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Determining the Optimal NPK Rate for the Growth and Yield of Voandzou (*Vigna subterranea* (L.) Verdc.) in the Sudanese Zone of Chad

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Voandzou (Bambara groundnut, *Vigna subterranea* (L.) Verdc.) is an underutilised legume in Chad, where production remains largely traditional and technical recommendations for mineral fertilisation are limited. This study evaluated graded NPK (15-15-15) rates to identify an appropriate application rate for the local Houlsar ecotype under Sudanese-zone conditions. A Fisher block design comprising four treatments and four replicates was used. The treatments were T1 (0 kg/ha NPK), T2 (50 kg/ha), T3 (100 kg/ha), and T4 (150 kg/ha). Leaf number was assessed at 30 and 45 days after sowing (DAS), and pod number, pod yield, and 1,000-seed weight were measured. Leaf number did not differ significantly among treatments at either

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assessment. T3 recorded the highest mean leaf number at 30 DAS (33.25 ± 8.70) and 45 DAS (73.40 ± 14.497). T2 produced the highest number of pods per plant (53.00 ± 2.581), whereas T3 recorded the highest pod yield (1.958 ± 0.587 t/ha), followed by T2 (1.846 ± 0.037 t/ha). T2 also produced the highest 1,000-seed weight (0.632 ± 0.038 kg). The unfertilised control and the highest NPK rate generally produced lower yield-related values. Under the conditions of this trial, 50 kg/ha NPK (15-15-15) provided strong yield performance while using less fertiliser than the higher-rate treatments. Further trials are required to confirm the recommendation across seasons and sites.

Keywords: Vigna subterranea (L.) Verdc.; optimal fertiliser rate; ecotype; productivity.

1. Introduction

In 2019, approximately 750 million people experienced severe food insecurity, equivalent to nearly one in ten people worldwide. In total, 2 billion people lacked regular access to safe, nutritious, and sufficient food (FAO et al., 2020). Food security and poverty reduction have therefore become major concerns for most countries worldwide (Nazal et al., 2023).

Africa is no exception, as it faces numerous challenges associated with climate variability, which is one of the factors exacerbating poverty and food insecurity. At the local level, climate variability is manifested through fluctuations in the timing and duration of rainfall, which are difficult to manage. Flooding, rainfall variability, drought, and soil degradation limit agricultural production and contribute to declining crop yields. This reduction in agricultural production constrains Africa's capacity to ensure food security for its population, despite the availability of potentially arable land.

In response to these multiple challenges, Africa must identify specific, sustainable, and adaptable solutions to increase agricultural production and meet the food requirements of its population. One such solution is crop diversification. The promotion of neglected species therefore provides a means of diversifying crops in certain African regions. Although these marginal crops may have low yields, they are well adapted to their growing environments and are generally hardy (Altieri, 1986). Furthermore, they often hold considerable social and cultural importance for the communities that cultivate them (Djè et al., 2005). Crop diversity and appropriate agricultural techniques are key factors in sustainably increasing agricultural productivity and strengthening food security.

To satisfy the growing demand of the world's population, which is projected to reach 9 billion by 2050, and to accommodate changes in dietary patterns, global agricultural production will need to increase by 60% over the same period (FAO, 2014). One of the major challenges facing agriculture in African countries is food self-sufficiency (Boyé et al., 2016). Accordingly, Chad's agricultural policy aims to ensure food security by sustainably providing the population with high-quality, affordable agricultural products (Goalbaye et al., 2018a) and contributing to poverty reduction in rural areas.

Chad is one of the largest countries in Africa and is located in the centre of the continent. Its population is concentrated in the southern part of the country, where agriculture is the principal economic activity. Agriculture is one of the most important pillars of the economy, accounting for 23% of gross domestic product and employing 80% of the rural labour force (Ministry of Agriculture and Irrigation, Republic of Chad, 2013). Arable land is estimated at more than 39 million hectares, representing 30.37% of Chad's total land area.

Despite the country's considerable potential, food insecurity has remained widespread in recent years, primarily because of climate change and poor agricultural practices. These practices reflect limited knowledge of crop rotation and cultivation techniques, producers' restricted access to high-yielding seed varieties, and the unsuitability of some cultivated varieties for specific agroecological zones.

