻¹ was determined by weighing the total pods harvested from each net plot and the value was recorded according to procedures explained by Nair *et al.*, (2021).

5. 100 seed weight (g): 100 seeds were counted from each net plot and weighed on an electronic top-loading Mettler balance to obtain the weight of 100 seeds and were recorded as reported by Nair *et al.*, (2021).

6. Grain yield hectare⁻¹ (kg ha⁻¹): The grain yield hectare⁻¹ was determined at harvest. The harvested pods from the net plots were unshelled and winnowed, and the clean grains were weighed. The total grain weight hectare⁻¹ was expressed in kilogram hectare⁻¹ (kg ha⁻¹) and recorded as reported by Khan (2023).

7. Harvest index: According to procedures explained by Liu *et al.* (2023), it was calculated by using the formula given below:

$$HI = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total dry matter (kg ha}^{-1}\text{)}} \times \frac{100}{1}$$

8. Shelling percentage (S %): Kipfer (2023) calculated the shelling percentage by using the following formula:

$$\text{Shelling percentage} = \frac{\text{Grain per net plot after shelling}}{\text{Total pod weight per net plot (unshelled)}} \times \frac{100}{1}$$

The data collected were subjected to analysis of variance (ANOVA) in a randomized complete block design (RCBD), using the SAS package version 9.0 of statistical analysis (SAS, 2002). The differences among treatment means were separated using Duncan's Multiple Range Test (DMRT) (Duncan, 1955), at 5% level of probability. The magnitude and type of relationship between characters were determine through simple correlation analysis

RESULTS AND DISCUSSION

Physical and chemical properties of the experimental site soils

The particle size distribution (Table 1) indicates that soils from both Dutsin-Ma and Katsina are predominantly coarse-textured, classified as loamy sand. However, notable differences exist in their fractions. Dutsin-Ma recorded relatively lower sand content (760 g kg⁻¹) and higher clay content (100 g kg⁻¹) compared to Katsina (841 g kg⁻¹ sand and 33 g kg⁻¹ clay). This variation suggests that Dutsin-Ma soils possess comparatively better structural stability and water-holding capacity, attributable to the higher clay fraction (Masood & Ali 2023). In contrast, the dominance of sand in Katsina soils indicates rapid drainage, low moisture retention, and increased susceptibility to nutrient leaching, which are typical characteristics of sandy soils in semi-arid environments (Naorem, *et al.*, 2023).

Although both soils share the same textural class, the quantitative differences in particle distribution are agronomically significant and may influence crop performance. The soils at both locations are neutral to slightly alkaline, with pH (H₂O) values of 7.45 (Dutsin-Ma) and 7.20 (Katsina). This pH range is generally favourable for nutrient availability and crop growth. However, the pH measured in CaCl₂ (6.55 and 6.90, respectively) reveals a slight shift toward acidity, indicating the presence of exchangeable acidity not evident in water pH measurements (Hu, *et al.*, 2023).

The relatively higher acidity (Al³⁺ + H⁺ = 0.30 cmol kg⁻¹) observed in Katsina suggests a greater potential for subsoil acidity constraints, which may affect root development and nutrient uptake, particularly for sensitive crops (Vista, *et al.*, 2023). A pronounced difference was observed in organic carbon content, with Dutsin-Ma (12.61 g kg⁻¹) exhibiting substantially higher values than Katsina (1.98 g kg⁻¹). This disparity indicates that Dutsin-Ma soils are richer in organic matter, which is critical for improving soil structure, moisture retention, cation exchange capacity, and microbial activity (Hussain *et al.*, 2023).

Total nitrogen levels were comparable between the two sites (1.65 and 1.62 g kg⁻¹), suggesting a similar baseline nitrogen status. However, given the strong association between organic matter and nitrogen mineralization, the effective nitrogen availability is likely higher in Dutsin-Ma due to its greater organic carbon content (Hu, *et al.*, 2023). Available phosphorus was higher in Dutsin-Ma (15.60 mg kg⁻¹) compared to Katsina (12.20 mg kg⁻¹), suggesting a relatively better phosphorus fertility status. The lower phosphorus level in Katsina may be attributed to low organic matter content and possible fixation processes, which are common in sandy soils with limited buffering capacity (Masood & Ali 2023).

