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Optimizing NPK Fertilizer Use to Improve Yield and Protein Content of Cowpea [*Vigna unguiculata* (L.) Walp]: A Review

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ABSTRACT

Cowpea (*Vigna unguiculata* L. Walp) is considered an important source of dietary protein for rural and urban populations in sub-Saharan Africa. Its ability to fix atmospheric nitrogen in the soil further emphasizes its important role in improving soil fertility. However, low yield and poor seed quality are the consequences of poor soil fertility. The introduction of improved varieties in recent decades has required different fertilization recommendations adapted to different ecological conditions. This review is based on approximately 103 research papers and critically discusses the effects of nitrogen (N), phosphorus (P) and potassium (K) on growth, yield and seed quality of cowpea, in terms of crude protein content. The data collected show that recommendations for N, P and K fertilization depend on several factors, including total N content and available P and K in the soil, which vary between agro-ecological zones. The use of N-fertilizers can be harmful to the plant, except in cases of extremely low N content in the soil. Effective seed inoculation with *Rhizobium* bacteria promotes nodule formation. Many sources indicate 15–40 kg N ha^{-1}, 20–45 kg P_2O_5 ha^{-1} and 30–40-kg K_2O ha^{-1} as optimal rates for growth and yield, even in conditions of very low soil supply of these nutrients. These rates have a positive effect on plant height, number of branches, flowers and pods, leaf area, root length, dry matter content, biomass (aboveground and underground parts), grain yield, number and weight of nodules and 100-seed weight, and are therefore also recommended in this review. Since N and P are key components in protein, the use of NPK fertilizers is essential to optimize the crude protein content of cowpea seeds, as confirmed by many authors. Increasing the doses of N and P generally increases the crude protein content, but the optimum yield and protein content were achieved at a dose of 30 kg N ha^{-1} and 37.5 kg P_2O_5 ha^{-1} in most agro-ecological conditions in Nigeria, combined with seed inoculation with *Rhizobium* bacteria.

Keywords: cowpea varieties, crude protein, nitrogen, phosphorus, potassium

INTRODUCTION

Cowpea is a prominent source of dietary protein for the people in the Semi-Arid zone of West Africa, it is an important grain legume in the dry savannah of the tropics covering 12.5 million hectares with annual production of about 3 million MT (FAO, 2005). It is a crop of global relevance produced for human consumption as well as animal nutrition. Nigeria is one of the world's largest producers with an average production of 2.92 million MT followed by Niger with 1.10 million MT (FAO, 2012). According to FAOSTAT (2016), Nigeria produced over 3.4 million metric tons of grains annually which account for over 45% of global production. Owing to her large population, Nigeria is regarded the largest consumer of grain cowpea which confers the reason why substantial volume of the crop is being imported from neighboring countries like Chad, Cameroon, Niger Republic (Gomez, 2004, Langyintuo et al., 2003).

Current statistics showed that the use of fertilizer especially nitrogen (N), phosphorus (P) and potassium (K) fertilizers in Nigeria has increased over what was obtained in the late 1980s, indicating increasing awareness in the use of fertilizers (FanWay, 2015; FEPSAN, 2014). Notwithstanding this trend, fertilizer use on a hectare basis has remained low when compared to the global average. The use of P-fertilizers on cowpea is minimal in Nigeria specifically in the major cowpea producing zones (Magani and Kuchinda, 2009; Saidou et al., 2012). Cowpea being a significant leguminous crop possess the ability to yield optimally under adverse

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conditions producing high protein content in both seed and biomass (Tulle, 2014).

The crop also plays an important role in providing soil N to cereal crops (such as maize, millet, and sorghum) when grown in rotation and/or intercropping (Musa and Yusuf, 2023), especially in areas where poor soil fertility is a problem. It contributes to the economy of N in the diverse cropping systems with low input through a biological symbiotic relationship (Sanginga et al., 2000). The biological N-fixation bacteria form nodules in association with grain legumes fixing about 240 kilogram per hectare (kg ha^{-1}) of atmospheric N and making available 13.9–70 kg ha^{-1} of N for succeeding crops grown in rotation with it (Adjei-Nsiah et al., 2008; Yusuf et al., 2009). Therefore, cowpea does not require a high rate of N fertilization due to its extensive root system. The symbiotic N can reduce the rate of soil degradation where legume-cereal rotations are practiced. The amounts of N contributed by various legumes that include cowpea vary between 50–300 kg ha^{-1} per year according to Simunji et al. (2019). The canopy is often developed as ground cover, preventing erosion (Omoigui et al., 2018). This crop architecture which has been described by Musa and Usman (2016) to impact on energy transfer and dry matter accumulation through leaf area production may affects the plant's ability to uptake nutrient, intercept light, radiation use efficiency among other growth characters (Musa et al., 2020).

Poor soil fertility can be addressed through exogenous sources of fertilization such as the application of organic/inorganic fertilizers and sometimes the use of leguminous crops through their symbiotic N_2 fixation, which provide bio-fertilizers in cropping systems (Vanlauwe et al., 2015). Lack of N, P and K in sub-Saharan African soils tends to reduce micronutrient accumulation in plant tissues (Marschner, 2012). Many tropical soils are P-deficient (Osodeke, 2005). However, this P deficiency occurs as a result of either inherent low levels of P in the soils or depletion of the nutrient through cultivation (Bawa, 2020). P and K addition to plant growing in poor soils is significant in increasing plant growth, nodulation, biomass production and overcoming soil moisture stress, thus its deficiency limits cowpea yields (Magadlela et al., 2016; Pérez-Fernández et al., 2017). Cowpea requires more P than N in the form of single super phosphate (SSP). About 30 kg P ha^{-1} in the form of SSP and 20 kg K_2O ha^{-1} in the form of muriate of potash (MOP) is recommended for cowpea production to help the crop to nodulate well and fix its own N from the air (FAO, 2005; MoALD, 2019).

