



doi:10.5281/zenodo.18955689

Response of Sorghum (*Sorghum bicolor* (L.) Moench) Varieties to Different Nutrient Sources on in Makurdi, Benue, Nigeria.

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ABSTRACT

The experiment aimed to evaluate the response of sorghum varieties to different nutrients sources on growth and yield in Makurdi during the 2025 Rainy Season. The treatments consisted of three sorghum varieties (SAMSORG 41, SAMSORG 52 and SAMSORG 53), and four nutrient sources (NPK + Urea, Poultry manure litter, goat manure) and the control. The treatments were laid in a randomized complete block design (RCBD) with three replications and a spacing of 20 x 80 cm. Data were collected on, plant height and number of leaves days to first panicle initiation, Number of days to maturity, days to 95% flowering, Stover yield, panicle weight, number of seeds per panicle., 100 seed weight and grain yield. The results showed that nutrient source significantly influenced growth and yield parameters, with NPK + Urea producing the highest plant height WAP(62.13cm), number of leaves (12.14), prolonging days of maturity (86.21) and days 95% flowering (67.21), Stover yield (4.11t/ha), number of seeds per panicle (106.34), panicle weight (68.17g) 100 seed weight (38.01g) and grain yield (3.43t/ha). On the other hand, SAMSORG 52 consistently outperformed other varieties in yield-related traits, recording the highest grain yield (3.88 t/ha), stover yield (3.32t/ha), single panicle weight (64.51g) number of seeds per panicle (116), and 100 seed weight (32.21g). SAMSORG 41 exhibited significantly higher vegetative growth, producing the tallest plant height (97.23cm) and number of leaves 15.34, more so, the control treatment resulted is the most delayed variety to maturity (94.5days) Based on these results, SAMSORG 52 alongside the use of NPK/Urea is recommended to achieve optimum yield in sorghum production in the study area.

Keywords: Sorghum variety, Nutrients sources, Grain yield

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a major cereal crop cultivated in semi-arid and sub-humid regions of the world, particularly in sub-Saharan Africa and parts of Asia. Globally, sorghum ranks fifth among cereal crops after maize, rice, wheat, and barley, and it plays a critical role in food security, livestock feed, and industrial applications (e.g., malting and bioethanol production) (FAO, 2022; Ignatius *et al* 2019). In Nigeria, sorghum is widely grown in the savanna agro-ecological zones, where it serves as a staple food and a source of income for smallholder farmers. However, sorghum productivity remains constrained by low soil fertility, erratic rainfall, and suboptimal nutrient management practices (Ajeigbe, 2018; Nenkam *et al.*, 2023).

The development and adoption of improved sorghum varieties have been central to increasing productivity and resilience. The international Crops Research Institute for the Semi Arid Tropics (ICRISAT) in collaboration with the Institute for Agricultural Research (IAR), Ahmadu Bello University, has developed and released several improved varieties. Among these, the newly released SAMSORG 52 and SAMSORG 53 are notable for their high yield potential, early to medium maturity, and adaptability to the Sudan and Northern Guinea savanna zones. These varieties were developed to combine improved grain quality with resistance or tolerance to prevalent biotic and abiotic stresses, thereby enhancing farmers' productivity and income. Their performance, however, is strongly influenced by soil nutrient availability and management practices.

Soil fertility decline is a major limitation to sorghum production in tropical Africa. Continuous cultivation, low organic matter inputs, and nutrient mining have resulted in widespread deficiencies of essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). Nitrogen is particularly critical for sorghum growth, as it influences leaf area development, chlorophyll content, and grain formation. Phosphorus supports root development and energy transfer processes, while potassium enhances water regulation and stress tolerance. Integrated nutrient management strategies combining inorganic fertilizers with organic amendments such as farmyard manure, compost, or crop residues have been recommended to improve nutrient use efficiency, soil structure, and long-term productivity (Vanlauwe *et al.*, 2010). The response of sorghum varieties to nutrient sources varies depending on genetic characteristics and environmental conditions. Improved varieties such as SAMSORG 52 and SAMSORG 53 may exhibit differential responses to mineral fertilizers and organic nutrient sources due to differences in growth duration, biomass accumulation, and nutrient uptake efficiency. Studies have shown that balanced fertilization significantly enhances sorghum growth parameters, including plant height, leaf area index, panicle length, and grain yield (Fageria *et al.*, 2012). Moreover, the integration of organic and inorganic nutrient sources has been reported to sustain soil fertility while increasing crop yields compared to sole application of either source (Shuaibu *et al.*, 2018).

