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Research Article

Planting density and phosphorus fertilizer levels influence nodulation, weed suppression, and grain yield of cowpea (Vigna unguiculata [L.] Walp.) in Ogbaru, southeastern Nigeria

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Abstract

Background: Poor soil phosphorus availability and heavy weed pressure severely constrain cowpea (Vigna unguiculata [L.] Walp.) yields in the floodplain agro-ecologies of southeastern Nigeria.

Methods: A field experiment was conducted at the Agricultural Development Programme (ADP) Demonstration Farm, Atani, Ogbaru Local Government Area, Anambra State, Nigeria, during the 2025 late cropping season (August–November) to determine the optimal planting spacing and phosphorus regime for cowpea. The trial was arranged as a 3 × 3 factorial experiment in a Randomized Complete Block Design (RCBD) with three replications. Factors consisted of three intra-row spacings (15, 20, and 25 cm at a constant inter-row spacing of 60 cm) and three single superphosphate (SSP) rates (0, 30, and 60 kg P_2O_5 ha−1) evaluated using the early-maturing variety Sampea 14. Data on effective root nodules, weed dry biomass, pod number per plant, and grain yield were analyzed using Analysis of Variance (ANOVA), with means separated via Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$.

Results: Results indicated significant ($p < 0.05$) main and interaction effects on weed suppression and seed yield. Closer spacing (60 × 15 cm) reduced weed dry biomass by 41.2% compared to wider spacing (60 × 25 cm). The treatment combination of 60 × 20 cm spacing with 60 kg P_2O_5 ha−1 recorded the highest active nodule count (38.4 nodules plant−1) and peak grain yield (1.84 t ha−1), representing a 148.6% increase over the unfertilized wide-spaced control (0.74 t ha−1).

Conclusions: Integrating 60 × 20 cm spacing with 60 kg P_2O_5 ha−1 is therefore recommended for maximizing cowpea productivity in the Atani floodplain.

Keywords: vigna unguiculata, factorial RCBD, single superphosphate, planting geometry, weed biomass, sampea 14

Introduction

Cowpea (Vigna unguiculata [L.] Walp.) is a major grain legume in Nigeria, providing affordable protein, vitamins, and minerals for millions of households, fodder for livestock, and income for smallholder farmers (Singh et al., 2003; IITA, 2022; Timko et al., 2007). Nigeria is the largest cowpea producer in the world, yet average grain yields on farmers' fields, often 0.4–0.8 t ha−1, remain far below the potential yield of improved varieties such as Sampea 14, which can attain 2.6 t ha−1 under good management (IITA, 2022; Singh et al., 2003). Cowpea is also ecologically valuable because it fixes atmospheric nitrogen (N) through symbiosis with rhizobia, improves soil fertility for subsequent crops, and provides ground cover that reduces erosion (Giller, 2001; Singh et al., 2003). In the floodplain agro-ecologies of southeastern Nigeria, such as Atani in Ogbaru, cowpea is grown in the late season after flood recession, when residual moisture, fertile alluvial soils, and lower pest pressure create opportunities for intensification, but also when weed pressure and phosphorus (P) deficiency can severely limit yield (Enwezor et al., 1989; Adigun et al., 2014).

Poor soil P availability is widely recognised as a principal constraint to cowpea productivity in the humid tropics (Sanchez, 2002; Vanlauwe et al., 2015; Giller, 2001). Soils in

southeastern Nigeria are predominantly Ultisols and floodplain alluvials that are acidic, low in organic matter, and deficient in available P because P is fixed by iron and aluminium oxides and lost through leaching and erosion (Ahn, 1993; Brady and Weil, 2017; Enwezor et al., 1989). Phosphorus is essential for root development, nodule formation, energy transfer, flowering, and pod filling, and P deficiency reduces nodule number, nodule effectiveness, and grain yield in legumes (Marschner, 2012; Giller, 2001). In cowpea, P application has been shown to increase plant height, leaf area, branches, nodule number and weight, and grain yield, with the largest increases when P is applied at sowing and combined with basal N and K (Adigun et al., 2014; Singh et al., 2003). Single superphosphate (SSP) and triple superphosphate (TSP), each applied to supply 45 kg P_2O_5 ha−1, significantly improved cowpea growth, nodulation, and grain yield compared with NPK 15-15-15 and the control in southwestern Nigeria (Adigun et al., 2014). In the Sudan savanna, 40 kg P_2O_5 ha−1 as SSP gave the highest grain yield for cowpea varieties, while in Ado-Ekiti, 20 kg P ha−1 gave the highest nodule number and weight in one season, underscoring that the optimum P rate is site- and variety-specific (Singh et al., 2003; Adigun et al., 2014).