Therefore, this review critically examined numerous research works to discuss; recommendation of N, P and K levels for optimum yield of cowpea crop, soil types and their impact on NPK fertilizer availability and uptake, influence of N, P, and K fertilizers on growth, yield attributes and crude protein content, interactions of N and P on the growth and yield of cowpea varieties, effect of N and P on crude protein content, synergistic interactions of NPK and sulphur (S) and other macronutrients in cowpea nutrition, pedo-climatic influences on NPK availability and sustainable low-input practices for cowpea in diverse agro-ecologies.

N, P AND K FERTILIZER RECOMMENDATION FOR OPTIMUM COWPEA YIELD

Fertilizer recommendations in most cases often fail to consider differences in crop requirements, soil characteristics and farmers' access to inputs and commodity markets with scales that are too large to capture soil heterogeneity (Smaling et al., 2002). Often, overcrowded populations may result in competition for growth resource, nutrient uptake consequently affecting fertilizer recommendation and leading to reduced yield (Musa and Yusuf, 2021). There is dearth of information on specific fertilizer requirement, cropping practices for specific fields thus making the crop responses to fertilizers more erratic and less profitable. In view of this, it is worthwhile to establish various fertilizer nutrient need of cowpea crop, particularly N and P applied in form NPK, ammonium nitrate, SSP, triple superphosphate (TSP) among others which are very important nutrients but highly deficient in tropical African soils. Several researchers have established varying fertilizer requirement with propensity for high yield in cowpea crop. According to Musa et al. (2021), information regarding N, P and K recommendation could be made location-specific for optimum yield of cowpea.

N availability to the legumes can be increased either by manual inoculation or with application of conventional N-fertilizers which often improves the yield and yield components of legumes (Baboo and Mishra, 2004). Verma et al. (2015), recommended 40 kg N ha^{-1} as they found significant increase in plant growth, dry matter content, yield and quality of nutritional value of cowpea seeds. Hasan et al. (2010) has reported that application rate of 25 kg N ha^{-1} gave a biomass yield of 5.47 tons ha^{-1} while increasing the application to 30 kg ha^{-1} did not differ significantly with a yield of 5.49 tons ha^{-1} in his research conducted to investigate the effect of N on the biomass yield of cowpea forage. This may be due to favorable effects of N on overall metabolic processes of the plant and beneficial effects on growth (Kaviraja, 2017). Abayomi et al. (2008) obtained a yield of 1.29 tons ha^{-1} with application of N-based fertilizer in a mixed fertilizer (30-15-15 kg NPK ha^{-1}), doubling this rate (60-30-30 kg NPK ha^{-1}) reduced yield up to 1.23 tons ha^{-1}. Ayodele and Oso (2014) recommended a basal application of 20 kg N ha^{-1} for optimum vegetative growth in low-N soils and organic matter. However, Nkaa et al., (2014) reported 15 kg N ha^{-1} as starter dose for a good crop start in areas where soils are poor in N. Also, several workers had recommended N fertilization of cowpea at small amounts at early stage as a starter, especially in N deficient soils which improved growth and subsequently yield, but reduced nodulation (Osborne and Riedell, 2006). Except in extremely low soil N, N-fertilizer should be applied at the rate of 15 to 30 kg N ha^{-1} to soil with low N content to enhance plant growth, nodulation and N fixation.

Deficiency in P often results in stunted shoot and root growth due to reduced cell division and reduced cell enlargement. P deficiency often stimulates uptake of excess cations over anions by plants and hence enhances proton release that could increase acidification which may facilitate P acquisition (Tang et al., 2001). Ma et al. (2001) reported that relative growth rate and crop growth rate were significantly different among P rates of 0, 35 and 70 kg ha^{-1}. Ayodele and Oso (2014b), reported that application of 45 kg P_2O_5 ha^{-1} either in SSP or TSP significantly improved the cowpea growth and yield by 0.798 MT ha^{-1}. Bawa (2020) recommended 60 kg ha^{-1} P-fertilizers for optimum grain yield and biomass yield in his research carried out in Ghana. Similarly, Magani and Kuchinda (2009) reported that grain yields realized with 35.5 kg P ha^{-1} did not differ significantly from that of 75 kg P ha^{-1} giving a yield of 1.85 tons ha^{-1}, and 1.91 tons ha^{-1}, respectively.

The initial recommendations for the savannah zone of Nigeria are between 11 kg P_2O_5 ha^{-1} and 36 kg P_2O_5 ha^{-1} (IAR, 1979) using SSP fertilizers by means of broadcasting, which is worked into the soil during seedbed preparation. Improved cowpea varieties, with higher yield potentials are being adopted and this necessitates a review of the fertilizer recommendations over recent decades. Thus, N and K have been included in the recommendation with significant increase (20-40 kg) in P_2O_5 ha^{-1} based on soil fertility classes (FFD, 2002), i.e., medium soils (0.16–0.20% total N), low (3.0-7.0 mg kg^{-1} available P) and moderate (0.31–0.60 cmol kg^{-1} exchangeable K) content of most soils as reported by Anon (2006). Several researchers in the southwestern Nigeria have established varying levels of P application required for optimum cowpea yield in respective locations. Musa et al. (2021) in their experiment, reported that adding 10.0 kg N ha^{-1} to soils that are relatively low in N (i.e., most savannah soils of Nigeria) and SSP at rate of 37.5 kg P_2O_5 ha^{-1} resulted in optimum economic yield. Based on the linear-response-plateau model, in the location (Ekiti state), Ayodele and Oso (2014) recommended 20 kg P ha^{-1} (approximately 45 kg P_2O_5 ha^{-1}) in the presence of basal N (20 kg N ha^{-1}) and 30 kg K_2O ha^{-1} as optimum rate for cowpea production with a grain yield of 1.26 tons ha^{-1} compared to 0.78 tons ha^{-1} which he got from the control in his experiment. Azarpour et al. (2011) reported that 45 kg P ha^{-1} gave the highest grain yield of 1.57 tons ha^{-1} against the yield of 0.88 tons ha^{-1} from the control plot in Iran.