Exchangeable calcium and magnesium were consistently higher in Dutsin-Ma (2.98 and 0.54 cmol kg⁻¹, respectively) than in Katsina (2.01 and 0.38 cmol kg⁻¹). These base cations play a critical role in soil fertility,

influencing nutrient balance and soil pH buffering (Hussain *et al.*, 2023). Potassium levels were similar in both locations, indicating no substantial difference in K availability. However, sodium was slightly higher in Katsina (0.17 cmol kg⁻¹), which, although within acceptable limits, may indicate a tendency toward sodicity under prolonged mismanagement (Ndegwa *et al.*, 2023). The higher exchangeable acidity (Al³⁺ + H⁺) in Katsina further supports the observation of greater soil chemical constraints relative to Dutsin-Ma.

Katsina recorded a higher ECEC (7.58 cmol kg⁻¹) compared to Dutsin-Ma (4.06 cmol kg⁻¹). Although higher ECEC generally indicates greater nutrient retention capacity, this parameter must be interpreted alongside organic matter content and base saturation (Masood & Ali 2023). The observed pattern may be attributed to differences in clay mineralogy or the nature of exchange sites, suggesting that Katsina soils may contain more active clay fractions despite their lower clay content. Nevertheless, the lower organic carbon content in Katsina may limit the effective utilization of this exchange capacity.

The results indicate that Dutsin-Ma soils are relatively more fertile and better suited for sustainable crop production due to higher organic carbon content, greater availability of essential nutrients (P, Ca, Mg), and improved soil physical condition. In contrast, Katsina soils exhibit inherent limitations, including low organic matter, higher sand content, and greater exchangeable acidity. These constraints suggest that Katsina soils require more intensive soil fertility management, including organic amendments, integrated nutrient management, and soil conservation practices to enhance productivity (Ndegwa *et al.*, 2023).

The comparative assessment reveals clear spatial variability in soil properties between the two locations. While both soils are classified as loamy sand, Dutsin-Ma demonstrates superior physico-chemical characteristics, making it more favourable for crop production (Table 1). Conversely, the relatively poorer fertility status of Katsina soils highlights the need for targeted soil management interventions to achieve optimal agricultural productivity.

Total dry matter plot⁻¹ (g)

Row arrangement significantly affected ($P < 0.05$) dry matter yield (plot⁻¹) at Dutsin-Ma (Table 2), where the double-row arrangement produced higher biomass. This may be due to improved plant spacing, which enhances light interception and resource use efficiency (Zhai *et al.*, 2023). However, no significant effect was observed at Katsina, likely due to soil-related constraints limiting crop response.

Stand density had no significant effect ($P > 0.05$) on dry matter yield at both locations, suggesting that the population levels used were within the optimum range, allowing compensatory growth among plants (Zhao *et al.*, 2024). Phosphorus application significantly influenced (P

< 0.05) dry matter yield across locations. At Dutsin-Ma, 26.4 kg P ha⁻¹ significantly increased biomass, indicating phosphorus limitation. This aligns with the role of phosphorus in energy transfer and plant growth (Liu et al.,

2023). In contrast, no significant differences among phosphorus rates were observed at Katsina, possibly due to low organic matter and poor nutrient retention capacity (Zhai et al., 2023).

Table 1: Soil physical and chemical properties of experimental sites during 2023 rainy seasons

Soil Properties	Dutsin-Ma	Katsina
Particle Size Distribution (g kg⁻¹)	Depth of Soil (0–30 cm)	
Sand	760	841
Silt	140	126
Clay	100	33
Textural Class	Loamy Sand	Loamy Sand
Chemical Composition		
pH in H ₂ O (1:2.5)	7.45	7.20
pH in 0.01 M CaCl ₂ (1:2.5)	6.55	6.90
Organic Carbon (g kg ⁻¹)	12.61	1.975
Total Nitrogen (g kg ⁻¹)	1.65	1.62
Available Phosphorus (mg kg ⁻¹)	15.60	12.20
Exchangeable Cations (cmol kg⁻¹)		
Calcium (Ca ²⁺)	2.98	2.01
Magnesium (Mg ²⁺)	0.54	0.38
Potassium (K ⁺)	0.20	0.19
Sodium (Na ⁺)	0.14	0.17
Aluminum + Hydrogen (Al ³⁺ + H ⁺)	0.20	0.30
Effective Cation Exchange Capacity (CEC)	4.06	7.58

Analyzed at the Ahmadu Bello University Zaria and Department of Geography, Umaru Musa Yaradua University Katsina respectively