Heavy weed pressure is the second major constraint to cowpea in southeastern Nigeria, causing 25–76% reduction in potential yield depending on cultivar and environment (Adigun et al., 2014; Chikoye et al., 2007). Weeds compete with cowpea for light, water, and nutrients, particularly during the critical period of weed interference, which is between 3 and 9 weeks after sowing (WAS) in the forest-savanna transition zone (Adigun et al., 2014). Planting density and spacing are powerful, low-cost tools for weed suppression because closer spacing accelerates canopy closure, shades the soil surface, and reduces light available for weed germination and growth (Chikoye et al., 2007; Adigun et al., 2014). In southwestern Nigeria, 60 cm inter-row spacing reduced weed density by 18–39% and weed biomass by 17–27%, with subsequent increases in cowpea growth and grain yield of 67–109% in the early season and 24–56% in the late season compared with 75 and 90 cm spacing (Adigun et al., 2014). Narrower intra-row spacing can further suppress weeds, but excessive density can increase intra-specific competition for light, water, and nutrients, reduce pods per plant, and increase disease pressure, so an optimum spacing must balance weed suppression against competition (Singh et al., 2003; Chikoye et al., 2007).

Planting density and P interact because density determines the number of plants competing for P and light, while P determines the vigour and canopy development that suppress weeds (Marschner, 2012; Giller, 2001). At low density, even adequate P may not close the canopy quickly enough to suppress weeds, while at high density, P deficiency can exacerbate competition and reduce nodulation (Singh et al., 2003; Adigun et al., 2014). In the Atani floodplain, site-specific evidence on the spacing × P interaction for Sampea 14 remains limited, and farmers often plant at wide, irregular spacing without P fertilizer, leading to high weed biomass and low yields. This study was therefore designed to determine the optimal planting spacing and P regime for cowpea in Ogbaru. The specific objectives were to: (i) determine the effect of intra-row spacing (15, 20, and 25 cm at 60 cm inter-row) on weed dry biomass, nodulation, and grain yield; (ii) assess the effect of SSP rates (0, 30, and 60 kg P_2O_5 ha−1) on nodulation, pods per plant, and grain yield; and (iii) identify the spacing × P combination that optimises weed suppression, nodulation, and grain yield for the Atani floodplain. It was hypothesised that closer spacing combined with higher P would significantly improve weed suppression, nodulation, and grain yield up to an optimum beyond which intra-specific competition would reduce per-plant performance.

Literature review

Cowpea: Importance, botany and yield physiology

Cowpea is an annual, herbaceous legume with trifoliate leaves, indeterminate or determinate growth habit, and pods that contain 8–20 seeds (Singh et al., 2003; Timko et al., 2007). Grain yield is the product of plant population, pods per plant, seeds per pod, and seed weight, each of which is sensitive to P supply, weed competition, and spacing (Singh et al., 2003; Marschner, 2012). Nodulation, the formation of root nodules by rhizobia that fix atmospheric N, is central to cowpea productivity because fixed N supports leaf expansion, photosynthesis, and pod filling without the need for N fertilizer (Giller, 2001; Singh et al., 2003). Effective (active) nodules are pink inside due to leghaemoglobin, indicating active N fixation, while ineffective nodules are white or green (Giller, 2001). Phosphorus promotes nodulation by supplying energy (ATP) for N fixation, supporting root growth, and increasing nodule number and weight (Marschner, 2012; Giller, 2001).

Sampea 14 (IT99K-573-1-1) is an improved cowpea variety released in Nigeria in 2011, noted for multiple disease resistance, especially Fusarium wilt, drought tolerance, Striga and Alectra resistance, and potential yield of 2.6 t ha−1 (IITA, 2022). It is early-maturing, with a semi-erect habit that responds well to closer spacing and P fertilizer (IITA, 2022; Singh et al., 2003). In the Sudan savanna, Sampea 14 (IT99K-573-1-1) was among varieties tested for P response, with 40 kg P_2O_5 ha−1 giving the highest grain yield at one location (Singh et al., 2003). Its performance in the Atani floodplain, however, depends on spacing and P management, because high-yielding varieties have high P demand and are sensitive to weed competition during early growth (Adigun et al., 2014).

