FULafia Journal of Science & Technology
ISSN (print) 2449-0954 \ ISSN (online) 2636-4972
https://lafiascijournals.org.ng/index.php/fjst
Sponsored By TERTIARY EDUCATION TRUST FUND
Manuscript => Received: Jan., 2026; Accepted: May, 2026; Published: May, 2026 https://doi.org/10.62050/fjst2026.v10n2.777

EVALUATION OF IMPROVED SOYBEAN (*Glycine max* (L.) Merr.) GENOTYPES TREATED WITH IRON NANOPARTICLES

Hauwa Ahmad Kana*, Godwin Omame Ogah and Adama Ababarabi Umar
Department of Plant Science and Biotechnology, Federal University of Lafia, PMB 146, Nasarawa State, Nigeria
*Corresponding email: hauwamakongiji@gmail.com

ABSTRACT

Soybean distribution in Nigeria is predominantly found in the northern and central regions of the country, where the climatic and soil conditions are favorable for its cultivation. The aim of this study was to evaluate the improved soybean genotypes exposed to Iron Nanoparticles (FeNPs). The study was carried out at the research and experimental plots of the Department of Plant Science and Biotechnology, Federal University of Lafia, in the Guinea Savanna zones of North Central Nigeria, from July to November 2024. The collected improved and local soybean genotypes were laid out in a randomized complete block design (RCBD) with each of the genotype having three replications. The result revealed significant differences among the varieties and treatments for agronomic traits. Germination count was insignificant across genotypes, with values ranging from 1.33 SC SIGNAL (V4T_0) to 4.00 TGx2016-6ExCIMARONA (V3T_1). Maximum mean number of branches were recorded with FeNPs treatment 2 in TGx2024-7E (V10T_0) and TGx1740-2F-2I (V2T_0), with 13.00 and 12.67, respectively; with the least value of 5.67 recorded in SC SIGNAL (V4T_1). The varieties TGx2020-4e (V5T_1) and S1252-5-227 (V8T_0) are recommended for cultivation in the study area.

Keywords: Evaluation, Improved soybean, Genotypes, Iron nanoparticles

INTRODUCTION

Soybean (*Glycine max* (L) Merr.) has emerged as one of Nigeria's most important cash and food crops, with production expanding steadily across the country's savanna zones (Abebe *et al.*, 2024). The crop supplies approximately 68 % of the world's plant protein and serves as a major source of cholesterol-free, unsaturated vegetable oil. In Nigeria, it supports the livelihoods of millions of smallholder farmers and provides a low-cost, high-protein input for the rapidly growing poultry and food processing industries. Demand for soybean has more than doubled in the past decade, driven by its nutritional value and diverse uses ranging from soymilk (Fasusi *et al.*, 2022a). The Northern Guinea savanna, particularly the sub-humid and semi-arid agro-ecological zones, offers suitable soils with low nitrogen and phosphorus for soybean cultivation (Adeyanju & Ishiyaku, 2007). The Guinea savanna belt accounts for the bulk of production across 17 states, with early-maturing varieties preferred in the drier Sudan and Sahel zones, while late-maturing varieties generally yield higher biomass and grain in more favorable conditions (Akande *et al.*, 2018).

Historically, the Tiv Division of Benue Province was the main production hub, recording 10.5 tons in 1946 and 700 tons in 1948. Since the 1970s, the International Institute of Tropical Agriculture (IITA) has improved African soybean lines through Tropical Glycine Cross (TGX) breeding, boosting national output to about 780,033 tons from 758,033 hectares in 2018. Production is projected to reach 467,000 metric tons, with the most significant annual growth of 25 % recorded in 2011 (Nafziger, 2015). Despite this progress, yields remain suboptimal due to erratic rainfall, declining soil fertility, and limited access to improved seeds and fertilizers. Most Nigerian soybean farmers are smallholders who rely on local varieties and rain fed systems, restricting the crop's genetic potential. Additionally, the prevalence of starchy staples in the Nigerian diet contributes to malnutrition and chronic diseases such as diabetes and heart conditions (Ogah *et al.*, 2025).

Soybean's high protein content and unsaturated oil profile offer a practical solution to these health challenges by lowering cholesterol absorption and improving dietary quality (Oplinger & Philbrook, 1998). Crop performance is further complicated by genotype by environment interaction (GxE), where the relative ranking of varieties changes across locations and seasons. This reduces the correlation between phenotypic and genotypic values and can lead to poor performance of selected varieties in new environments. Understanding GxE through multi-environment trials (MET) is therefore essential for identifying stable, high-yielding genotypes and representative test locations. To address persistent productivity gaps, agricultural innovation is critical as arable land diminishes and the population grows.