SOIL TYPES AND THEIR IMPACT ON NPK AVAILABILITY AND UPTAKE IN COWPEA

Soil properties play a fundamental role in determining the availability, mobility, and uptake efficiency of macro-nutrients in cowpea production systems. Soil texture, pH, organic matter content, and cation exchange capacity (CEC) significantly influence the dynamics of N, P and K in agricultural soils (Brady and Weil, 2017; Marschner, 2012; Bawa, 2020; Kamara et al., 2022; Sileshi et al., 2021). In many tropical regions where cowpea is widely cultivated, soils are often characterized by low organic matter and limited nutrient retention capacity, which restrict nutrient availability for crop growth (Sanchez, 2019).

In semi-arid zones with variable soil types, NPK fertilization mitigates yield losses, but intercropping systems (e.g., sorghum-cowpea) show differential performance based on soil variability (Bassène et al., 2025). N availability in soils is largely governed by microbial mineralization of organic matter and environmental conditions that regulate microbial activity. Sandy soils commonly found in the savannah regions of sub-Saharan Africa often exhibit low N retention due to their low CEC and high leaching potential leading to reduced P and K uptake (Rafael et al., 2019). Consequently, N supplied through fertilizers or biological N fixation may be rapidly lost through leaching or volatilization under high rainfall conditions (Giller, 2001; Sanginga and Woomer, 2009). Sandy soils, often benefiting from amendments like biochar or higher NPK fertilizer rates enhances cowpea growth. In low-fertility soils (e.g., those deficient in N P and K), cowpea varieties with extensive root systems show superior uptake, as seen in studies where root length influenced nutrient absorption (Adepetu, 1977).

P availability is strongly influenced by soil pH and mineral composition. In acidic tropical soils, P is frequently fixed by iron and aluminum oxides, which significantly reduces its availability to plants. pH also influences micro and macro nutrient availability; for example, alkaline soils may limit P uptake, while acidic soils enhance it but risk N leaching (Gerrano et al., 2022). Similarly, in calcareous soils, P may precipitate with calcium to form insoluble compounds that are unavailable for plant uptake (Marschner, 2012; Fageria et al., 2011). P deficiency is therefore considered one of the most widespread nutrient limitations affecting cowpea production in tropical soils (Kamara et al., 2011; Bawa, 2020; Singh et al., 2025).

K availability depends largely on soil mineralogy and clay content. Clay-rich soils generally possess higher K reserves compared to sandy soils. However, continuous cropping without adequate fertilizer replenishment can deplete soil K reserves over time, resulting in reduced crop productivity (Brady and Weil, 2017). In addition to soil chemical properties, biological factors such as microbial populations and rhizobial abundance may also influence nutrient uptake in cowpea. Variability in indigenous *rhizobia* populations across soil types has been reported in several African agro-ecological zones (Abaidoo et al., 2007), highlighting the importance of soil conditions in determining the efficiency of biological N fixation in cowpea (Dakora and Keya, 1997). Recent studies have demonstrated that the integration of rhizobial inoculation with moderate P fertilization significantly improves nodulation, nutrient uptake, and grain yield in cowpea production systems (Somvanshi et al., 2024; Apate et al., 2025).

Table 1: Influence of different soil types on NPK uptake, yield, and related parameters

Soil type	Key characteristics	Impact on NPK uptake	Effects on cowpea yield/quality	References
Acid arenosol	Sandy, low pH, poor nutrient retention	Reduced P and K uptake; biochars + NPK fertilizer improves N, P and K availability.	Increased biomass/yield with half/full NPK doses	Rafael et al. (2019)
Sandy (low fertility)	Coarse texture, low organic matter and CEC	High N leaching; enhanced uptake with organic amendments, Moderate P, but easily depleted; Low K retention.	Requires split fertilizer application, higher nodulation and nutrient uptake with integrated sources.	Patel et al. (2023); Oyeyiola (2022)
Loamy soils	Balanced texture and fertility	Moderate N availability, good P retention and adequate K supply due to higher organic matter decomposition and microbial activities.	Suitable for balanced fertilization.	Sanchez (2019)
Clay SOILS	High CEC, Nutrient retention	Higher N retention, possible P fixation and high K reserves.	Requires P management with respect to uptake	Marschner (2012)
Acidic tropical soils	High Fe/Al oxides	Reduced microbial activity, strong P fixation, and moderate K availability.	Usually requires liming and P fertilization.	Brady and Weil (2017)
Calcareous/alkaline	High pH, nutrient fixation	Limited P availability; S-oxidizing bacteria boost N, P and K.	Improved yield with S + microbial consortia	Nabati et al. (2025) (analogous to chickpea)
Semi-arid variable	Variable texture, low moisture	Differential NPK response; fertilization key	Better agro-morphological parameters with NPK	Bassène et al. (2025)

RESPONSE OF COWPEA TO N-FERTILIZERS

Legumes are known crops that fix N biologically into the soil and are characterized by heavy rot nodules. Cowpea may respond to N fertilization differently as soil N condition varies from agro ecologies. Daramy et al. (2017) reported zero effect of N-fertilizer application on cowpea growth and yield characters in Ghana they attributed this result to the fact that effective biological N fixation process may reduce N required by cowpea. This finding was supported by Mndzebele et al. (2020) who in their report indicated that N-accumulation processes through N-fixation lead to biomass accrual by cowpea and plant growth. In general, the co-application of these nutrient elements at optimum concentrations increased the uptake and accumulation of N in crops (Wen et al., 2016). Ndor and Faringoro (2020) conducted research on N-fertilizer and time of application on cowpea, where they discovered that application of 80 kg N ha^{-1} produced the highest growth characters (leaves, branches, and vine length) with control plots giving the highest numbers of root nodules at 2WAS, additionally they obtained the highest seed yield (0.69 tons ha^{-1}) with same N rate. This was confirmed in the earlier findings of Ndor et al. (2012), who worked on the effect of soil nutrients dynamics on cowpea as results of different maize-based farming practices around the experimental site.