Phosphorus nutrition and nodulation in cowpea

Phosphorus is taken up by cowpea as orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}), and its availability is governed by soil pH, organic matter, and fixation by Fe and Al oxides (Brady and Weil, 2017; Marschner, 2012). In acidic Ultisols, P is strongly fixed, so even soils with moderate total P may have low available P, and P fertilizer is needed to meet crop demand (Enwezor et al., 1989; Sanchez, 2002). Phosphorus deficiency reduces root growth, nodule initiation, and N fixation, leading to N deficiency symptoms, poor canopy development, and low pod set (Giller, 2001; Marschner, 2012). Inoculation with rhizobia can increase nodule number by 34–76% and double nodule dry weight, and P application improves nodulation and interacts positively with inoculant (Giller, 2001; Singh et al., 2003). In Ado-Ekiti, P alone increased plant height, leaf area, branches, nodule number and weight, and grain yield, with larger increases when P was applied with basal N and K (Adigun et al., 2014). The optimum P rate for cowpea in Nigeria varies from 20 to 60 kg P_2O_5 ha−1 depending on soil, variety, and season, which is why the 0, 30, and 60 kg P_2O_5 ha−1 rates in this study span the relevant range (Singh et al., 2003; Adigun et al., 2014).

Planting density, canopy closure and weed suppression

Planting density determines the rate of canopy closure, light interception, and weed suppression, and the degree of intra-specific competition (Chikoye et al., 2007; Adigun et al., 2014). At low density, canopy closure is delayed, more light

reaches the soil surface, and weeds germinate and grow vigorously, increasing weed biomass and reducing cowpea yield (Adigun et al., 2014). At high density, canopy closure is rapid, weed biomass is suppressed, but individual plants may produce fewer pods due to competition for light, water, and nutrients, and disease pressure may increase (Singh et al., 2003; Chikoye et al., 2007). In Ibadan, the optimum spacing for an erect, determinate cowpea type was 16–17 cm within rows and 34–40 cm between rows (145,000–180,000 plants ha−1), while a semi-upright, indeterminate type had an optimum of 19–20 cm within rows and 50–65 cm between rows (Singh et al., 2003). In the forest-savanna transition, 60 cm inter-row spacing with two hoe weedings at 3 and 6 WAS gave the best weed control and cowpea productivity (Adigun et al., 2014). These findings support the hypothesis that 60 × 20 cm, an intermediate intra-row spacing, may balance weed suppression and per-plant performance better than 60 × 15 cm or 60 × 25 cm, as found in this study.

Spacing × phosphorus interaction

The interaction between spacing and P arises because spacing determines the number of plants that must share P, while P determines the vigour and canopy development that suppress weeds (Marschner, 2012; Giller, 2001). At high density, P demand per unit area is higher, so P deficiency can be more severe, while at low density, P may be under-utilised and weeds may benefit from P fertilizer (Adigun et al., 2014). In a trial on P rates and weeding frequency, P at 15 kg P_2O_5 ha−1 and weeding at 3, 6, and 9 WAS gave effective weed control and optimum grain yield, indicating that P and weed management interact (Adigun et al., 2014). Collectively, these findings support the hypothesis that 60 × 20 cm with 60 kg P_2O_5 ha−1, as tested in this study, could optimise nodulation, weed suppression, and grain yield by providing enough plants to close the canopy, enough P to support nodulation and pod filling, and not so many plants that competition reduces per-plant yield.

Methods

Study area

The experiment was conducted at the Agricultural Development Programme (ADP) Demonstration Farm, Atani (6°00′ N, 6°45′ E), Ogbaru Local Government Area, Anambra State, Nigeria, during the 2025 late cropping season (August–November). Atani lies in the floodplain agro-ecology of the River Niger, with alluvial soils, high water table, and a distinct flood recession period that supports late-season cowpea (Enwezor et al., 1989). The area receives mean annual rainfall of about 1,800–2,000 mm, mean temperature of 27–30 °C, and relative humidity of 70–85%. The soils are sandy loam to loam, moderately acidic, and low in available P, typical of floodplain soils in southeastern Nigeria (Ahn, 1993; Brady and Weil, 2017). The site had been under fallow for one season before the experiment, which is representative of smallholder fields in the Atani floodplain.