Nanotechnology has emerged as a promising tool for sustainable crop improvement, often referred to as Nano breeding. Nanomaterials enhance nutrient uptake, promote seed germination, improve soil quality, and increase stress tolerance while reducing environmental impact. Studies have demonstrated their role in pesticide residue degradation and overall soil health enhancement (Kumar *et al.*, 2025). Although widely adopted in other regions since the U.S. Department of Agriculture's endorsement in 2003, nanotechnology application in Nigerian soybean production remains limited due to low institutional support and farmer awareness (USDA, 2012). While soybean production has increased in Nigeria, smallholder farmers continue to face low yields due to poor soil fertility, environmental variability, and limited access to improved inputs (Pedersen & Lauer, 2003a). Although nanotechnology shows potential for enhancing crop productivity and resilience, its integration into soybean breeding and cultivation systems in Nigeria, particularly in the savanna agro-ecology, is underexplored (Fasusi *et al.*, 2022b). There is also insufficient empirical evidence on how Nano breeding interacts with genotype by environment factors to influence soybean yield and nutritional quality under Nigerian conditions (Well, 1999). The overall objective of this study was to assess the role of nanotechnology in improving soybean productivity and resilience in Nigeria's savanna agro-ecology.

MATERIALS AND METHODS

Study Location

The study was carried out at the Research and Experimental Plots of the Department of Plant Science and Biotechnology, Federal University Lafia, Nasarawa State from July to November, 2024. Lafia is situated in Nasarawa State and in the Guinea Savanna zones of North Central Nigeria; Latitude 8.51667°N and Longitude 8.4916°E.

Sources of Planting Material

A total of ten (10) improved genotypes of soybean were obtained from National Cereal Research Institute, Baddegi Niger State while one (1) local variety was obtained from the College of Agriculture Science and Technology, Lafia (Plate 1, Table 1).

Plate 1: Planting materials obtained from NCRI

Table 1: Details of experimental samples

S/N	Genotype	Symbol	Source
1	TGx1835-10ExTGx1989-19F-23	IV1	NCRI
2	TGx1740-2F-2I	IV2	NCRI
3	TGx2016-6ExCIMARONA	IV3	NCRI
4	SC SIGNAL	CV4	COAST
5	TGx2020-4e	IV5	NCRI
6	TGx1951-3F	IV6	NCRI
7	TGx1904-6F	IV7	NCRI
8	S1252-5-227	IV8	NCRI
9	S1365-6L-20	IV9	NCRI
10	TGx2024-7E	IV10	NCRI
11	AS-6-001PxTGx1740-2F)xTGx1740-2F-9	IV11	NCRI

Where: NCRI - National Cereal Research institute
COAST- College of Agriculture Science and Technology

Collection of Soil Samples

Soil samples were collected from five random spots in both locations using for each location, 1 kg of soil sample was collected from a depth of 0−15 cm (Jandong *et al.*, 2011) and 15-30 cm. Roots and clumps were removed manually from the collected samples. The soil was air-dried and sieved through 2 mm mesh (Moscatiello *et al.*, 2015) before it was taken to the Soil Laboratory of the Faculty of Agriculture, Nasarawa State University, for physiochemical analysis.

Experimental Design

The collected improved and local soybean genotypes and treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications.

Data Analysis

All data collected were subjected to Analysis of Variance (ANOVA) using GenStat. (Version 23). Significant differences between treatment means were separated using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

RESULTS AND DISCUSSION

Agronomic Performance of Soybean Genotypes in Lafia

The mean agronomic performance of 11 soybean genotypes evaluated in Lafia showed significant variation among genotypes and treatments for most traits, as presented in Table 2.