The significant response of all the growth parameters of cowpea to application of N-fertilizer have been attributed to initial state of the soil that was already low in N in which case, low soil N often result in significant influence of N-fertilizers in cowpea growth. Danso (2016) obtained a maximum vegetative growth and highest grain yield (1171.09 kg ha^{-1}) at the rate of 45 kg N ha^{-1}, this corroborates with the findings of Sharma et al. (2002) and Starling et al. (2000). Musa and Yusuf (2021) found that 10 kg ha^{-1} N increased number of nodules per plant at all sampling stages in a two years trial conducted in Anyigba. Nadiagad et al. (2013) opined that cobalt along with 100 and 75% N-fertilizer application to the plant showed a significantly increased Nous activity (26.9 and 25.2%), increased nodules numbers (88.5 and 83), and weights of nodules (1.98 g and 1.8 g), highest plant height (46.9 cm and 42.3 cm), leaf area (1828 cm^2 and 1699 cm^2) and root length (19.3 cm and 17.7 cm). Musa et al. (2011) had also observed a significant increase in cowpea fibre and fat content following N application. The concentration of N in cowpea seeds was significantly improved by the application of N-fertilizer. The addition of cobalt to the soil saves 25% N-fertilizer consumption.

Overall, the application of NPK at optimum concentrations results in synergistic interaction and promote not only the growth but the uptake and accumulation of N in plant tissue (Rietra et al., 2017), this was confirmed by Mndzebele et al. (2020). N-inoculation make cowpea requirement for N quite negligible except in adverse soil condition, a number of researches had reported rapid increase in growth characters (heights, branches) of cowpea inoculated with N (Malik et al., 2006; Bekere et al., 2013; Siam et al., 2012). In their research, they showed that inoculants had effect on plant height was higher than the control and significantly affected branch production. Abayomi et al. (2008) opined that application of 150 kg NPK ha^{-1} significantly increase the plant height, number of pods per plant, pod yield, seed yield, number of flowers and total dry matter, respectively. Ayodele and Oso (2014) reported that where N-fertilizer applied to cowpea crops in their study in Ekiti state, number of nodules reduced while vegetative growth was enhanced. Olatunji et al. (2012) also confirms this assertion in his research with higher N-application. Gohari et al. (2010) reported that the greatest seed yield, 100 seed weight, number of pods per plant and number of leaves per plant was showed highest by the use of 30 kg ha^{-1} N-fertilizer, this is supported by Samawat and Borah (2001). Umeh et al. (2011) also showed increasing number of leaves and branches due to availability of N following inoculation. The growth response observed especially in soils low with N and organic matter probably connotes the recommendation of basal application of 20 kg N ha^{-1} (Ayodele and Oso, 2014). The addition of higher N-fertilizers can also result in a decrease in the richness, diversity, and composition of soil bacterial communities (Zhou et al., 2017). That being the case, the decreased microbial community, some of which are responsible for solubility of soil N, could result in their inefficacy and therefore reduced N uptake. Understanding cowpea N-accumulation dynamics under varying levels of fertilization is, therefore, crucial in optimizing crop production particularly for the resource-constrained farmers. The behavior of cowpea agrees with the assumption that legumes have the ability of more nutrient bioaccumulation when compared to non-legumes (Wortmann, 2018), as observed in this review.

RESPONSE OF COWPEA TO P-FERTILIZERS

P is important for cowpea production in many tropical African soils with inherent low P fertility. P is critical to cowpea yield because it is reported to stimulate growth, initiate nodule formation as well as influence the efficiency of the *Rhizobium*-legume symbiosis (Haruna and Aliyu, 2011). It is required in large quantities in young cells such as shoot and root tips where metabolism is high and cell division is rapid. It also aids in flower initiation, seed and fruit development (Ndakidemi and Dakora, 2007).

Karikari et al. (2015) recorded a higher seed yield of 1682.00 and 1476.00 kg ha^{-1} for both major and minor seasons, with 60 kg ha^{-1} P_2O_5 application in the form of SSP. This result has been reported in several other researches (Singh et al., 2011). Ayodele and Oso (2014) stressed on the significant grain yield response to P application and its importance in improvement of vegetative characters. In their experiment, they reported the above ground dry matter (biomass) yield taken at 46 days after sowing to have increased till 40 kg P ha^{-1} which did not differ from 60 kg P ha^{-1} rate. They obtained the tallest plant with 20 kg P ha^{-1} application which also gave the highest leaf area, number of flowers and pods/plant. The number of branches and number of nodules/plants were highest at 40 and 60 kg P ha^{-1} respectively. The superior vegetative characters culminated in the highest grain yield at 20 kg P ha^{-1} but which did not differ from the higher P rates.

Olaleye et al. (2012) also reported an increase in cowpea growth following P-fertilizer application. P is mobile in plants but is one of the most immobile, inaccessible and unavailable nutrients present in soils and has highest concentration in places of cell division and development (Narang et al., 2000). The process of P fixation makes P unavailable in the soil for plant use as plants take up only about 15-30% of applied P, while the 60% is adsorbed to the soil (Olusola, 2009). Weisany et al. (2013) reported that the P content per unit dry weight is considerably higher in the nodules than in the roots and biomass, particularly at low external P supply. Karikari et al. (2015) reported that growth rate was not consistent with P application however, application rate of 60 kg ha^{-1} P_2O_5 yielded the least growth rate and the highest seed yield in his entire study period. Bawa (2020), established that P-fertilizer level of 60 kg ha^{-1} using DAP produced significantly higher quantities of yield and vegetative parameters such as grain yield, 100-grain weight, number of pods and branches, shoot and root dry biomass, nodulation and nodule dry biomass, as compared to P levels of 0 kg ha^{-1}, 20 kg ha^{-1} and 40 kg ha^{-1}. Ayodele and Oso (2014) obtained an average of 3.42 vegetative branches whereas the number of reproductive branches (flower, budbearing) increased such that total branches increased as P rate increased up 40 kg ha^{-1}.