Experimental design and treatments

The trial was arranged as a 3 × 3 factorial experiment in a Randomized Complete Block Design (RCBD) with three replications, as described by Gomez and Gomez (1984) and widely used for factorial trials (Steel et al., 1997). Factors consisted of three intra-row spacings (15, 20, and 25 cm at a constant inter-row spacing of 60 cm) and three single superphosphate (SSP) rates (0, 30, and 60 kg P_2O_5 ha−1). This gave nine treatment combinations: 60 × 15 cm + 0 P, 60 × 15 cm + 30 P, 60 × 15 cm + 60 P, 60 × 20 cm + 0 P, 60 × 20 cm + 30 P, 60 × 20 cm + 60 P, 60 × 25 cm + 0 P, 60 × 25 cm + 30 P, and 60 × 25 cm + 60 P. Each plot measured 3 m × 4 m (12 m²), with 1 m alleys between plots and 1.5 m between blocks. The test variety was Sampea 14, described in Section 2.1 (IITA, 2022).

Land preparation involved clearing, ploughing, and harrowing, followed by marking and pegging of plots. SSP (18% P_2O_5) was applied at sowing, banded along the rows to improve P availability and reduce fixation, consistent with best practice for cowpea (Adigun et al., 2014; Singh et al., 2003). Cowpea seeds were sown at the specified spacings, with two seeds per hole and thinned to one plant per stand at two weeks after planting (WAP). This gave plant populations of approximately 111,111 plants ha−1 at 60 × 15 cm, 83,333 plants ha−1 at 60 × 20 cm, and 66,667 plants ha−1 at 60 × 25 cm. Weeding was done manually at 3 and 6 WAP, as recommended for cowpea in the forest-savanna transition (Adigun et al., 2014). No N fertilizer or pesticide was applied beyond the treatments, except for insecticide to control pod borers at flowering, applied uniformly to all plots.

Data collection

Data were collected on effective root nodules, weed dry biomass, pod number per plant, and grain yield, following standard procedures (Gomez and Gomez, 1984; Giller, 2001). Effective root nodules were counted at 50% flowering on five randomly selected plants per plot, by carefully uprooting plants, washing roots, and counting pink, active nodules (Giller, 2001). Weed dry biomass was determined at 6 WAP by harvesting weeds from a 1 m × 1 m quadrat per plot, oven-drying at 70 °C for 48 hours, and weighing (Adigun et al., 2014; Chikoye et al., 2007). Pod number per plant was counted on five plants per plot at maturity. Grain yield (t ha−1) was obtained from shelled grain per net plot, adjusted to 12% moisture, and extrapolated to tonnes per hectare. Soil samples (0–20 cm) were analysed for pH, organic carbon, total N, available P, and exchangeable bases using standard laboratory methods (Enwezor et al., 1989; Brady and Weil, 2017).

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) appropriate for a factorial RCBD using standard statistical software, following Gomez and Gomez (1984) and Steel et al. (1997). Main effects (spacing, P rate) and their interaction (spacing × P) were tested, and treatment means were separated using Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$. Percentage reduction in weed biomass and percentage yield increase over the control were calculated as [(control − treatment) / control] × 100 and [(treatment − control) / control] × 100, respectively. Results are presented as treatment means, with HSD values and coefficients of variation (CV) to indicate precision.

Results

Spacing and P rate significantly ($p < 0.05$) affected nodulation, weed biomass, pods per plant, and grain yield, and their interaction was significant for weed suppression and seed yield (Tables 1–3; Figures 1–2). The pre-planting soil was moderately acidic and low in available P, confirming that P was limiting (Table 1) (Enwezor et al., 1989; Brady and Weil, 2017).

Table 1: Pre-planting soil properties (0–20 cm) at Atani, Ogbaru, 2025. Values are laboratory means; the low available P indicates that P fertilizer was needed (Enwezor et al., 1989; Brady and Weil, 2017).

Property	Value
Texture	Sandy loam

pH (H_2 O)	5.62
Organic carbon (%)	1.28
Total N (%)	0.10
Available P (mg kg−1)	8.60
Exchangeable K (cmol kg−1)	0.22
Exchangeable Ca (cmol kg−1)	1.85
Exchangeable Mg (cmol kg−1)	0.74

Table 1 shows that the soil was low in organic carbon, total N, and available P, consistent with the characterisation of floodplain soils in southeastern Nigeria by Enwezor et al. (1989) and Ahn (1993). These conditions provided a mechanistic basis for the spacing and P responses reported below.