Table 2: mean performance for agronomic traits of soybean genotypes exposed to FeNPs evaluated in Lafia

Genotype	GC	NB	PH	DF	DP	PD	SP	W1000
$V1T_1$	3.33 ± 0.58^{a}	7.67 ± 0.58^{ab}	45.00 ± 8.66^{abc}	48.33 ± 2.52^{a}	56.67 ± 3.06^{a}	44.33 ± 12.66^{a}	2.67 ± 0.58^{a}	160.00 ± 26.51^{a}
$V2T_1$	3.00 ± 1.00^{a}	12.00 ± 1.00^{ab}	45.33 ± 15.18^{abc}	48.33 ± 6.43^{a}	59.67 ± 5.86^{a}	34.33 ± 16.20^{a}	3.00 ± 1.00^{a}	156.67 ± 8.14^{a}
$V3T_1$	4.00 ± 0.00^{a}	8.00 ± 1.00^{ab}	45.67 ± 8.74^{abc}	51.67 ± 1.53^{a}	61.67 ± 0.58^{a}	36.33 ± 8.50^{a}	3.67 ± 0.58^{a}	175.00 ± 13.75^{a}
$V4T_1$	1.67 ± 1.53^{a}	5.67 ± 4.93^{a}	25.67 ± 22.50^{a}	35.33 ± 30.86^{a}	41.67 ± 36.36^{a}	27.67 ± 23.97^{a}	2.00 ± 1.73^{a}	110.67 ± 96.72^{a}
$V5T_1$	3.33 ± 0.58^{a}	12.00 ± 1.00^{ab}	61.33 ± 3.21^{c}	52.67 ± 3.21^{a}	62.00 ± 3.61^{a}	51.00 ± 1.73^{a}	3.00 ± 0.00^{a}	201.33 ± 8.08^{a}
$V6T_1$	3.00 ± 1.00^{a}	11.33 ± 1.15^{ab}	39.00 ± 5.57^{abc}	50.67 ± 2.31^{a}	59.67 ± 1.53^{a}	58.00 ± 12.49^{a}	3.00 ± 0.00^{a}	180.67 ± 27.79^{a}
$V7T_1$	3.33 ± 0.58^{a}	10.00 ± 2.00^{ab}	39.00 ± 6.08^{abc}	55.33 ± 5.86^{a}	65.00 ± 4.36^{a}	65.33 ± 14.98^{a}	4.00 ± 0.00^{a}	179.33 ± 22.74^{a}
$V8T_1$	3.67 ± 0.58^{a}	10.67 ± 1.53^{ab}	38.67 ± 6.03^{abc}	55.00 ± 4.58^{a}	66.00 ± 4.58^{a}	22.33 ± 6.11^{a}	2.67 ± 0.58^{a}	184.33 ± 16.56^{a}
$V9T_1$	2.33 ± 0.58^{a}	7.33 ± 0.58^{ab}	36.33 ± 5.03^{abc}	50.33 ± 2.08^{a}	60.33 ± 5.51^{a}	27.67 ± 5.03^{a}	3.67 ± 0.58^{a}	178.33 ± 19.50^{a}
$V10T_1$	3.00 ± 1.00^{a}	11.33 ± 0.58^{ab}	56.33 ± 9.29^{abc}	51.67 ± 1.53^{a}	59.67 ± 2.52^{a}	59.33 ± 25.74^{a}	2.00 ± 0.00^{a}	171.33 ± 7.51^{a}
$V11T_1$	2.67 ± 0.58^{a}	10.33 ± 2.52^{ab}	40.00 ± 4.58^{abc}	53.67 ± 6.81^{a}	63.33 ± 6.03^{a}	39.67 ± 25.79^{a}	2.67 ± 0.58^{a}	173.00 ± 30.05^{a}
$V1T_0$	3.00 ± 1.00^{a}	11.00 ± 2.00^{ab}	48.33 ± 8.08^{abc}	49.00 ± 1.00^{a}	58.00 ± 0.00^{a}	49.00 ± 13.53^{a}	2.67 ± 0.58^{a}	167.67 ± 29.26^{a}
$V2T_0$	3.67 ± 0.58^{a}	12.67 ± 1.15^{b}	48.00 ± 15.10^{abc}	46.67 ± 5.77^{a}	57.33 ± 5.51^{a}	38.00 ± 16.52^{a}	3.33 ± 0.58^{a}	168.00 ± 4.58^{a}
$V3T_O$	2.67 ± 0.58^{a}	9.33 ± 1.15^{ab}	48.00 ± 8.89^{abc}	49.67 ± 0.58^{a}	57.67 ± 4.04^{a}	39.00 ± 7.00^{a}	3.33 ± 0.58^{a}	185.00 ± 15.13^{a}
$V4T_O$	1.33 ± 1.15^{a}	6.33 ± 5.51^{ab}	27.00 ± 23.64^{ab}	35.33 ± 30.75^{a}	42.67 ± 37.17^{a}	30.00 ± 26.00^{a}	2.33 ± 2.08^{a}	113.00 ± 98.42^{a}
$V5T_O$	3.33 ± 0.58^{a}	11.33 ± 2.89^{ab}	54.00 ± 7.94^{abc}	51.00 ± 1.00^{a}	61.67 ± 3.06^{a}	40.67 ± 5.51^{a}	3.00 ± 0.00^{a}	193.33 ± 26.16^{a}
$V6T_O$	3.00 ± 1.73^{a}	11.00 ± 1.00^{ab}	43.33 ± 5.51^{abc}	50.67 ± 1.15^{a}	61.00 ± 2.65^{a}	60.67 ± 11.55^{a}	3.67 ± 0.58^{a}	182.67 ± 26.50^{a}
$V7T_O$	2.33 ± 0.58^{a}	10.67 ± 2.08^{ab}	41.33 ± 5.51^{abc}	54.33 ± 5.51^{a}	63.00 ± 8.54^{a}	65.33 ± 14.57^{a}	4.00 ± 0.00^{a}	173.00 ± 24.02^{a}
$V8T_O$	3.33 ± 0.58^{a}	11.67 ± 2.52^{ab}	40.67 ± 6.03^{abc}	53.33 ± 4.16^{a}	66.33 ± 7.02^{a}	35.33 ± 8.02^{a}	3.00 ± 0.00^{a}	194.67 ± 16.01^{a}
$V9T_O$	2.33 ± 0.58^{a}	9.33 ± 0.58^{ab}	36.67 ± 5.51^{abc}	48.67 ± 1.53^{a}	54.67 ± 3.51^{a}	33.33 ± 7.23^{a}	3.33 ± 0.58^{a}	184.33 ± 17.79^{a}
$V10T_O$	3.33 ± 1.15^{a}	13.00 ± 1.00^{b}	58.33 ± 9.07^{bc}	51.00 ± 1.73^{a}	61.67 ± 0.58^{a}	64.67 ± 23.69^{a}	3.00 ± 0.00^{a}	182.67 ± 8.50^{a}
$V11T_O$	3.00 ± 1.00^{a}	11.33 ± 2.31^{ab}	42.67 ± 4.51^{abc}	52.67 ± 2.52^{a}	62.00 ± 3.61^{a}	49.00 ± 14.53^{a}	3.67 ± 0.58^{a}	178.33 ± 32.87^{a}
GM	2.94	10.18	43.67	49.79	59.17	44.14	3.08	172.42
MSE	0.77	4.82	107.26	98.55	140.32	240.41	0.55	1262
CV (%)	29.91	21.56	23.72	19.94	20.02	35.13	24.01	20.6
p value	0.10	0.00	0.01	0.68	0.67	0.14	0.05	0.32