Furthermore, agriculture in Chad is predominantly rainfed and based on family farms (Nadjiam & Goalbaye, 2014). Agricultural production often falls short of demand because of climatic uncertainty and rudimentary production methods, among other factors (Nadjiam & Goalbaye, 2014). Voandzou production in the Sudanese zone of Chad requires improved farming practices, particularly the application of mineral or organic fertilisers. Chemical fertilisers supply nutrients to crops and can improve soil conditions for plant growth (Mulaji, 2011).

Thus, the development of underutilised crops such as voandzou represents an important option for strengthening food and nutritional security and reducing poverty in Chad. Research efforts remain insufficient, while drought continues to be one of the most complex constraints on agricultural production in the country (Goalbaye et al., 2013). Recent experimental evidence indicates that phosphorus supply can influence the growth and physiological performance of Bambara groundnut under water limitation, while field responses also vary according to variety and fertiliser rate (Temegne et al., 2024; Umar et al., 2025).

Voandzou, scientifically known as *Vigna subterranea* (L.) Verdc. and also called Bambara groundnut, is a minor food legume cultivated mainly in sub-Saharan Africa, where it is adapted to diverse climatic and ecological conditions, including steppe, savanna, and forest environments. The seeds are consumed either alone or in combination with other foods. The seeds and leaves are also used in traditional medicine (Nacoulma-Ouédraogo, 1996), and the crop contributes to the fertility of degraded soils. It ranks third among the edible legumes consumed in Africa, after groundnut and cowpea. Despite its high nutritional value, global voandzou production is estimated at only 300,000 metric tonnes. Recent evidence identifies Bambara groundnut as a nutritionally valuable and drought-tolerant African legume suited to low-input and marginal production systems, while also indicating that its productivity and wider utilisation remain constrained by limited crop-management technologies and uneven research coverage (El Bilali et al., 2024; Kundy et al., 2023; Majola et al., 2021).

In Chad, particularly in the provinces of Moyen-Chari and Mandoul, voandzou production declined from 11,468.2 metric tonnes in 2018 to 10,804 metric tonnes in 2022 (ANADER, 2022). Production is declining because the cultivation of voandzou (*Vigna subterranea*) remains neglected and is largely practised within traditional family farming systems. Consequently, productivity is low because technical guidelines remain limited and poorly understood. Nevertheless, the crop should be promoted and made more widely available because of its contribution to food security and soil fertility. It is grown in crop rotations and intercropping systems and is well adapted to harsh climatic conditions. Therefore, this crop warrants particular attention under current climate-change conditions.

Voandzou is traditionally cultivated in the Sudanese zone of Chad; however, little scientific research has been conducted on the crop (Goalbaye et al., 2023). Consequently, voandzou productivity and producers' incomes remain low. This situation raises two principal questions: which factors limit voandzou production in the Sudanese zone of Chad, and which cultivation practices could increase its yield? Research should therefore focus on developing appropriate cultivation techniques to improve crop yields (Taffouo et al., 2008). Various studies have nevertheless investigated organic or mineral fertilisation in different crops (Diaité et al., 2020; Diallo et al., 2016, 2019; Ganyo et al., 2018; Goalbaye et al., 2016a, 2016b, 2017, 2018b, 2019, 2024, 2025a, 2025b).

The rationale for this study is therefore consistent with the Chadian Government's policy of ensuring food security through the sustainable production of high-quality agricultural products (Goalbaye et al., 2018a).

Whether used for household consumption or sale, voandzou is a valuable dietary supplement for the Chadian population, among whom malnutrition in its various forms remains prevalent. Massawe et al. (2005) reported that voandzou seed proteins are rich in lysine. Combining voandzou with cereals, which are staple foods in Chad, can therefore provide a useful dietary supplement for local communities that cannot afford the high cost of animal protein (Guei, 2020). Nevertheless, locally validated evidence on the response of the Houlsar voandzou ecotype to graded NPK application rates under the Sudanese-zone conditions of Chad remains limited. This knowledge gap constrains the formulation of practical, location-specific fertiliser recommendations for improving crop productivity while avoiding unnecessarily high mineral inputs.

1.1 Objectives

The overall objective of this study was to improve voandzou production in the Sudanese zone of Chad.

The specific objectives were:

- ✓ to determine the optimal NPK application rate for the voandzou ecotype in the Sudanese zone of Chad;
- ✓ to develop a technical data sheet on voandzou cultivation for farmers;

Experimentation was adopted as the research method to achieve these objectives.