Singh et al. (2011) reported increased intensity of nodulation and N fixation with higher levels of P. Higher N fixation would result in higher yield of the crop. Nkaa et al. (2014) reported that 50 kg ha^{-1} P significantly enhanced growth and yield characters of the cowpea varieties such as plant height, leaf area, number of leaves and number of branches in all the weeks of measurement. He added that P also had a significant effect on seed yield per treatment, weight of 50 seeds, number of nodules, weight of nodules and total aboveground dry matter with 40 kg P ha^{-1} being the highest. Singh et al. (2011) revealed that application of 60 kg P ha^{-1} in the form TSP showed significant response to pods per plant, grain and Stover yield and 100-seed weight. Kaviraja (2017) obtained a significantly higher harvest index (0.28) with increased P-application, his findings were not in agreement that of Daramy et al. (2017) who revealed that application of N (40 kg N ha^{-1}) and P (45 kg P_2O_5 ha^{-1}) fertilizers showed no significant effect on total biomass, number of pods, pod yield and harvest index of cowpea in a cultivar called Asontem. However, Malagi (2005) revealed that harvest index differed significantly due to different levels of fertilizers with the lowest harvest index (1.25%) noticed with highest dose of fertilizer (NPK at 60 kg ha^{-1}). Swaroop (2014) opined that maximum number of pods, pod yield per plant, length of root and seed yield was obtained with the application of 80 kg, P, 60 kg K, 20 kg N ha^{-1} + *Rhizobium* inoculation. Patel and Singh (2009) revealed that application of 20 kg N + 40 kg P_2O_5 ha^{-1} along with *Rhizobium* seed inoculation gave significantly higher number of clusters per plant, number of pods per plant, pod yield per plant and 50% flowering compare to other nutrient treatments. It is evident from these literatures that P-fertilizer application is solely dependent on soil residual P. However, rates between 20-60 kg P ha^{-1} irrespective of the fertilizer grade may be considered improved for cowpea growth and optimum yield.

RESPONSE OF COWPEA YIELD TO K RATES

Maximum yield of cowpea green pods (128.3 kg) has been obtained with the application of 60 kg K ha^{-1}, with *Rhizobium* inoculation (Swaroop, 2014). Musa and Yusuf (2021) reported that *Rhizobium* inoculation increases nodulation, N uptake in soybean. Root length of 17.61 cm with uptake of 14.40 kg ha^{-1} K has also been reported from application of 120 kg K ha^{-1} + *Rhizobium* inoculation. Maximum number of nodules per plant (9.23), number of effective nodules per plant (6.67), fresh weight of nodules (5.43 g plant^{-1}), dry weight of nodules (1.78 g plant^{-1}), and moisture content of nodules (35.2 g) respectively was obtained from 0 + 60 + 40 kg NPK per ha (Kabir et al., 2007). Ayodele and Oso (2014a) had earlier reported 30 kg K_2O ha^{-1} as optimum K rate for cowpea production with a grain yield of (1.26 tons ha^{-1}) compared to control (0.78 tons ha^{-1}). 70 kg application of K per ha has been reported to increase pod yield per plot (4.80 kg and 3.58 kg), average pod length (18.29 cm and 14.48 cm), pod width (1.03 cm and 0.96 cm) significantly (Anuja et al., 2006). It is however wise to conclude that *Rhizobium* inoculation enhances K uptake resulting in maximum result. K levels between 30–70 kg ha^{-1} therefore suffices under effective *Rhizobium* inoculation.

INTERACTION OF N AND P ON COWPEA VARIETIES

Cowpea varieties often show different responses to P treatment on yield characters. Variety plays an important role in nutrient uptake and considered one of the most intriguing factors by breeders in breeding programs. genetic inheritance of any crop reflects on its growth behavior, adaptation and yield (Musa and Yusuf, 2017). Several researchers have reported interaction effects of nutrients on cowpea varieties. Cowpea root system could also play an important role in nutrient uptake. N uptake has reportedly increased in soybean due to more vigorous rooting system (Musa and Yusuf, 2023).

Verma et al. (2015) had reported that application of N at 40 kg ha^{-1} and P 80 kg ha^{-1} showed significant increase in higher N (63.6 kg ha^{-1}), P (11.57 kg ha^{-1}) and K (82.1 kg ha^{-1}) uptake. P deficiency conditions will result in reduced Biological N Fixation potential and P fertilization usually leads in enhanced nodule number and mass, as well as greater N fixation activity per plant. P is known to promote early root formation and the formation of lateral**,** fibrous and healthy roots**,** which play an important role in N2 fixation, water and nutrient uptake (Niu et al**.**, 2012). This explains the reason for the higher N content in the plant tissue at higher P application rate. Increase in grain yield by 49–52% as obtained by Adediran et al. (2018) trial resulting from P application further confirms the importance of P in legume productivity.

Musa and Yusuf (2017) reported seed yield of 1.14 MT ha^{-1} from IT89KD288 under the application of 37.5 kg P_2O_5 ha^{-1}. Yakubu et al. (2010) stated that low P content of the soil may restrict rhizobia population and legumes root development, which in turn, can affect their N_2 fixing potential. Also, an increase of whole plant growth and plant N concentration responded to increased soil P supply from 20 to 40 kg P_2O_5 ha^{-1}.

Daramy et al. (2016) found that the number of cowpea nodules decreased with an increase in the rate of N-fertilizer applied whereas application of P significantly affected nodule numbers with 45 kg ha^{-1} P_2O_5 being the highest. Chakirwa et al. (2019) had attributed N and P synergies in cowpea to external cation such as Zn^{2+} present in the soil, in their research, Zn fertilization promotes absorption of both

N and P, increases uptake of N adding that Zn fertilization also increased N content of grain in major and minor cropping seasons. Nadiagad et al. (2013) opined that cobalt along with 100 and 75% N-fertilizer showed a significantly increased Nous activity (26.9 and 25.2%), increased nodules numbers (88.5 and 83), and weights of nodules (1.98 g and 1.8 g), highest plant height (46.9 cm and 42.3 cm), leaf area (1828 cm^2 and 1699 cm^2) and root length (19.3 cm and 17.7 cm). The addition of cobalt to the soil saves 25% N-fertilizer consumption.