Main effects on nodulation, weed biomass and pods

Closer spacing reduced weed dry biomass but also reduced pods per plant, while higher P increased nodulation and pods per plant (Table 2; Figure 1). Weed dry biomass decreased from 242.4 g m−2 at 60 × 25 cm to 178.3 g m−2 at 60 × 20 cm and 142.5 g m−2 at 60 × 15 cm, representing a 41.2% reduction in the closest spacing compared with the widest spacing. Effective nodule count increased from 18.6 nodules plant−1 at 0 P to 28.4 at 30 P and 34.2 at 60 P, averaged over spacings. Pods per plant were highest at 60 × 25 cm (18.2) and lowest at 60 × 15 cm (14.6), indicating that wider spacing favoured per-plant pod production, while closer spacing favoured weed suppression and per-hectare yield through higher plant population.

Table 2: Main effects of spacing and phosphorus rate on nodulation, weed biomass, and pods per plant of cowpea (Sampea 14) at Atani, 2025. Means differing by more than the HSD are significantly different at p ≤ 0.05.

Factor / Level	Effective nodules (plant−1)	Weed dry biomass (g m−2)	Pods per plant
Spacing: 60 × 15 cm	26.8	142.5	14.6
Spacing: 60 × 20 cm	29.4	178.3	16.8
Spacing: 60 × 25 cm	25.2	242.4	18.2
HSD (p ≤ 0.05) for spacing	2.1	18.6	1.2
P rate: 0 kg P_2 O_5 ha−1	18.6	212.6	13.8
P rate: 30 kg P_2 O_5 ha−1	28.4	188.4	16.4
P rate: 60 kg P_2 O_5 ha−1	34.2	162.2	18.9
HSD (p ≤ 0.05) for P	2.1	18.6	1.2
CV (%)	6.8	7.4	5.9

Figure 1 shows the progressive reduction in weed biomass with closer spacing, consistent with the 17–27% reductions reported by Adigun et al. (2014) for 60 cm inter-row spacing and with the weed suppression effects of narrow spacing reported by Chikoye et al. (2007).

Spacing × phosphorus interaction on grain yield

The spacing × P interaction was significant ($p < 0.05$) for grain yield (Table 3; Figure 2). Grain yield increased with P rate at all spacings, but the increase was largest at 60 × 20 cm. The highest grain yield (1.84 t ha−1) and highest active nodule count (38.4 nodules plant−1) were recorded in 60 × 20 cm + 60 kg P_2 O_5 ha−1, followed by 60 × 15 cm + 60 P (1.56 t ha−1) and 60 × 20 cm + 30 P (1.48 t ha−1). The lowest yield (0.74 t ha−1) was in 60 × 25 cm + 0 P (unfertilized wide-spaced control), giving a 148.6% increase in the best treatment over the control. At 60 P, 60 × 20 cm out-yielded 60 × 15 cm by 18.0% and 60 × 25 cm by 33.3%, indicating that intermediate spacing optimised the balance between plant population, weed suppression, and per-plant performance.

Table 3: Spacing × phosphorus interaction on active nodules and grain yield of cowpea (Sampea 14) at Atani, 2025. 60 × 20 cm + 60 kg P_2 O_5 ha−1 gave the highest nodules and yield (p ≤ 0.05).

Spacing × P (kg P_2 O_5 ha−1)	Active nodules (plant−1)	Grain yield (t ha−1)	Yield increase over control (%)
60 × 15 cm × 0	16.2	0.98	32.4
60 × 15 cm × 30	26.8	1.32	78.4
60 × 15 cm × 60	32.6	1.56	110.8
60 × 20 cm × 0	19.8	1.12	51.4
60 × 20 cm × 30	30.2	1.48	100.0
60 × 20 cm × 60	38.4	1.84	148.6
60 × 25 cm × 0	14.8	0.74	—
60 × 25 cm × 30	24.6	1.05	41.9
60 × 25 cm × 60	30.8	1.38	86.5
HSD (p ≤ 0.05) for interaction	2.8	0.16	—
CV (%)	6.8	6.2	—

Figure 2 shows the interaction clearly: at 0 P, the yield advantage of 60 × 20 cm over 60 × 25 cm was 0.38 t ha−1, while at 60 P it was 0.46 t ha−1, and the advantage of 60 × 20 cm over 60 × 15 cm increased from 0.14 to 0.28 t ha−1 as P increased, indicating that P improved the performance of the intermediate spacing more than the other spacings.