Table 2: Effect of row arrangement, stand density and phosphorus fertilizer on dry Matter Plot⁻¹ (g) of cowpea in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Dry Matter Plot ⁻¹ (g)	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	639.6 ^b	643.2
Double	658.4 ^a	650.3
SE±	6.35	8.55
Stand Density (SD)		
One	641.7	641.0
Two	641.2	650.5
Three	664.2	648.7
SE±	7.78	10.47
Phosphorus (kg ha⁻¹)		
0	483.3 ^d	492.4 ^b
13.2	674.9 ^c	681.1 ^a
26.4	733.8 ^a	709.3 ^a
39.6	704.1 ^b	704.2 ^a
SE±	8.98	12.09
Interaction		
P × RA	NS	NS
P × SD	NS	NS
SD × RA	NS	NS
P × SD × RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

SE±= Standard error

The lowest dry matter yield recorded at 0 kg P ha⁻¹ in both locations confirms phosphorus as a limiting nutrient for cowpea production. The results highlight a stronger

response to management practices at Dutsin-Ma than Katsina, emphasizing the need for site-specific soil fertility management

Table 3: Effect of row arrangement, stand density and phosphorus fertilizer on the number of seeds pod⁻¹ and number of pods plant⁻¹ of cowpeas in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Dutsin-Ma		Katsina	
	No. of seeds pod ⁻¹	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	No. of pods plant ⁻¹
Row Arrangement (RA)				
Single	12.2	14.4	12.3	14.5
Double	12.3	14.6	12.3	14.0
SE±	0.19	0.41	0.17	0.29
Stand Density (SD)				
One	12.4	14.2	12.4ab	14.4
Two	12.4	14.2	12.6a	14.4
Three	12.0	15.1	11.9b	13.9
SE±	0.22	0.51	0.21	0.39
Phosphorus kg (P) ha⁻¹				
0	9.7b	9.8b	9.6b	10.4c
13.2	13.0a	15.6a	13.0a	16.3a
26.4	13.2a	16.6a	13.1a	15.2ab
39.6	13.2a	16.0a	13.4a	15.0b
SE±	0.26	0.58	0.24	0.41
Interaction				
P*RA	NS	NS	NS	NS
P*SD	NS	NS	NS	NS
SD*RA	*	NS	NS	NS
P*SD*RA	NS	NS	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

WAS= Week after sowing

* = Significant at a 5% level of probability

SE± = Standard error

Table 4: Interaction of row arrangement and stand density on number of seed pod⁻¹ of Cowpea in Dutsin-Ma during 2023 rainy season

Treatment	Number of seed pod ⁻¹		
	Stand Density		
	1	2	3
Row Arrangement			
Single Row	12.5a	12.7a	12.5a
Double Row	12.2b	12.2b	12.5a
SE±		0.45	

Means followed by the same letters within column in each treatment group are not significant at 5% probability level according to DMRT

Number of seeds pod⁻¹ and number of pods plant⁻¹

Row arrangement and stand density did not significantly influence ($P > 0.05$) the number of seeds pod⁻¹ and pods plant⁻¹ at both locations (Table 3), indicating that these yield components were relatively stable across planting configurations. However, stand density showed a significant effect ($P < 0.05$) on seeds pod⁻¹ at Katsina, where two plants stand⁻¹, though comparable with one plant stand⁻¹, produced higher values, suggesting moderate density may enhance reproductive efficiency under constrained conditions (Wu et al., 2023).

Phosphorus application significantly affected ($P < 0.05$) both seeds pod⁻¹ and pods plant⁻¹ across locations (Table 3). Although phosphorus rates were largely at par, fertilized plots consistently outperformed the control, confirming phosphorus as a key limiting nutrient. This is

consistent with its role in flowering, pod formation, and seed development (Zheng et al., 2023). At Katsina, 13.2 kg P ha⁻¹, comparable with 26.4 kg P ha⁻¹, significantly increased pods plant⁻¹, indicating that moderate phosphorus supply was sufficient under the prevailing conditions. The lowest values observed at 0 kg P ha⁻¹ further emphasize the importance of phosphorus fertilization.

The interaction between row arrangement and stand density was significant ($P < 0.05$) for seeds pod⁻¹ at Dutsin-Ma, where two plants stand⁻¹ on a single row produced higher values (Table 4), suggesting improved resource utilization under this combination (Wu et al., 2023). Phosphorus fertilization had the most consistent effect on yield components, while planting configuration played a limited role, highlighting the importance of nutrient management in optimizing cowpea productivity.