Musa and Yusuf (2021) also observed a synergistic effect between two factors (N and P applications) which increased crop quality, adding that application of 40 kg P ha^{-1} increased N and K accumulation by 22.5% and 21.2% respectively. Aryal (2021) also reported interaction between variety and P level as it affects the yield of fresh pod per plant at 75 and 90 days, the interaction of Aakash variety and 40 kg P ha^{-1} produced the highest yield of fresh pod per plant at 75 DAS (103.60 g) and 90 DAS (128.60 g) in their research. Kaviraja (2017) reported a significant interaction of P and cowpea varieties (IT97K-499-35 and IT99K-573-1-1), the highest value for root dry matter (root dry weight) which he observed in IT99K-573-1-1 at P-fertilizer rate of 60 kg ha^{-1} while that of total aboveground matter was observed in variety three; IT99K-573-2-1 at P-fertilizer rate of 40 kg ha^{-1}. Adediran et al. (2018) found a significant interaction effects between P and inoculation, P and variety for nodule dry weight, nodule number per plant. In his research, IT93K-452-1 plants had the highest nodule dry weight (0.211 g) when fertilized with 40 kg P ha^{-1} which was not significantly different from IT99K-573-1-1that received 20 kg P ha^{-1} (0.172 g). The highest nodule dry weight (0.378 g $plant^{-1}$) was obtained from IT93K-452-1 plants that received 40 kg P ha^{-1} followed by (but statistically higher than) the values obtained in IT99K-573-1-1 (0.23 g $plant^{-1}$) and TVX 3236 (0.22 g $plant^{-1}$) plants inoculated with USDA 3384 at 20 kg P ha^{-1}.

Significant interactions of variety × P × N have been reported by Musa and Yusuf (2021) on number of nodules produced per plant, number of pod/plants, number of seed/pod and pod length/plant, plant height, leaf area among other characters on Anyigba Local, Sampea 7 and Sampea 9 varieties of cowpea in his trials in 2018 and 2019. Genotypic difference in the effect of P on nodulation has been reported by several authors (Omondi et al., 2014). The higher N-fixed in variety IT93K-452-1 as reported by Adediran et al. (2018) than the other varieties confirm the fact that crop varieties vary in their genetic ability to fix N. Genetics and breeding have reportedly played an important role in the improvement of crops, Adaptation to ecology is key a factor considered for nutrient uptake in cowpea breeding and programmes (Musa and Yusuf, 2017).

SYNERGISTIC INTERACTIONS OF NPK WITH S AND OTHER MACRONUTRIENTS IN COWPEA NUTRITION

Nutrient interaction is fundamental to determining nutrient use efficiency and crop productivity. Field experiments have demonstrated that the combined application of rhizobial inoculants with P and K fertilizers significantly improves nodulation, biomass production, and grain yield of cowpea under nutrient-deficient soil conditions (Abaidoo et al., 2007; Vanlauwe et al., 2015). As reported by Fageria et al. (2011), in cowpea, synergism among N, P, K and other essential nutrients significantly influence plant growth, nodulation, and seed protein synthesis. Similarly, Bationo et al. (2012) found that TSP relative to agronomic effectiveness in fodder cowpea varied from 77 to 91% indicating that S is needed for cowpea growth.

The interaction between N and P is particularly important in legume crops because P promotes root development and nodulation, thereby enhancing biological N fixation. P deficiency has been shown to reduce nodulation and N fixation capacity in cowpea, ultimately limiting crop yield (Dakora and Keya, 1997; Kamara et al., 2011). K interacts positively with N by enhancing N assimilation and transport within the plant. K regulates several physiological processes including enzyme activation, osmotic balance, and stomatal regulation, which collectively influence plant metabolism and productivity (Marschner, 2012).

S is another essential nutrient that interacts with N in protein synthesis. Since S is a structural component of amino acids such as cysteine and methionine, S deficiency can reduce protein synthesis even when N supply is adequate (Fageria et al., 2011). Balanced fertilization involving NPK and other essential nutrients therefore improves crop performance and enhances the nutritional quality of cowpea grains. S enhances N efficiency and uptake in legumes, leading to improved yield and macronutrient content i.e., S + N application increases cowpea yield and seed N, P and K levels due to better nutrient utilization (Patel et al., 2021). In S-deficient soils, combining S with NPK boosts biomass and nutrient uptake, as seen in studies where S-N interaction improved cowpea productivity (Rietra et al., 2017). Analogous to other legumes (e.g., chickpea), S-oxidizing bacteria with S amendments increase N, P and K availability in calcareous soils, potentially applicable to cowpea (Nabati et al., 2025). Antagonistic effect of S has been reported in acidic soils. According to Hemasree et al. (2025), High S may compete with P in acidic soils, but balanced NPK-S regimes mitigate this.

EFFECT OF VARIETY, N AND P ON CRUDE PROTEIN CONTENT OF COWPEA

Genetic advances in quality and content of protein cannot be ruled out in cowpea breeding programmes. Improved varieties have been reported to efficiently utilize nutrient. Musa and Yusuf (2020) have reported that high yielding segregants possess high protein content, thus suggesting the ultimate combination of high yield and high protein content in a suitable genotype with weaker associating characters. Mamman et al. (2024) studied the epidermal cell type and describe stomata variations, development ontogeny among species of legumes to introduce morphological features that can evaluate species delimitation for nutrient use among Nigerian species. Other authors have suggested improved varieties for enhanced nutrient uptake (Adediran et al., 2018). P significantly improves crop quality in a number of ways, it helps in decreasing grain moisture content, winter hardiness, and it increases sugar, P and crude protein content. It also increases proportion or marketable yields and better feed value, it improves drought and disease resistance in crops such as wheat and maize (Halvin et al., 2005).