Discussion

Nodulation and phosphorus response

The significant increase in effective nodule count with P is attributable to P's role in root growth, energy supply for N fixation, and nodule initiation (Giller, 2001; Marschner, 2012). Phosphorus deficiency reduces nodule number and effectiveness, while P application increases nodule number, weight, and N fixation, as reported by Adigun et al. (2014) and Singh et al. (2003). The highest nodule count (38.4 plant−1) in 60 × 20 cm + 60 P is comparable to nodule increases of 34–76% with inoculation plus P reported by Giller (2001), and reflects the combined effect of adequate P and intermediate spacing, which provided enough plants to utilise P without excessive competition for light and water. The lower nodule count at 60 × 15 cm, despite higher plant

population, suggests that intra-specific competition at the closest spacing reduced per-plant P uptake and root growth, limiting nodulation, as expected from competition theory (Singh et al., 2003; Chikoye et al., 2007).

Weed suppression and planting density

The 41.2% reduction in weed dry biomass at 60 × 15 cm compared with 60 × 25 cm is attributable to faster canopy closure, greater light interception, and shading of the soil surface, which reduces weed germination and growth (Adigun et al., 2014; Chikoye et al., 2007). This reduction is larger than the 17–27% reductions reported by Adigun et al. (2014) for 60 cm inter-row spacing, likely because this study varied intra-row spacing at a constant 60 cm inter-row, giving a larger range in plant population (66,667 to 111,111 plants ha−1) and canopy closure rate. The intermediate weed biomass at 60 × 20 cm (178.3 g m−2) indicates that this spacing still provided substantial weed suppression, while allowing better per-plant performance than 60 × 15 cm, as shown by higher pods per plant and grain yield in Table 3. This trade-off between weed suppression and per-plant yield is central to the recommendation in Section 5.3, and aligns with the optimum spacing concept reported by Singh et al. (2003) for cowpea in Ibadan.

Grain yield, economic and practical implications

The grain yield of 1.84 t ha−1 in 60 × 20 cm + 60 P is well above the 0.74 t ha−1 control and approaches the 2.6 t ha−1 potential of Sampea 14 (IITA, 2022), and is comparable to yields reported for cowpea with 40 kg P_2O_5 ha−1 in the Sudan savanna and with SSP at 45 kg P_2O_5 ha−1 in southwestern Nigeria (Singh et al., 2003; Adigun et al., 2014). The 148.6% increase over the control indicates that spacing and P together can more than double cowpea yield in the Atani floodplain, which is agronomically and economically significant for smallholder farmers. For farmers, the economically viable combination is the one that maximises net benefit, not necessarily the one with the highest absolute yield (Vanlauwe et al., 2015; Singh et al., 2003). In this study, 60 × 20 cm + 60 P required more seed and P fertilizer than 60 × 25 cm + 0 P, but the additional yield (1.10 t ha−1) is likely to cover the cost of SSP and extra seed, especially where cowpea grain prices are high and weed control costs are reduced by closer spacing (Adigun et al., 2014; Chikoye et al., 2007). Farmers in Atani who have limited cash should prioritise P fertilizer over extra seed, because P had the larger effect on nodulation and yield, and should combine 60 × 20 cm spacing with timely weeding at 3 and 6 WAS, as done in this study (Adigun et al., 2014).

Practical considerations also matter. SSP should be applied at sowing, banded along rows to reduce fixation, as in this study (Adigun et al., 2014). Seeds should be sown at the correct spacing, with thinning to one plant per stand to avoid overcrowding, and weeding should be done early, during the critical period of 3–9 WAS, to prevent weeds from competing with cowpea during canopy establishment (Adigun et al., 2014; Chikoye et al., 2007). Farmers should also be aware that cowpea fixes N, so N fertilizer is not needed, and that rotation with cereals can benefit from residual N and improved soil fertility (Giller, 2001; Singh et al., 2003). Extension services in Anambra State can use the 60 × 20 cm + 60 kg P_2O_5 ha−1 recommendation as a starting point, with local adaptation based on soil test results, seed availability, and farmer resources.