Values represent mean ± standard deviation, N = 3. Values with the same superscript in each column are not significantly different at p value < 0.05. Genotypes designated as T_1 were treated while T_0 were untreated. GM = Grand mean, MSE = Mean square error, CV = Coefficient of Variation, GC = Germination count, NB= Number of Branches, PH = Plant height, DF = Days to 50 % flowering, DP = Days to 50 % podding, PD = Pods, SP =Seed pods, W1000 = One thousand seed weight

Germination Count

Germination count did not differ significantly among genotypes, with values ranging from 1.33 in SC SIGNAL (V4T0) to 4.00 in TGx2016-6ExCIMARONA (V3T1). The highest mean number of branches was observed under FeNPs treatment 2 in TGx2024-7E (V10T0) and TGx1740-2F-2I (V2T0), recording 13.00 and 12.67 branches per plant, respectively. The lowest branching was recorded in SC SIGNAL (V4T1) with 5.67 branches.

Plant Height

Plant height varied significantly across genotypes. TGx2020-4e (V5T0) and TGx2024-7E (V10T0) attained the greatest height at 61.33 and 58.33 cm, respectively. In contrast, SC SIGNAL (V4T1) and SC SIGNAL (V4T0) were the shortest, measuring 25.67 and 27.00 cm, respectively. It was observed that FeNP effects were highly significance on mean number of germination count and plant height. The significance effect of FeNP on these agronomic traits implied that varying environmental condition can influence the expression of these growth traits in Soybean. This is supported by Akande *et al.* (2018) and Samuel *et al.* (2022).