2. Materials and Methods

2.1 Experimental Site

The experiment was conducted in July 2025 at the Doyaba campus of the University of Sarh (UDS) (09'081''89°N, 18'42''947°E; elevation: 360 m), in Moyen-Chari Province. The area has a Sudanese climate characterised by a hot, dry season from November to April and a hot, humid rainy season from May to October. Mean annual rainfall is 1,100 mm, and temperatures range from 24 to 38°C. The soil has a uniform sandy-clay texture.

2.2 Materials

The plant material comprised the local 'Houlsar de Voandzou' variety, which has a 90-day growth cycle. Its mean yield at the station had not been determined before the experiment.

2.3 Methods

The experiment was conducted using a Fisher block design with four treatments (T1, T2, T3, and T4) and four replicates. Treatments T1, T2, T3, and T4 corresponded, respectively, to the control (0 kg/ha NPK) and NPK (15-15-15) rates of 50, 100, and 150 kg/ha. Each plot measured 5 m × 3.5 m, giving an area of 17.5 m². A planting spacing of 30 cm × 30 cm was used, resulting in 204 plants per plot. The total plot area in each block was 70 m². The spacing between blocks was 0.5 m, and that between basic plots was 30 cm. The total experimental area was 70 m² × 4 = 280 m², with 204 × 16 = 3,264 plants. Only one factor, fertiliser rate, was studied.

2.4 Crop Management

The individual plots were ploughed to a depth of 15–20 cm after either a 'blank' trial or a 'homogenisation' trial conducted with maize, a crop that is sensitive to soil fertility. The plots were then harrowed to prepare the seedbed. Sowing was carried out after effective rainfall of at least 20 mm. One seed was sown per hole at a depth of approximately 5 cm, with a spacing of 30 cm × 30 cm. Fertiliser was applied as a basal dressing at sowing. The first weeding was conducted 14 days after sowing (DAS), and the second was conducted 21 days after the first weeding.

2.5 Experimental Design

Block 1	T1 (0 kg) NPK	T2 50Kg/ha NPK (15-15-15)	T3 100Kg/ha NPK (15-15-15)	T4 150Kg/ha NPK (15-15-15)
Block 2	T2 50Kg/ha NPK (15-15-15)	T4 150Kg/ha NPK (15-15-15)	T1 (0 kg) NPK	T3 100Kg/ha NPK (15-15-15)
Block 3	T3 100Kg/ha NPK (15-15-15)	T1 (0 kg) NPK	T4 150Kg/ha NPK (15-15-15)	T2 50Kg/ha NPK (15-15-15)
Block 4	T4 150Kg/ha NPK (15-15-15)	T2 50Kg/ha NPK (15-15-15)	T1 (0 kg) NPK	T3 100Kg/ha NPK (15-15-15)

2.6 Statistical Analysis

Data entry and graphical presentation of the measured agronomic parameters were carried out using Excel 2007. The data were analysed using the Statistical Package for the Social Sciences (SPSS), version 20.0. Treatment means were separated using the Student–Newman–Keuls (SNK) multiple-range test.

3. Results and Discussion

3.1 Results

3.1.1 Number of Leaves at 30 DAS

Fig. 1 shows the number of leaves at 30 DAS. Treatment T3 (33.25 ± 8.7) had the highest number of leaves, followed by T2 (32.35 ± 10.858) and T4 (30.05 ± 5.154). Treatment T1 (29.2 ± 5.486) recorded the lowest number of leaves. Statistical analysis of leaf number (F = 0.005; P = 0.315) indicated no significant difference among treatments at the 5% level.