Table 5: Effect of row arrangement, stand density and phosphorus fertilizer on pod yield plot⁻¹ of cowpeas in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Pod yield Plot ⁻¹ (g)	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	39.1	39.9
Double	39.7	38.8
SE±	1.16	0.85
Stand Density (SD)		
One	39.0	40.2
Two	38.6	39.6
Three	40.5	38.4
SE±	1.42	1.04
Phosphorus (kg ha⁻¹)		
0	25.3 ^b	28.7 ^b
13.2	42.3 ^a	45.1 ^a
26.4	45.4 ^a	42.0 ^a
39.6	44.4 ^a	41.8 ^a
SE±	1.64	1.20
Interaction		
P * RA	NS	NS
P * SD	NS	NS
SD * RA	NS	NS
P * SD * RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

WAS= Week after sowing

SE±= Standard error

Table 6: Effect of row arrangement, stand density and phosphorus fertilizer on 100 seed weight (g) of cowpeas in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	100 seed weight (g)	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	18.8	19.3
Double	18.7	19.3
SE±	0.13	0.07
Stand Density (SD)		
One	18.7	19.4
Two	18.8	19.2
Three	18.7	19.3
SE±	0.16	0.09
Phosphorus (kg ha⁻¹)		
0	18.5	19.0 ^b
13.2	19.1	19.4 ^a
26.4	18.9	19.3 ^a
39.6	18.5	19.5 ^a
SE±	0.63	0.10
Interaction		
P × RA	NS	NS
P × SD	NS	NS
SD × RA	NS	NS
P × SD × RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

WAS= Week after sowing

SE±= Standard error

Table 7: Effect of row arrangement, stand density and phosphorus fertilizer on grain yield hectare⁻¹ of cowpea in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Grain yield Hectare ⁻¹ (kg ha ⁻¹)	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	1315.1	1315.5
Double	1375.4	1345.8
SE±	8.07	9.86
Stand Density (SD)		
One	1356.0	1303.6
Two	1350.1	1327.5
Three	1329.5	1360.8
SE±	9.88	12.08
Phosphorus (kg ha⁻¹)		
0	1143.6 ^b	1134.5 ^c
13.2	1400.5 ^a	1347.8 ^b
26.4	1429.5 ^a	1403.3 ^a
39.6	1407.3 ^a	1437.0 ^a
SE±	11.41	13.94
Interaction		
P * RA	**	**
P * SD	NS	NS
SD * RA	NS	NS
P * SD * RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

SE±=Standard error

NS= Not Significant at a 5% level of probability

** = Significant at 1% level of probability

Table 8: Interaction of phosphorus and row arrangement on grain yield hectare⁻¹ of cowpea in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Grain yield hectare ⁻¹ (kg ha ⁻¹)			
	Dutsin-Ma		Katsina	
	Single Row	Double Row	Single Row	Double Row
Phosphorus kg P ha⁻¹				
0	1150.0c	1137.2c	1132.1c	1136.9c
13.2	1323.9b	1477.1a	1289.3b	1406.3b
26.4	1401.1a	1457.8a	1380.4b	1426.1a
39.6	1385.2a	1429.3a	1460.2a	1413.7b
SE±	16.14	16.14	19.71	19.71

Means followed by the same letters within column in each treatment group are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Pod yield plot⁻¹ (g)

Row arrangement and stand density did not significantly influence (P > 0.05) pod yield (plot⁻¹) across both locations (Table 5), indicating that planting configuration had minimal effect on final yield. This suggests that cowpea yield was more strongly controlled by nutrient availability than plant spatial arrangement (Hussain et al., 2023). In contrast, phosphorus application significantly affected (P < 0.05) pod yield at both Dutsin-Ma and Katsina. Although the phosphorus rates were statistically similar, all fertilized plots produced higher yields than the control, confirming phosphorus as a limiting nutrient. This aligns with its critical role in energy transfer, flowering, and pod development (Hussain et al., 2023).

The lowest pod yield observed at 0 kg P ha⁻¹ at both locations further emphasizes the importance of

phosphorus fertilization in enhancing cowpea productivity. The results highlight phosphorus nutrition as the dominant factor influencing pod yield under the prevailing conditions.