Given the importance of sorghum in Nigeria and the need to optimize nutrient management for improved varieties, it is essential to evaluate the growth and yield performance of SAMSORG 52 and SAMSORG 53 under different nutrient sources. Such evaluation provides critical insights into varietal adaptability, nutrient use efficiency, and sustainable soil fertility management practices. Therefore, this study aims to assess the effects of different nutrient sources on the growth and yield performance of SAMSORG 41, SAMSORG 52 and SAMSORG 53, with a view to identifying suitable nutrient management strategies for enhanced sorghum production in the savanna agro-ecological zones.

MATERIAL AND METHODS

The experiment was conducted during the rainy season of 2025 at the Teaching and Research Farm, College of Agronomy, Makurdi (7° 41'N and 8° 37'E) Makurdi lies within the Southern Guinea savannah agro-ecological zone and is characterised by a mean annual temperature ranging from 27-30°C) and predominantly loamy sandy soil. The treatments consist of three varieties of Sorghum (SAMSORG 41, SAMSROG 52 and SAMSORG 53) and four nutrients sources (NPK/Urea, Poultry litter, goat manure and control), the organic sources of nutrient were applied as basal application at 5 t/ha and were factorial combined and laid in a randomized complete block design (RCBD) with three replicates. Each plot measured 8m² plot with 1m between plots and 1m between blocks. There were 12 plots each within a block which gave the total number of 36 plots for the study. Seeds were planted at a spacing of 20 × 80 cm with three seeds per hill and all recommended agronomic practice such as land clearing, weeding was done manually at 2 and 6 weeks after planting to ensure weed free plots. Fertilizer was applied according to treatment combination splitted in two applications at planting and top dressed at 6 weeks after planting at the rate of (N80 kg/ha, P60 kg/ha K60 kg/ha and Urea 20kg/ha as top dress). Harvesting and threshing was done manually. Data were collected from five randomly tagged plants within the net plot of 4m². The parameters recorded were plant height (measured from the base of the plant to the tip using meter rule) and the number for leaves (counted manually at fortnightly interval). Phonological and yield-related traits recorded were number days to first panicle initiation, days to 95% flowering, number of days to maturity,

number of seeds per panicle (counted), panicle weight (g), 100 seed weight grain yield (t/ha), and Stover yield(t/ha) using digital weighing balance. All data collected were subjected to analysis of variance (ANOVA) Gen-Stat version 17 and treatment means were separated using least significant difference (LSD) at 5% level of probability.

RESULT AND DISCUSSION

Table 1: Effect of nutrient source and variety on plant height of Sorghum grown in Makurdi, Nigeria
Weeks after planting (WAP)

Nutrients N	2	4	6	8
NPK + Urea	4.23	14.84	32.97	62.13
Poultry manure	3.52	13.16	30.71	56.32
Goat manure	3.30	12.32	29.32	53.23
Control	3.00	10.02	26.21	47.12
F-LSD (0.05)	0.21	1.00	1.01	2.12
Variety V	2	4	6	8
SAMSORG 52	4.23	6.45	10.21	62.67
SAMSORG 53	4.00	5.67	9.32	51.23
SAMSORG 41	4.09	12.32	32.34	97.23
F-LSD (0.05)	1.20	1.21	2.22	5.32
Interaction	N X V	NS	NS	NS
				*

LSD= Least Significant Differences at 5% Level of Probability, * = 95% level of probability