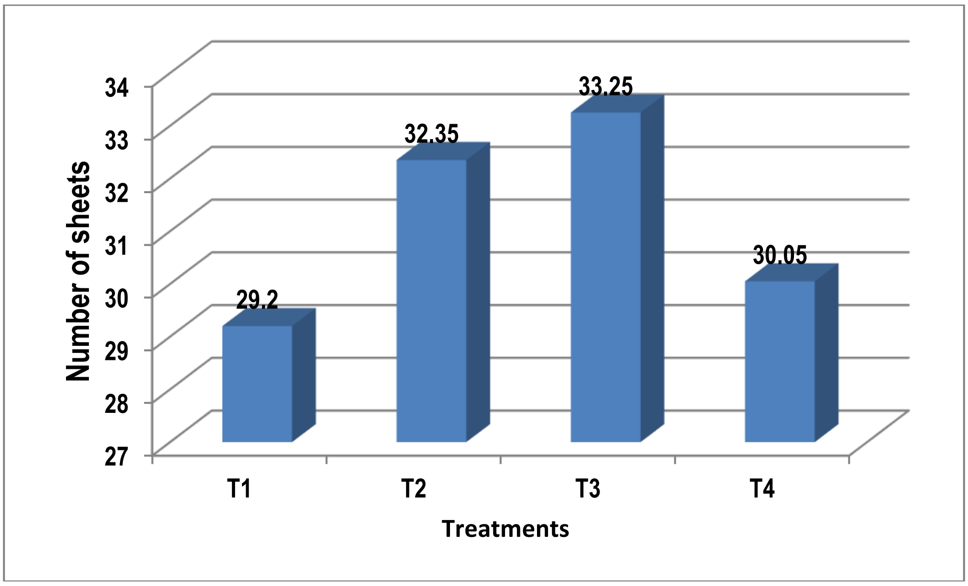

Fig. 1. Number of leaves at 30 DAS

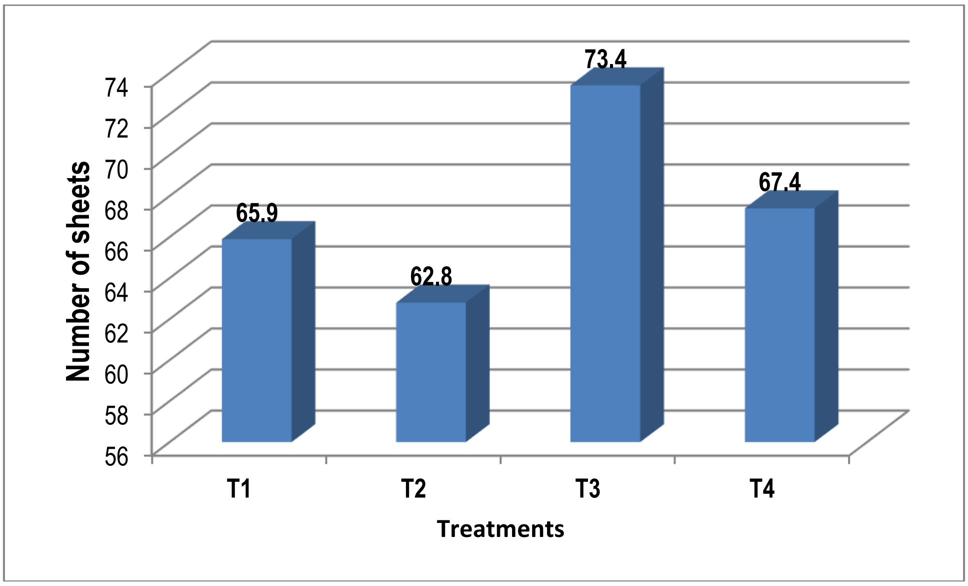

Fig. 2. Number of sheets: 45 DAS

3.1.2 Number of Leaves at 45 DAS

Fig. 2 shows the number of leaves at 45 DAS. Treatment T3 (73.4 ± 14.497) had the highest number of leaves, followed by T4 (67.4 ± 19.473) and T1 (65.9 ± 11.678). Treatment T2 (62.8 ± 6.935) had the lowest number of leaves. Statistical analysis indicated no significant difference in leaf number among treatments at the 5% level ($F = 0.89$; $P = 0.124$).

3.1.3 Pod Yield

Fig. 3 shows the pod yield of voandzou. Treatment T3 (1.958 ± 0.587 t/ha) recorded the highest yield, followed by T2 (1.846 ± 0.037 t/ha). Treatments T1 (0.7925 ± 0.341 t/ha) and T4 (0.551 ± 0.222 t/ha) recorded the lowest yields. Statistical analysis indicated a highly significant difference in pod yield at the 1% level ($F = 13.31$; $P < 0.001$).