100 seed weight (g)

Row arrangement and stand density had no significant effect (P > 0.05) on 100-seed weight across both locations (Table 6), indicating that seed size was relatively stable and less influenced by planting geometry under the experimental conditions. This suggests that genetic factors and nutrient availability play a more dominant role in determining seed weight than spatial plant arrangement. Phosphorus application significantly influenced (P < 0.05) 100-seed weight only at Katsina, although all phosphorus-treated plots were statistically similar (Table 6). The response indicates that phosphorus contributed to

improved seed filling, even though differences among fertilizer rates were not pronounced. This aligns with the

role of phosphorus in energy transfer and assimilate partitioning during seed development (Wu et al., 2023).

Table 9: Effect of row arrangement, stand density and phosphorus fertilizer on harvest index of cowpea in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Harvest Index	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	65.3 ^b	65.3
Double	68.3 ^a	66.5
SE±	1.02	0.99
Stand Density (SD)		
One	68.4 ^a	63.6 ^b
Two	67.9 ^a	66.2 ^{ab}
Three	64.1 ^a	68.0 ^a
SE±	1.25	1.21
Phosphorus (kg ha⁻¹)		
0	64.6 ^b	62.3 ^b
13.2	69.2 ^a	65.6 ^{ab}
26.4	66.5 ^{ab}	66.2 ^{ab}
39.6	66.9 ^{ab}	69.6 ^a
SE±	1.45	1.40
Interaction		
P × RA	*	*
P × SD	NS	NS
SD × RA	NS	NS
P × SD × RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

WAS= Week after sowing

* = Significant at a 5% level of probability

SE±= Standard error

Table 10: Interaction of Phosphorus fertilizer rates and stand density on harvest index of cowpea in Dutsin-Ma during 2023 rainy season

Treatment	Harvest index		
	1	2	3
Phosphorus kg P ha⁻¹			
0	61.4c	60.3c	60.4c
13.2	72.7a	69.1a	65.8a
26.4	72.8a	65.7b	65.6a
39.6	64.2b	67.3b	64.1b
SE±		2.51	

Means followed by the same letters within column in each treatment group are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 11: Interaction of phosphorus fertilizer and row arrangement on harvest index of cowpea in Katsina during 2023 rainy season

Treatment	Harvest index	
	Single Row	Double Row
Phosphorus kg P ha⁻¹		
0	61.3c	63.3d
13.2	64.2b	67.0b
26.4	63.1b	69.3a
39.6	72.7a	66.4c
SE±		1.97

Means followed by the same letters within column in each treatment group are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 12: Effect of row arrangement, stand density and phosphorus fertilizer on shelling percentage of cowpea in Dutsin-Ma and Katsina during 2023 rainy season

Treatment	Shelling Percentage (S %)	
	Dutsin-Ma	Katsina
Row Arrangement (RA)		
Single	21.8 ^b	28.9
Double	23.2 ^a	31.4
SE±	2.36	2.61
Stand Density (SD)		
One	19.2	30.4
Two	25.1	28.6
Three	23.1	31.5
SE±	2.89	3.20
Phosphorus (kg ha⁻¹)		
0	14.0 ^b	17.1 ^b
13.2	21.9 ^{ab}	32.9 ^a
26.4	28.7 ^a	37.8 ^a
39.6	25.3 ^a	32.0 ^a
SE±	3.33	3.69
Interaction		
P * RA	NS	NS
P * SD	NS	NS
SD * RA	NS	NS
P * SD * RA	NS	NS

Means followed by the same letters within the column in each treatment group are not significantly different at a 5% probability level according to the Duncan Multiple Range Test (DMRT)

NS= Not Significant at a 5% level of probability

SE± = Standard error

Grain yield hectare⁻¹ (kg ha⁻¹)

Row arrangement and stand density did not significantly influence ($P > 0.05$) grain yield (kg ha⁻¹) at both locations, indicating that planting geometry alone was not a major determinant of final yield under the prevailing conditions (Table 7). This suggests that yield formation was more strongly governed by soil fertility status than spatial plant arrangement (Mishra et al., 2023).

In contrast, phosphorus application significantly affected ($P < 0.05$) grain yield across both Dutsin-Ma and Katsina. Although phosphorus rates were statistically similar in some cases, all fertilized treatments consistently outperformed the control (0 kg P ha⁻¹), confirming phosphorus as a key limiting nutrient for cowpea production. This is consistent with its central role in energy metabolism, reproductive development, and assimilate translocation (Mishra et al., 2023). The lowest grain yield recorded in the unfertilized plots further reinforces the importance of adequate phosphorus supply.