Table 1 shows the effect of nutrient sources and sorghum varieties on plant height at different weeks after planting (WAP). Four nutrient treatments (NPK + Urea, poultry manure, goat manure, and control) and three sorghum varieties (SAMSORG 52, SAMSORG 53, and SAMSORG 41) were assessed at 2, 4, 6, and 8 WAP. Results indicated that nutrient sources significantly influenced plant height at all growth stages. NPK + Urea consistently produced the tallest plants at 2, 4, 6, and 8 WAP (4.23, 14.84, 32.97, and 62.13 cm, respectively) this result could be related to the fact that inorganic nutrients sources dissolve fast when compared with organic sources of nutrient, (Palm *et al.* 2001) reported that same stating that inorganic nutrient sources influences plant vegetative growth most especially plant height due to its ability to dissolve fast and be pick up by plant for its physiological activities, it added that improved soil conditions may enhance root growth, indirectly increasing plant height over time (Ajeigbe *et al.*, 2018), while the control recorded the lowest values across the sampling periods. On the contrary Madina *et al.*, 2023 stated that organic sources of nutrients releases it nutrients gradually through-out the plant life cycle (shuaibu *et al.*, 2018)

Varietal differences were also observed. At 8 WAP, SAMSORG 41 recorded the greatest plant height (97.23 cm), followed by SAMSORG 52 (62.67 cm) and SAMSORG 53 (51.23 cm). This variation can be attributed to inherent genetic differences among the varieties, particularly in growth habit and stem elongation capacity. These corroborate with the finding of Smith & Frederiksen (2000), who reported that inherent genetic traits could have led the variability in plant height furthermore morphological characteristics differences in Stem elongation genes, internode length, leaf orientation and photosynthetic efficiency these directly affect plant height and biomass production, although varietal effects were evident at earlier growth stages, the interaction between nutrient source and variety was not significant at 2, 4, and 6 WAP but became significant at 8 WAP, indicating differential varietal responses under nutrient treatments at later growth stages (Ajeigbe *et al.*, 2018).

The findings demonstrate that the application of NPK + Urea enhances vegetative growth, and SAMSORG 41 exhibits superior plant height performance under the agro-ecological conditions of Makurdi. This suggests that SAMSORG 41 partitions assimilates more toward vegetative "sources" rather than reproductive "sinks," a trait often linked to lower partitioning efficiency and higher biomass

accumulation (Ajeigbe *et al.*, 2018). Appropriate nutrient management combined with suitable variety selection is therefore essential for optimizing sorghum growth.

Table 2: Effect of nutrient source and variety on Number of leaves of Sorghum grown in Makurdi, Nigeria

Nutrients N	Weeks after planting (WAP)			
	2	4	6	8
NPK + Urea	4.87	6.78	8.45	12.14
Poultry manure	3.78	5.38	7.65	11.36
Goat manure	3.23	5.12	7.00	10.54
Control	3.15	4.62	6.34	9.32
F-LSD (0.05)	0.20	1.00	1.01	1.22
Variety V				
SAMSORG 52	4.21	6.85	8.98	13.87
SAMSORG 53	4.00	5.97	6.76	11.76
SAMSORG 41	4.98	6.82	10.14	15.34
F-LSD (0.05)	0.40	1.11	1.62	1.81
Interaction				
N X V	NS	NS	NS	*

LSD= Least Significant Differences at 5% Level of Probability, * = 95% level of probability

Table 2 is the effect of nutrient sources and sorghum varieties on the number of leaves at different weeks after planting (WAP). Four nutrient treatments (NPK + Urea, poultry manure, goat manure, and control) and three sorghum varieties (SAMSORG 52, SAMSORG 53, and SAMSORG 41) were evaluated at 2, 4, 6, and 8 WAP. The results showed that nutrient application significantly increased leaf production across all growth stages. NPK + Urea consistently produced the highest number of leaves at 2, 4, 6, and 8 WAP (4.87, 6.78, 8.45, and 12.14, respectively), Vanlauwe *et al.* (2010) reported that if nutrient release from organic sources synchronizes well with crop demand, number of leaves can be significantly improved he further reported that most plants especially sorghum partition nutrients in early stage of plant establishment to vegetative growth when the nutrient are readily available (Ajeigbe *et al.*, 2018) while the control recorded the lowest values throughout the assessment periods (Nenkam *et al.*, 2023).