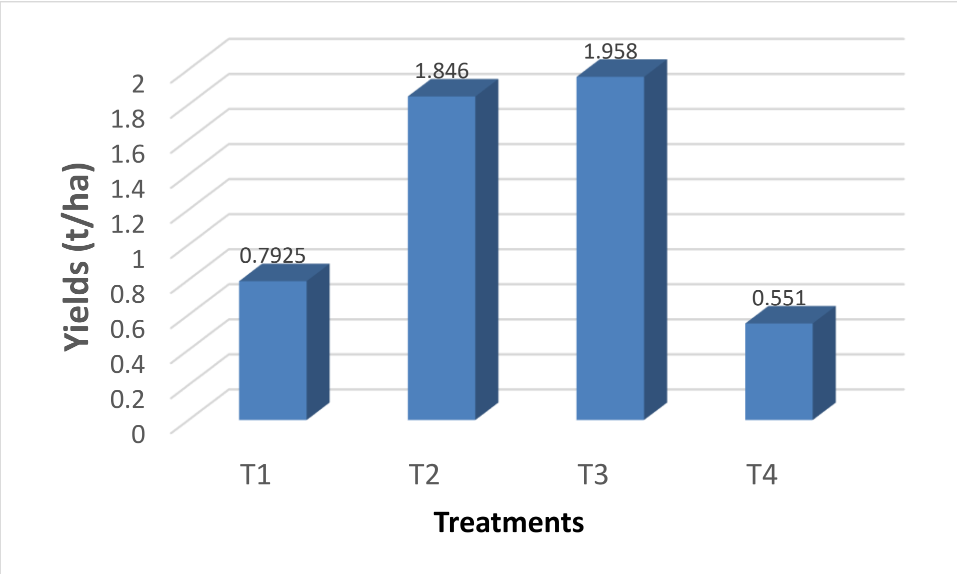

Fig. 3. Voandzou yields in shells (t/ha)

3.1.4 Number of Pods Per Plant

Fig. 4 shows the number of pods per plant. Treatment T2 (53 ± 2.581) had the highest number of pods, followed by T3 (51.25 ± 0.957). Treatments T1 (26.75 ± 2.986) and T4 (28 ± 3.265) had the lowest numbers of pods. Statistical analysis indicated a highly significant difference among treatment means in the number of pods per plant at the 1% level ($F = 104.66$; $P < 0.01$).

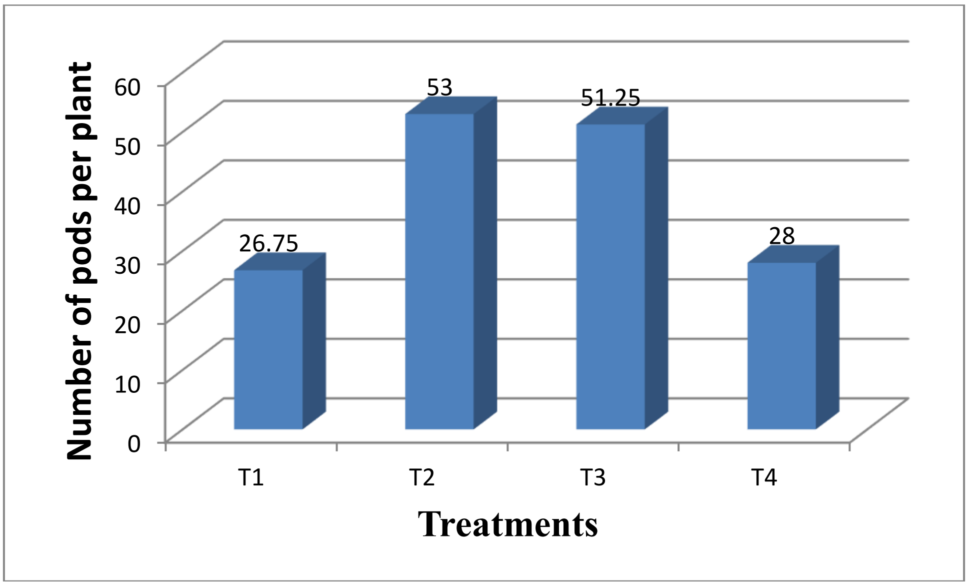

Fig. 4. Number of pods per plant

3.1.5 Weight of 1,000 Seeds

Fig. 5 shows the weight of 1,000 seeds. Treatment T2 (0.632 ± 0.038 kg) recorded the highest seed weight, followed by T3 (0.582 ± 0.068 kg). Treatments T1 (0.319 ± 0.025 kg) and T4 (0.34325 ± 0.039 kg) recorded the lowest seed weights. Statistical analysis revealed a highly significant difference in seed weight at the 1% level ($F = 64.75$; $P < 0.001$).