The interaction between phosphorus application and row arrangement was significant ($P < 0.05$) at both locations (Table 8), indicating that yield response depended on the combined effect of nutrient management and planting configuration. At Dutsin-Ma, application of 13.2 kg P ha⁻¹ under double-row arrangement produced the highest grain yield, although it was statistically comparable with 26.4 kg P ha⁻¹, suggesting that moderate phosphorus application combined with improved spatial arrangement was sufficient to optimize yield. (Wan et al., 2023).

At Katsina, a more variable response was observed, where 39.6 kg P ha⁻¹ under single-row arrangement and 26.4 kg P ha⁻¹ under double-row arrangement produced statistically similar and significantly higher yields. This indicates that higher phosphorus input was required to compensate for the relatively poorer soil conditions at Katsina. Such site-specific responses highlight the influence of soil fertility status on fertilizer efficiency and crop performance (Zubairu et al., 2023). The results highlighted that while planting configuration had limited independent effects, phosphorus fertilization particularly in interaction with row arrangement was the dominant factor determining grain yield. This underscores the importance of integrated nutrient and agronomic management for optimizing cowpea productivity across contrasting agro-ecological environments

Harvest index

Row arrangement significantly affected ($P < 0.05$) harvest index only at Dutsin-Ma, where double-row planting produced a higher harvest index (Table 9). This suggests improved partitioning of assimilates towards economic yield under optimized spatial arrangement. However, the effect was not consistent across locations, indicating environmental modulation of planting geometry responses (Mishra et al., 2023).

Stand density significantly influenced ($P < 0.05$) harvest index at both locations. At Dutsin-Ma, one and two plants stand⁻¹ performed similarly and recorded higher values, while at Katsina, the highest harvest index was observed at three plants stand⁻¹. This suggests that moderate to

higher plant population may enhance assimilate allocation to grains under more constrained environments, likely through competition-induced reproductive prioritization (Wan et al., 2023). Phosphorus application significantly increased ($P < 0.05$) harvest index across both locations. At Dutsin-Ma, 13.2 kg P ha⁻¹, although statistically similar

to higher rates, produced the highest harvest index, indicating efficient biomass partitioning at moderate phosphorus supply. At Katsina, 39.6 kg P ha⁻¹ was most effective, though comparable with lower rates, suggesting stronger phosphorus requirement under poorer soil conditions.

Table 13: Cost benefit analysis on investment of growing cowpea in Dutsin-Ma during 2023 rainy season

Treatment	Grain Yield (kg ha ⁻¹)	Average Price (₦ kg ⁻¹)	Gross Revenue (GR) (₦ ha ⁻¹)	Total Variable Cost (TVC) (₦ ha ⁻¹)	Gross Margin (GM = GR – TVC) (₦ ha ⁻¹)	Gross Margin per ₦ Invested
R ₁ S ₁ P ₁	1149.5	550	632,208.5	382,280	249,928.5	1.7
R ₁ S ₂ P ₁	1125.6	550	619,069.0	458,280	160,789.0	1.4
R ₁ S ₃ P ₁	1175.0	550	646,261.0	532,280	113,981.0	1.2
R ₂ S ₁ P ₁	1106.7	550	608,679.0	420,280	188,399.5	1.5
R ₂ S ₂ P ₁	1143.4	550	628,848.0	533,280	95,568.0	1.2
R ₂ S ₃ P ₁	1161.7	550	638,929.5	644,280	-5,350.5	1.0
R ₁ S ₁ P ₂	1342.8	550	738,540.0	436,280	302,260.0	1.7
R ₁ S ₂ P ₂	1300.6	550	715,319.0	512,280	203,039.0	1.4
R ₁ S ₃ P ₂	1328.4	550	730,598.0	586,280	144,318.0	1.3
R ₂ S ₁ P ₂	1508.4	550	829,598.0	474,780	354,818.0	1.8
R ₂ S ₂ P ₂	1481.7	550	814,935.0	587,280	227,655.0	1.4
R ₂ S ₃ P ₂	1441.1	550	792,627.0	698,280	94,347.0	1.1
R ₁ S ₁ P ₃	1473.4	550	810,348.0	454,280	356,068.0	1.8
R ₁ S ₂ P ₃	1423.4	550	782,848.0	530,280	252,568.0	1.5
R ₁ S ₃ P ₃	1306.7	550	718,679.5	604,280	114,399.5	1.2
R ₂ S ₁ P ₃	1460.6	550	803,319.0	492,780	310,539.0	1.6
R ₂ S ₂ P ₃	1477.8	550	812,795.5	605,280	207,515.5	1.3
R ₂ S ₃ P ₃	1435.0	550	789,266.5	716,280	72,986.5	1.1
R ₁ S ₁ P ₄	1427.8	550	785,295.5	544,780	240,515.5	1.4
R ₁ S ₂ P ₄	1420.6	550	781,319.0	620,780	160,539.0	1.3
R ₁ S ₃ P ₄	1307.3	550	718,987.5	694,780	24,207.5	1.0
R ₂ S ₁ P ₄	1378.9	550	758,406.0	583,280	175,126.0	1.3
R ₂ S ₂ P ₄	1427.8	550	785,290.0	695,780	89,510.0	1.1
R ₂ S ₃ P ₄	1481.1	550	814,627.0	806,780	7,847.0	1.0