Varietal differences were also significant. At 8 WAP, SAMSORG 41 produced the highest number of leaves (15.34), followed by SAMSORG 52 (13.87), whereas SAMSORG 53 recorded the lowest (11.76). This agrees with Fageria (2009). Who reported that variation in leaves is mostly influence by genetic make-up, cultural practice and environmental factors, he further reported that Some genotypes respond better to applied fertilizer than others due to superior nutrient assimilation mechanisms. The interaction between nutrient source and variety was not significant at 2, 4, and 6 WAP but became significant at 8 WAP, indicating differential varietal response to nutrient treatments at later growth stages.

Overall, the application of NPK + Urea enhanced vegetative growth, and SAMSORG 41 demonstrated superior leaf production under the agro-ecological conditions of Makurdi. These findings highlight the importance of appropriate nutrient management and varietal selection for improved sorghum growth performance and over all yield, (Madina *et al.*, 2023; Shuaibu *et al.*, 2018)

Table 3: Effect of nutrient source and variety on yield related character of Sorghum grown in Makurdi, Nigeria

Weeks after planting (WAP)				
Nutrients N	FHI	DM	95%F	SY t/ha
NPK + Urea	57.12	86.21	67.12	4.11
Poultry manure	65.23	85.35	68.21	3.61
Goat manure	52.23	84.32	66.21	3.20
Control	47.34	94.56	70.30	2.01
F-LSD (0.05)	9.12	4.01	1.01	0.21
Variety V				
SAMSORG 52	57.45	86.23	68.91	3.32
SAMSORG 53	50.56	85.54	68.32	2.43
SAMSORG 41	64.90	106.12	89.54	1.65
F-LSD (0.05)	10.10	1.11	1.12	1.01
Interaction				
N X V	NS	*	NS	NS

FHI= First head initiation, DM= days to maturity, 95%F= 95% Flowering, SY= Stover yield LSD= Least Significant Differences at 5% Level of Probability, * = 95% level of probability

Table 3 is the effects of nutrient sources and sorghum varieties on selected phenological traits and Stover yield. Four nutrient treatments (NPK + Urea, poultry manure, goat manure, and control) and three sorghum varieties (SAMSORG 52, SAMSORG 53, and SAMSORG 41) were assessed for first head initiation (FHI), days to maturity (DM), 95% flowering (95% F), and Stover yield (SY t/ha) Ajeigbe, (2018). Nutrient source significantly influenced all measured parameters. Poultry manure recorded the late head initiation (65.23 days) probably due to slow release of nutrient as reported by FAO 1995, while the control treatment delayed maturity (94.56 days) and flowering (70.30 days). NPK + Urea produced the highest Stover yield (4.11 t/ha), followed by poultry manure (3.61 t/ha) due to nutrient partitioning as reported by Lynch & Walsh (1998). whereas the control recorded the lowest yield (2.01 t/ha) this underscores the important of nutrient in Stover yield which could be used for animal feed. Provide readily available nutrients, especially nitrogen in mineral form (NH₄⁺ or NO₃⁻). Rapid nutrient availability promotes, quick vegetative growth, leading to increased early reproductive attribute in the season as reported by (FAO, 2006). Variation in Yield related characters among NPK/urea, poultry manure, and goat manure treatments may be attributed to differences in nutrient concentration, mineralization rates, C:N ratio, nutrient synchrony with crop demand, and their contrasting effects on soil physical and biological properties (Brady & Weil, 2016; Havlin *et al.*, 2014; Vanlauwe *et al.*, 2010).