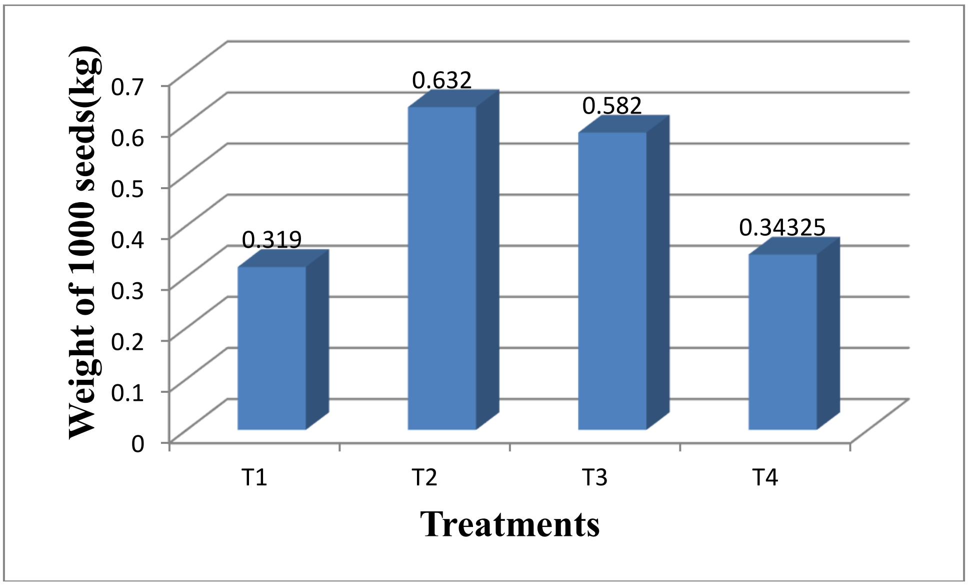

Fig. 5. Weight of 1000 seeds (kg)

3.2 Discussion

Comparison of the mean number of leaves across treatments indicated that the differences were not statistically significant at the 5% level. Thus, the vegetative growth of voandzou seedlings at 30 and 45 DAS was similar across all plots.

The observed differences may be attributable to uncontrolled factors. Mineral fertilisation appeared to have no effect at these stages on the vegetative development of the local Houlsar voandzou variety. These results differ from those of Goalbaye et al. (2016a, 2025a), who observed significant differences in the vegetative development of groundnut between unfertilised and fertilised treatments. Similar findings were reported by Useni et al. (2013) in a maize fertilisation study. For pod yield, statistical analysis revealed highly significant differences among treatment means. These findings are consistent with those of Goalbaye et al. (2025a), who reported significant differences in mean groundnut yield among NPK application rates. Similarly, Fortes et al. (2013) observed increased sugarcane yield across four varieties with increasing nitrogen (urea) rates.

For the number of pods per plant, statistical analysis revealed highly significant differences among treatments at the 1% level. These findings are consistent with those of Goalbaye et al. (2025b), who recorded differences in pod number per plant in response to the mineral fertilisation of groundnut.

Furthermore, statistical analysis revealed highly significant differences among the mean seed weights. Similar findings have been reported in studies of voandzou inoculation with *Rhizobium spp.* and fertilisation (Goalbaye et al., 2025b; Gomoung et al., 2017; Guei, 2020).

A positive correlation was observed between the two yield components, namely seed weight and number of pods per plant, and pod yield.

The trial showed that low yields occurred in the unfertilised control and in the treatment receiving the highest chemical fertiliser rate. This may be because the high fertiliser rate inhibited the expression of the crop's genetic yield potential. Thus, low NPK rates were the most effective for voandzou cultivation in the Sudanese zone of Chad.

4. Conclusion

This study evaluated four NPK (15-15-15) application rates for the local Houlsar voandzou ecotype under the Sudanese-zone conditions of Chad. Vegetative growth, assessed through leaf number at 30 and 45 DAS, did not differ significantly among treatments. In contrast, the yield-related variables responded markedly to NPK rate. Treatment T2 (50 kg/ha) produced the highest number of pods per plant and the highest 1,000-seed weight, while T3 (100 kg/ha) recorded the highest pod yield, followed closely by T2. The unfertilised control and T4 (150 kg/ha) generally recorded lower values for pod number, seed weight, and pod yield. These results indicate that increasing the NPK rate beyond 100 kg/ha did not improve performance under the conditions of this trial. Considering the strong yield-related performance of T2 and its lower mineral input, 50 kg/ha NPK (15-15-15) is the most appropriate rate for practical use among the treatments evaluated.

5. Limitations

The experiment was conducted at one site during one cropping period and evaluated one local ecotype under four NPK rates. Consequently, the findings may be specific to the soil and climatic conditions of the trial. Seasonal and multi-location stability were not assessed, and the response of other ecotypes remains uncertain. The recommended rate should therefore be validated through repeated trials across representative locations in the Sudanese zone before broad dissemination.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Competing Interests

Authors have declared that no competing interests exist.

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