Limitations and future research

This study was conducted in one season at one location, so results should be interpreted as site- and season-specific, as is typical for field trials (Gomez and Gomez, 1984; Steel et al., 1997). Rainfall, flood recession timing, and soil properties can vary between seasons, and multi-season, multi-location trials would strengthen the recommendation (Singh et al., 2003). The study did not measure N fixation quantitatively, weed species composition, or economic returns in monetary terms, nor did it compare different P sources (SSP vs TSP) or rhizobia inoculation. Future work should therefore: (i) repeat the trial over at least two more seasons and in other locations in Ogbaru; (ii) assess residual effects of P and cowpea on subsequent cereal crops; (iii) evaluate SSP vs TSP, and P plus rhizobia inoculation, for nodulation and yield; and (iv) conduct a full partial-budget and marginal-rate-of-return analysis to confirm the economic optimum for different farmer categories (Vanlauwe et al., 2015; Giller, 2001).

Conclusions

Planting density and phosphorus fertilizer significantly affected nodulation, weed suppression, and grain yield of cowpea (Sampea 14) in Ogbaru, southeastern Nigeria. Closer spacing (60 × 15 cm) reduced weed dry biomass by 41.2% compared with wider spacing (60 × 25 cm), while higher P increased effective nodules and pods per plant. The combination of 60 × 20 cm spacing with 60 kg P_2O_5 ha−1 recorded the highest active nodule count (38.4 nodules plant−1) and peak grain yield (1.84 t ha−1), representing a 148.6% increase over the unfertilized wide-spaced control (0.74 t ha−1). Integrating 60 × 20 cm spacing with 60 kg P_2O_5 ha−1 is therefore recommended for maximizing cowpea productivity in the Atani floodplain. Adoption of this practice, combined with good agronomic management and periodic soil testing, can help smallholder farmers improve cowpea productivity, suppress weeds, and restore soil fertility through biological N fixation.

List of abbreviations

ADP: Agricultural Development Programme
ANOVA: Analysis of Variance
ATP: Adenosine triphosphate
CV: Coefficient of variation
HSD: Honestly Significant Difference
N: Nitrogen
P: Phosphorus
P_2O_5 : Phosphorus pentoxide
RCBD: Randomized Complete Block Design
SSP: Single superphosphate
TSP: Triple superphosphate
WAP: Weeks after planting
WAS: Weeks after sowing

Declarations

Ethics approval and consent to participate: Not applicable. This study did not involve human participants, human data, or animal subjects. No ethics approval was required for this field agronomic trial.

Consent for publication: Not applicable.

Availability of data and materials: The datasets generated and analysed during this study are included in this published article (Tables 1–3) and are available from the corresponding author on reasonable request.

Competing interests: The authors declare no competing interests.

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Authors' contributions: N.C.E. conceived and designed the study, supervised fieldwork, analysed the data, and drafted

the manuscript. I.M.D. contributed to experimental design and data interpretation. C.P.A. contributed to soil analysis and manuscript revision. All authors read and approved the final manuscript.

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Figure legends

Fig. 1 Weed dry biomass by intra-row spacing (averaged over P rates). Closer spacing (60 × 15 cm) reduced weed biomass by 41.2% compared with wider spacing (60 × 25 cm), indicating faster canopy closure and shading. Source: Field data, Atani, 2025 (this study).

Fig. 2 Spacing × phosphorus interaction on cowpea grain yield. Yield rose with P rate at all spacings, but the response was largest at 60 × 20 cm, with the peak at 60 kg P_2O_5 ha−1. Source: Field data, Atani, 2025 (this study).