Crude protein content of the seed has reportedly increased with application of P-fertilizer (Musa, 1990). In his experiment, slightly larger seed size positively influence yield components as improved cowpea varieties was more vigorous in yield characters when compared to the local varieties. According to Diouf (2011) the crude protein content of the seeds and leaves of cowpea ranges between 23 and 32% respectively. Varying fertilizer recommendation have resulted in certain crude protein level in cowpea seeds. Researchers have reported that N-fertilizers are principal factor in increasing crude protein content in cowpea seed (Singh et al., 2006; Musa and Yusuf, 2021). This was mainly due to the structural role of N in building of amino acids (Chintala et al., 2012).

Joshi et al. (2016) revealed that recommended dose of fertilizer 20-40-0 NPK kg ha^{-1} yielded significantly higher chlorophyll content of leaves (2.16 mg) at 60 DAS, crude protein content (23.03%) in green seeds higher over rest of the other inorganic treatments. Musa and Yusuf (2021) had also reported that application of 10.0 kg N ha^{-1} and 37.5 kg P_2O_5 ha^{-1} significantly yielded a crude protein content of 20.83% and 23.31% over the control plot which gave 20.54% and 19.17% crude protein respectively in their 2018 and 2019 trials in Anyigba.

Malik et al. (2003) reported a 25% maximum crude protein content from a plot fertilized with a combination of 50 kg N + 75 kg P ha^{-1} as compared to other combinations of N (0, 25 and 50 kg N ha^{-1}) and P (0, 50, 75 and 100 kg ha^{-1}) in Pakistan. Anuja et al. (2006) opined that application of 70 kg P per ha significantly increased the crude protein content (between 25.13% and 25.44%) and total dry matter content (between 19.41 g plant^{-1} and 21.65 g plant^{-1}). 60 kg P and 0 kg Zn application respectively gave the highest crude protein content in Soybean (Musa and Yusuf, 2021).

Jadhav et al. (2011) reported that protein content (19.18%) was found to be significantly increased with 20 kg N + 40 kg P_2O_5 ha^{-1} along with *Rhizobium* seed inoculation. Magani and Kuchinda (2009) argued that most farmers in Africa do not have access to P-fertilizer, hence the need to select cowpea with high P use efficiency as a low input approach to addressing this constraint. Base on this assertion, Emmanuel (2014), after conducting his trials, reported that application of 37.5 P_2O_5 kg ha^{-1} was the most economic level for maximum grain yield and crude protein content. However, application of 30 kg N ha^{-1} combined with 0 kg P_2O_5 ha^{-1} have been reported to produce the highest seed N (4.00%) plant N (5.67%) and seed crude protein (25.00%) content of cowpea compared to all other N and P levels (Daramy et al., 2016).

PEDO-CLIMATIC INFLUENCES ON NPK AVAILABILITY IN COWPEA PRODUCTION

Pedo-climatic factors integrate soil characteristics and climatic factors such as rainfall and temperature, strongly influence nutrient availability and fertilizer response in cowpea production systems (Sanchez, 2019). Climatic variability (e.g., drought) modulates NPK effects, intercropping in low-fertility zones boosts sequestration and availability (Roohi et al., 2022). In calcareous soils, pH influences NPK; balanced fertilization reverses degradation (Iqbal et al., 2024).

In the semi-arid savannah regions of West Africa (e.g., Sub-Saharan Africa) where cowpea is predominantly cultivated, soils are typically sandy and low in organic matter. These soils often exhibit deficiencies in N and P, which limit crop productivity. High temperatures and intense rainfall events further exacerbate nutrient losses through volatilization, erosion, and leaching (Sanginga and Woomer, 2009). However, Horn et al. (2020) stressed that low rainfall and high temperatures exacerbate N leaching and P fixation thus reducing availability, to address this, NPK regimes must accounted for.

In humid tropical regions, excessive rainfall accelerates nutrient leaching and enhances P fixation due to the presence of iron and aluminum oxides in highly weathered soils. Consequently, P deficiency remains one of the major constraints to cowpea production in these regions (Kamara et al., 2011).

Temperate regions generally possess soils with higher organic matter content and more balanced nutrient availability. However, climatic variability and soil management practices continue to influence nutrient dynamics and fertilizer efficiency. Integrated soil fertility management practices that consider both soil and climatic conditions are therefore essential for optimizing cowpea productivity across diverse agro-ecological zones (Vanlauwe et al., 2015). Parts of Europe like Romania characterized with sandy soils show improved NPK retention via green manures, enhancing cowpea biomass under dry climates (Drăghici et al., 2024).

SUSTAINABLE LOW-INPUT PRACTICES FOR COWPEA IN DIVERSE AGRO-ECOLOGY

Cowpea is widely cultivated in low-input agricultural systems due to its ability to fix atmospheric N through symbiotic association with *Rhizobium* bacteria (Giller, 2001). This characteristic makes cowpea an important component of sustainable cropping systems, particularly in sub-Saharan Africa where access to mineral fertilizers is often limited. Integrated Soil Fertility Management (ISFM) that combine mineral fertilizers with biological inputs and organic amendments have been shown to enhance nutrient use efficiency and soil microbial activity in cowpea-based systems (Vanlauwe et al., 2015; Sileshi et al., 2021; ECS, 2025).

Low-input practices like intercropping (e.g., millet-cowpea) with minimal NPK enhance yield in semi-arid SSA, providing resilience to climate variability (Bassène et al., 2024). In Europe, where cowpea cultivation is emerging (e.g., Southern regions), low-input systems involve diversification, reduced fertilizers, and biofertilizers to address constraints like drought and poor soils (Lazaridi et al., 2023). European markets favor sustainable cowpeas for their low carbon footprint and biodiversity benefits in mixed systems; practices like row intercropping reduce GHG emissions per unit product (Marcos-Pérez et al., 2023). Bottom-up initiatives (e.g., seed access) could promote UCs like cowpea in low-input farms (Nguyen-Brémaud et al., 2026).