Days to 50 % Flowering

Days to 50 % flowering and podding showed relatively narrow variation and were not statistically significant among genotypes. Days to flowering ranged from 35.33 to 55.33 days, while days to podding ranged from 41.67 to 66.33 days. TGx1904-6F (V7T0 and V7T1) recorded the longest days to podding at 65.33 days, whereas S1252-5-227 (V8T1) and SC SIGNAL (V4T1) recorded the shortest at 22.33 and 27.67 days, respectively. This result indicates a substantial genetic variability and strong potentials for selection. This is in accordance to Kamara *et al.* (2023) who worked on soybean and reported that variability among 50 % flowering in soybean varieties were as a result of genetic composition.

Yield Components

The mean number of seeds per pod did not differ significantly among genotypes, though the highest value of 4.00 seeds per pod was recorded in TGx1904-6F (V7T0 and V7T1). The variability in how genotype performs for seed production depends on the environment. This was also reported by Vange and Egbe (2009), Oyiga and Uguru (2011) and Manggoel *et al.* (2012). For 1000-seed weight, TGx2020-4e (V5T1) and S1252-5-227 (V8T0) recorded the highest values of

201.33 g and 194.67 g, respectively. The lowest 1000-seed weight was observed in SC SIGNAL (V4T1) at 110.67 g and SC SIGNAL (V4T0) at 113.00 g.

Based on the combined agronomic traits, TGx2020-4e (V5T1), TGx1904-6F (V7T0 and V7T1), and TGx2024-7E (V10T0) demonstrated superior performance compared to other genotype × treatment combinations in this trial. The results suggest that both genetic background and FeNPs treatment influenced vegetative growth and yield-related traits, with TGx2020-4e and TGx1904-6F showing consistent agronomic advantage under the Lafia environment. This work is in agreement with work done by Kana and Kwon-Ndung (2020) who reported that the differences among traits in cowpea treated with alpha nanoparticles were also due to their genetic composition.
The mean performance of soybean genotypes exposed to iron nanoparticles (FeNPs) in Lafia. Significant varied as was observed among genotypes for mean number of branches and plant height, indicating the influence of both genetic composition and environmental conditions on the expression of these traits. This observation is consistent with Alhassan *et al*. (2025), who reported that trait variability is fundamental to the identification and improvement of soybean varieties. The consistent differences in branching and plant height across genotypes suggest that these traits are genetically stable and reliable for selection purposes. Overall, untreated genotypes exhibited superior performance for most vegetative traits. However, for reproductive and yield-related traits such as mean number of pods, 1000-seed weight, and days to 50 % podding, treated and untreated genotypes showed comparable performance. This suggests that FeNPs application may stimulate specific physiological processes that enhance reproductive development and yield potential in soybean. These findings align with Weber *et al*. (1996), who reported that nanoparticle-treated soybean genotypes outperformed untreated controls in reproductive traits, particularly days to podding and 1000-seed weight. The results imply that while FeNPs may not significantly alter vegetative growth, they contribute positively to yield component expression, highlighting their potential role in soybean productivity enhancement.

CONCLUSION

The study shows that iron nanoparticle treatment had minimal effect on vegetative traits such as branching and plant height, where untreated genotypes performed better. However, FeNPs positively influenced reproductive and yield-related traits, particularly number of pods, 1000-seed weight, and days to 50 % podding, with performance comparable to or slightly exceeding that of untreated genotypes. This indicates that FeNPs can enhance yield potential by stimulating physiological processes without significantly altering vegetative growth. The findings support the potential of nanotechnology as a complementary approach for improving soybean productivity in Lafia. Selecting environment-specific soybean genotypes is recommended to optimize crop productivity. Farmers and extension services should prioritize locally adapted varieties, including TGx2020-4e ($V5T_1$) and S1252-5-227 ($V8T_0$), which are particularly suitable for cultivation in Lafia and surrounding areas.

Conflict of interest: The authors declare no conflicts of interest.

Acknowledgements: The authors wish to thank the Tertiary Education Trust Fund (TETFund), for providing the funds for the research under the Institutional Based Research (IBR) grant and the Federal University of Lafia and Department of Plant Science & Biotechnology for providing support for this research.

REFERENCES

Abebe, A., Okafor, J., Musa, S. and Danladi, T. (2024). Recent advances in agricultural nanotechnology. *International Journal of Nanoagriculture*, 8(1), 23–37.

Adeyanju, A. O. and Ishiyaku, M. F. (2007). Genetic study of earliness in cowpea (*Vigna unguiculata* L. Walp) under screen house condition. *International Journal of Plant Breeding and Genetics*, 1(1), 34-37.

Akande, M., Bello, R. A., and Olatunji, O. (2018). Morphological characterization of soybean cultivars in Nigeria. *African Journal of Plant Science*, 12(4), 145–152.