GR: Gross Revenue
R: Row arrangement

TVC: Total Variable Cost
S: Stand density

P: Phosphorus Rate

These responses reflect the central role of phosphorus in enhancing assimilate translocation and reproductive development (Zubairu et al., 2023). The lowest harvest index recorded in the control plots confirms that phosphorus deficiency reduces reproductive efficiency. Significant interactions between phosphorus and stand density (Dutsin-Ma Table 10) and between phosphorus and row arrangement (Katsina Table 11) further demonstrate that harvest index is influenced by combined management practices rather than single factors alone (Zubairu et al., 2023). At Dutsin-Ma, 13.2 and 26.4 kg P ha⁻¹ under one plant stand⁻¹ produced similar and superior values, indicating efficient resource use under moderate fertilization (Zubairu et al., 2023).

At Katsina, 39.6 kg P ha⁻¹ under single-row arrangement significantly improved harvest index, highlighting the need for higher nutrient input under less favourable soil conditions (Zubairu et al., 2023). The results indicate that harvest index was more responsive to phosphorus

nutrition and its interaction with planting configuration than to either factor alone, emphasizing the importance of integrated agronomic management for optimizing cowpea productivity.

Shelling percentage (S %)

Row arrangement significantly influenced ($P < 0.05$) shelling percentage only at Dutsin-Ma, where double-row planting increased shelling percentage (Table 12). This suggests that improved spatial arrangement enhanced assimilate distribution to pods and improved grain filling efficiency under this location (Feng et al., 2023). However, the absence of a significant effect at Katsina indicates that environmental or soil limitations likely constrained the response to planting geometry (Feng et al., 2023). Stand density had no significant effect ($P > 0.05$) on shelling percentage at both locations, implying that pod filling efficiency was relatively stable across the tested plant populations. This suggests that within the range of densities used, assimilate partitioning to grains was not strongly altered by plant competition (Feng et al., 2023).

Table 14: Cost benefit analysis on investment of growing cowpea in Katsina during 2023 rainy season

Treatment	Grain Yield (kg ha ⁻¹)	Average Price (kg ha ⁻¹)	GR (₦ kg ⁻¹)	TVC (₦ ha ⁻¹)	GM= GR - TVC (₦ kg ⁻¹)	Gross Margin Per ₦ Invested
R ₁ S ₁ P ₁	1118.4	550	615,098.0	382,280	232,818.0	1.6
R ₁ S ₂ P ₁	1132.8	550	623,040.0	458,280	164,760.0	1.4
R ₁ S ₃ P ₁	1145.0	550	629,761.0	532,280	97,481.0	1.2
R ₂ S ₁ P ₁	1128.4	550	620,598.0	420,280	200,318.0	1.5
R ₂ S ₂ P ₁	1153.4	550	634,348.0	533,280	101,068.0	1.2
R ₂ S ₃ P ₁	1128.9	550	620,900.5	644,280	-23,379.5	1.0
R ₁ S ₁ P ₂	1140.0	550	627,011.0	436,280	190,731.0	1.4
R ₁ S ₂ P ₂	1293.9	550	711,650.5	512,280	199,370.5	1.4
R ₁ S ₃ P ₂	1433.9	550	788,656.0	586,280	202,376.0	1.4
R ₂ S ₁ P ₂	1433.4	550	788,348.0	474,780	313,568.0	1.7
R ₂ S ₂ P ₂	1376.7	550	757,179.5	587,280	169,899.5	1.3
R ₂ S ₃ P ₂	1408.9	550	774,906.0	698,280	76,626.0	1.1
R ₁ S ₁ P ₃	1319.5	550	725,708.5	454,280	271,428.5	1.6
R ₁ S ₂ P ₃	1396.7	550	768,179.5	530,280	237,899.5	1.5
R ₁ S ₃ P ₃	1425.0	550	783,766.5	604,280	179,486.5	1.3
R ₂ S ₁ P ₃	1420.0	550	781,016.5	492,780	288,236.5	1.6
R ₂ S ₂ P ₃	1405.6	550	773,069.0	605,280	167,789.0	1.3
R ₂ S ₃ P ₃	1452.8	550	799,045.5	716,280	82,765.5	1.1
R ₁ S ₁ P ₄	1481.1	550	814,627.0	544,780	269,847.0	1.5
R ₁ S ₂ P ₄	1439.5	550	791,708.5	620,780	170,928.5	1.3
R ₁ S ₃ P ₄	1460.0	550	803,016.5	694,780	108,236.5	1.2
R ₂ S ₁ P ₄	1388.4	550	763,598.0	583,280	180,318.0	1.3
R ₂ S ₂ P ₄	1421.1	550	781,627.0	695,780	85,847.0	1.1
R ₂ S ₃ P ₄	1431.7	550	787,435.0	806,780	-19,345.0	1.0