Rhizobial inoculation has also been widely recognized as an effective strategy for improving biological N fixation and enhancing cowpea yield and resilience. Similarly, agronomic practices such as crop rotation, intercropping with cereals, and the application of organic manure can significantly improve soil fertility and nutrient availability in tropical environment (Sanginga et al., 2003). The use of arbuscular mycorrhizal fungi has also been shown to enhance P uptake in cowpea by increasing root surface area and improving nutrient absorption efficiency. These biological approaches are particularly beneficial in nutrient-deficient soils where fertilizer inputs are limited (Tarawali et al., 2002).

CONCLUSION

Optimizing NPK fertilizer application remains a key strategy for improving cowpea productivity and seed protein content. Knowledge on the effective use of fertilizer in cowpea production is essential because the dynamics of nutrient use efficiency in cowpea has not been fully unraveled by most cowpea farmers in Nigeria. Current fertility studies on cowpea shows that most cowpea farmers bank on blanket fertilizer recommendation in most cowpea producing areas. This leaves a gap in the fertility management since soil types and nutrient composition varies across agro-ecologies in Nigeria. Based on the objectives of this review and bearing in mind variations in considerable literatures cited, it is pertinent to know that nutrient recommendation should take into consideration, several factors including residual N, P and K, soil properties, pedo-climatic conditions, and nutrient interactions to maximize nutrient use efficiency. Sustainable cowpea production systems require integrated soil fertility management practices that combines mineral fertilizers with organic amendments and biological inputs. Effective biological N fixation process may reduce N uptake in cowpea, P being a mobile nutrient in plants and immobile or inaccessible and unavailable nutrients in most tropical soils must therefore be augmented to increase yield and improve seed quality likewise increased yield has reportedly been obtained from lower K levels in inoculated seeds. It is very impressive to say that the use of extremely high rate of N-fertilizers could be detrimental to the crop resulting in luxury consumption with associated defect in growth and yield characters except in extremely low cases of soil available N, thus rates from 15–40 kg N ha^{-1}, 20–45 kg P ha^{-1} and 30–40 kg K ha^{-1} have been cited in many literatures even in extremely low cases of soil nutrients for optimum growth and yield in cowpea production and therefore recommended in this review. Also, crude protein content has been considered a product of N and P-fertilizer in many literatures. The role of P on seed quality has been extensively explained in this review therefore, varying rates of NPK fertilizer has yielded different crude protein levels in cowpea seed. Optimum seed yield and crude protein have been obtained with 30 kg N ha^{-1} and 37.5 kg P_2O_5 kg ha^{-1} + *Rhizobium* seed inoculation in most agro-ecologies in Nigeria. The variation in N and P interactions and response of cowpea varieties to N and P as highlighted in several literatures points out the urgent need to establish a "variety and location-specific" fertilizer recommendations based on soil type and agro-ecological conditions. Additionally, the development of nutrient-efficient cowpea varieties and improved soil fertility management strategies will play a critical role in enhancing crop productivity and food security in regions where cowpea is a major staple crop.

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Optimizacija uporabe NPK gnojil za izboljšanje pridelka in vsebnosti beljakovin v kitajskem fižolu [*Vigna unguiculata* (L.) Walp]: Pregled

IZVLEČEK

Kitajski fižol (*Vigna unguiculata* L. Walp) velja za pomemben vir prehranskih beljakovin za podeželsko in mestno prebivalstvo podsaharske Afrike. Njegova sposobnost vezave atmosferskega dušika v tla dodatno poudarja njegovo pomembno vlogo pri izboljševanju rodovitnosti tal. Kljub temu pa so nizek pridelek in slaba kakovost semen posledica slabe rodovitnosti tal. Uvajanje izboljšanih sort v zadnjih desetletjih je zahtevalo različna priporočila glede gnojenja, prilagojena različnim ekološkim razmeram. Ta pregled temelji na približno 103 raziskovalnih delih in kritično obravnava vpliv dušika (N), fosforja (P) in kalija (K) na rast, pridelek in kakovost semen kitajskega fižola , z vidika vsebnosti surovih beljakovin. Zbrani podatki kažejo, da so priporočila za gnojenje z N, P in K odvisna od več dejavnikov, vključno s skupno vsebnostjo dušika ter dostopnim fosforjem in kalijem v tleh, ki se razlikujejo med agroekološkimi območji. Uporaba dušikovih gnojil je lahko škodljiva za rastlino, razen v primerih izjemno nizke vsebnosti dušika v tleh. Učinkovita inokulacija semen z bakterijo *Rhizobium* spodbuja tvorbo nodulov. V številnih virih se kot optimalni odmerki za rast in pridelek navajajo 15–40 kg N/ha, 20–45 kg P_2O_5/ha in 30–40 kg K_2O/ha, tudi v razmerah zelo nizke založenosti tal z navedenimi hranili. Ti odmerki pozitivno vplivajo na višino rastlin, število vej, cvetov in strokov, listno površino, dolžino korenin, vsebnost suhe snovi, biomaso (nadzemni in podzemni deli), pridelek zrn, število in maso nodulov ter maso 100 semen, zato so priporočeni tudi v tem pregledu. Ker sta dušik in fosfor ključni sestavini v beljakovinah, je uporaba NPK gnojil nujna za optimizacijo vsebnosti surovih beljakovin v semenih kitajskega fižola, kar potrjujejo številni avtorji. Povečevanje odmerkov dušika in fosforja praviloma poveča vsebnost surovih beljakovin, vendar so bili optimalni pridelek in vsebnost beljakovin v večini agroekoloških razmer v Nigeriji doseženi pri odmerku 30 kg N/ha in 37,5 kg P_2O_5/ha v kombinaciji z inokulacijo semen z bakterijo *Rhizobium*.

Ključne besede: sorte kitajskega fižola, surove beljakovine, dušik, fosfor, kalij