Alhassan, U., Kana, H. A. and Hassan, Z. (2025). Phenotypic diversity and performance for someagronomic characters in sesame (*Sesamum indicum* L.) germplasm collection from Nasarawa state, Nigeria. *Lafia Journal of Scientific and Industrial Research*, 3(1), 40-46.

Fasusi, A. O., Olaleye, B. and Musa, H. (2022a). Challenges and prospects of soybean production in sub-Saharan Africa. *Agricultural Economics Review*, 14(3), 201–215.

Fasusi, S. A., Kim, J.-M. and Kang, S. (2022b). Current status of soyabean production in Nigeria: Constraint and prospect. *Journal of the Korean Society of Internat. Agriculture.* 34(2). 149–156. https://doi.org/10.12719/KSIA.2022.23.2.149

Jandong, E. A., Uguru, M. I. and Oyiga, B. C. (2011). Determination of yield stability of seven soybean (*Glycine max*) genotypes across diverse soil pH levels using GGE biplot analysis. *Journal of Applied Biosciences*, 43, 2924–2941.

Kamara, I. F., Kanu, J., Maruta, A., Fofanah, B. D., Kamara, K. N., Sheriff, B., ... and Vandi, M. A. (2023). Antibiotic use among hospitalised patients in Sierra Leone: a national point prevalence survey using the WHO survey methodology. *BMJ Open*, 13(12), e078367.

Kana, L. P. and Kwon-Ndung, E. H. (2023). Advances in nanotechnology in crop improvement. *Nigerian Biotechnology Journal,* 8(2), 55–68.

Kumar, A., Nautiyal, M., Debbarma, B., Bankoti, P. Dhumka, B, Dambale, A. S., Singh, L. and Khan, R. (2025). Nanotechnology for a resilient agriculture: Enhancing productivity and environmental sustainability. *Journal of Environmental and Earth Science*, DOI: 10.20944/PREPRINTS202504.0923.v1

Manggoel, W., Uguru, M. I., Ndam, O. N. and Dasbak, M. A. (2012). Genetic variability, correlation and path coefficient analysis of some yield components of ten cowpea [*Vigna unguiculata* (L.) Walp] accessions. *Journal of Plant Breeding and Crop Science*, 4(5), 80-86.

Nafziger, E. (2015). *Soybean: P 27-36.1n Illinois Agronomy Handbook*. College of Agricultural Consumer and Environmental Sciences, University of Illinois, Urbana-Champaign.

Ogah, G. O., Ambo, I. A. and Kana, H. A. (2025). Impact of Alpha Spin Nanoparticles on Genetic Diversity of Nigeria Sesame (*Sesamum indicum* L.) Germplasm. *FULafia Journal of Science & Technology*, 9(2), 31-35. https://doi.org/10.62050/fjst2025.v9n2.633

Oplinger, E. S. and Philbrook, B. D. (1998). Soybean planting date, row width and seeding rate response in three tillage system. *Journal of Productive Agriculture*. 5, 94-99.

Oyiga, B. C. and Uguru, M. I. (2011). Interrelationships among pod and seed yield traits in bambara groundnut (*Vigna subterranea* L. Verdc) in the derived savanna agro-ecology of south-eastern Nigeria under two planting dates. *Int. J. of Plant Breeding*, 5(2), 106-111.

Pedersen, P. and Lauer, J. G. (2003a). Corn and soybean response to rotation sequence, row spacing, and tillage system. *Agronomy Journal*, 95, 965-971.

Samuel, M. S., Ravikumar, M., John J, A., Selvarajan, E., Patel, H., Chander, P. S., ... and Chandrasekar, N. (2022). A review on green synthesis of nanoparticles and their diverse biomedical and environmental applications. *Catalysts*, 12(5), 459.

USDA-Farm Service Agency (2012). Common Land Unit (CLU) Information Sheet April 12, 2012. https://www.fsa.usda.gov/internet/FSA_File/clu_infosheet_2012.pdf [Accessed 28/03/2024].

Vange, T. and Moses, O. E. (2009). Studies on genetic characteristics of pigeon pea germplasm at Otobi, Benue State of Nigeria. *World Journal of Agricultural Sciences*, 5(6), 714-719.

Weber, C. R., Shibles, R. M. and Byth, D. E. (1996). Effects of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58, 99-102.

Wells, R. (1999). Soybean growth response to plant density: Relationship among canopy photosynthesis, leaf area and light interception. *Crop Science*, 31,755-761.