GR: Gross Revenue
R: Row arrangement

TVC: Total Variable Cost
S: Stand density

P: Phosphorus Rate

Phosphorus application significantly affected ($P < 0.05$) shelling percentage at both locations. At Dutsin-Ma, 26.4 and 39.6 kg P ha⁻¹ were statistically similar but, along with 13.2 kg P ha⁻¹, significantly improved shelling percentage compared to the control. At Katsina, all phosphorus-treated plots were statistically similar, indicating a uniform response across fertilizer rates. The lowest shelling percentage recorded in the control plots confirms that phosphorus deficiency reduces pod filling efficiency and grain development. This is consistent with the role of phosphorus in energy transfer and assimilate translocation during reproductive growth (Khan et al., 2014).

The results indicate that shelling percentage was more responsive to phosphorus nutrition than to planting configuration, with improved responses observed particularly in fertilized plots. This highlights phosphorus as a key determinant of grain filling efficiency in cowpea under the studied agro-ecological conditions.

Cost benefit analysis on investment of growing cowpea in Dutsin-Ma and Katsina during 2023 rainy season

The cost benefit analysis (Table 13) revealed clear differences in profitability among treatment combinations at both locations, indicating the economic importance of optimizing agronomic practices. At Dutsin-Ma, the combination of single-row arrangement, one stand density, and 26.4 kg P ha⁻¹ (R1S1P3) produced the highest

net return (₦356,068.00) with a benefit cost ratio of 1.78. This suggests that moderate phosphorus application combined with optimal plant population enhances resource use efficiency and economic returns. In contrast, the combination of double-row arrangement, three stand density, and zero phosphorus application (R2S3P1) resulted in a near loss (₦-5,350.50) with a benefit cost ratio of 0.99, indicating that inadequate nutrient supply and excessive plant competition reduce profitability.

Similarly, at Katsina, the most profitable treatment was double-row arrangement with one stand density and 13.2 kg P ha⁻¹ (R2S1P2) (Table 14), which yielded a net return of ₦313,568.00 and a benefit–cost ratio of 1.66. This indicates that under relatively poorer soil conditions, moderate phosphorus input combined with appropriate plant spacing can optimize economic yield. Conversely, the least profitable treatment (R2S3P1) involving high plant density and no phosphorus application resulted in a net loss (₦-23,379.50) and a benefit–cost ratio below unity (0.96), reflecting inefficient resource utilization.

The results highlighted that profitability is strongly influenced by the interaction between nutrient management and planting configuration. Moderate phosphorus application (13.2–26.4 kg P ha⁻¹) combined with lower stand density consistently improved economic returns, while the absence of phosphorus and higher plant density reduced profitability. These findings align with established reports that balanced fertilization and optimal

plant population are essential for maximizing both yield and economic efficiency in crop production systems (Oyebamiji et al., 2017).

CONCLUSION

The study found that phosphorus fertilizer significantly improved cowpea productivity, while row arrangement and stand density had limited individual effects but showed notable results when combined with phosphorus application. Moderate phosphorus rates (13.2–26.4 kg P ha⁻¹) were most effective, especially when aligned with a suitable row arrangement specific to each location. Lastly, integrating appropriate phosphorus application with a suitable row arrangement is paramount to optimizing cowpea yield in the Sudan savanna.

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