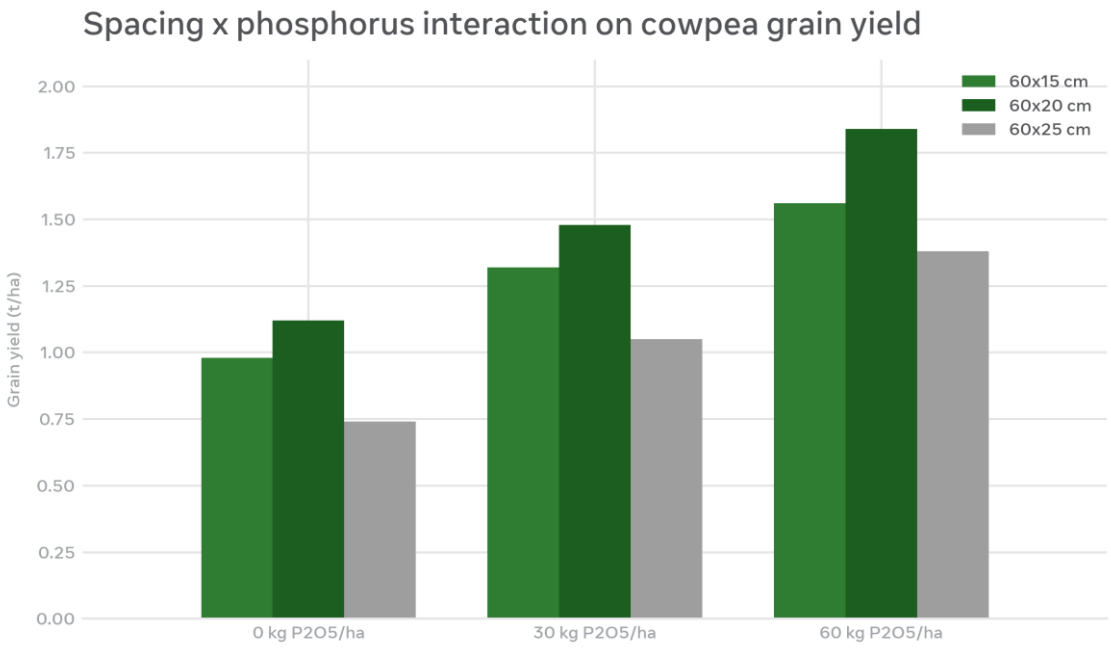

Figure 1 — reproduced from source manuscript file.

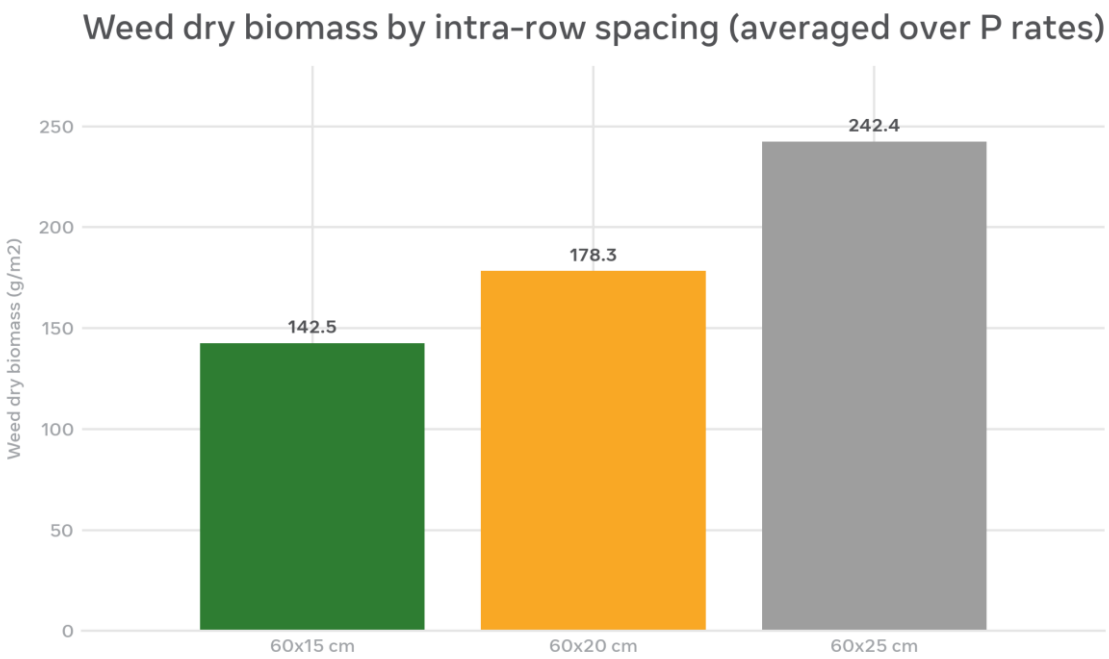

Figure 2 — reproduced from source manuscript file.