Varietal differences were also significant. SAMSORG 41 exhibited delayed maturity (106.12 days) and flowering (89.54 days) but produced the lowest Stover yield (1.65 t/ha). SAMSORG 52 recorded the highest stover yield (3.32 t/ha) with moderate maturity duration, this is true due to the facts that cultural practice such as time of weeding, varietal genetic make-up and rainfall pattern might have caused such variation as reported by Acquah (2012). The interaction between nutrient source and variety was significant only for days to maturity but not for first head initiation, flowering, or stover yield. Variation among SAMSORG 41, SAMSORG 52 and SAMSORG 53 is mainly due to genetic differences, which influence morphology, phenology, nutrient use efficiency, stress tolerance, and yield potential. Since these are improved sorghum varieties released in Nigeria, their performance differences are expected under the same environment

The results indicate that nutrient management, particularly the timely application of NPK + Urea, enhances stover yield and improves crop performance under the agro-ecological conditions of Makurdi. Among the varieties tested, SAMSORG 52 demonstrated superior adaptability and productivity as reported by IAR 2024

Table 4: Effect of nutrient source and variety on yield related character of Sorghum grown in Makurdi, Nigeria

Nutrients N	Weeks after planting (WAP)			
	PW (g)	NO. S/H	100 SW(g)	Yield t/ha
NPK + Urea	64.51	106.34	32.21	3.43
Poultry manure	63.28	102.08	30.00	3.02
Goat manure	58.34	100.43	27.43	2.96
Control	43.75	94.98	25.89	1.45
F-LSD (0.05)	5.20	2.00	3.01	0.12
Variety V				
SAMSORG 52	68.51	116.12	38.01	3.88
SAMSORG 53	64.30	105.32	36.16	2.43
SAMSORG 41	54.68	101.89	30.54	1.54
F-LSD (0.05)	3.10	2.11	5.12	0.01
Interaction				
N X V	NS	*	*	*

PW= panicle weight, NO.SH= Number of seed per head, 100 SW= 100 seed weight, LSD= Least Significant Differences at 5% Level of Probability, * = 95% level of probability

Table 4 is the effects of nutrient sources and sorghum varieties on yield and yield-related characteristics. Four nutrient treatments (NPK + Urea, poultry manure, goat manure, and control) and three sorghum varieties (SAMSORG 52, SAMSORG 53, and SAMSORG 41) were assessed for panicle weight (PW), number of seeds per head (NO/S/H), 100 seed weight (100 SW), and grain yield (t/ha). Results showed that nutrient source significantly influenced all measured parameters. NPK + Urea produced the highest single panicle weight (64.51 g), number of seeds per head (106.34), 100 seed weight (118.01 g), and grain yield (3.43 t/ha), while the control recorded the lowest yield (1.45 t/ha) the work is a par with the work of Acquah (2012) who reported that both vegetative and reproductive phase of plants are affected by nutrient availability and also the ability of the plants to able to uptake such nutrients, Madina *et al.*, 2022, further agrees with the finding in this work starting that number of seeds, head weight and gran yield is directly influence by nutrient availability and partitioning of such nutrients for grains formation and grains filling.

Among the varieties, SAMSORG 52 outperformed others with the highest head weight (68.17 g), number of seeds per head (116.12), 100 seed weight (38.01 g), and grain yield (3.88 t/ha). SAMSORG 41 recorded the lowest yield (1.54 t/ha). (ICRISAT 2025) reported such variation could be genetically influenced. The observed variation among SAMSORG 41, SAMSORG 52 and SAMSORG 53 could be attributed to inherent genetic differences governing growth, phenology, nutrient use efficiency, and environmental adaptation. Genotypic variation significantly influences morphological and physiological traits, thereby affecting plant height, biomass accumulation and yield potential (Acquah, 2012; Fageria, 2009; Smith & Frederiksen, 2000). The interaction between nutrient source and variety was significant for number of seeds per head, 100 seed weight, and grain yield but not significant for head weight. They were bred for specific agro-ecological conditions in Nigeria. Performance variation may result from differential tolerance to drought, resistance to pests and diseases and adaptation to soil type and rainfall patterns.

These findings indicate that the combined use of improved variety (SAMSORG 52) and inorganic fertilizer (NPK + Urea) enhances sorghum productivity under the agro-ecological conditions of Makurdi.

Table 5: Interaction between nutrient source and variety on yield related character of Sorghum grown in Makurdi, Nigeria

Variety V	Nutrients N	Weeks after planting (WAP)					100 SW(g)	Yield t/ha
		PH	NL	DM	NO. S/H			
SAMSORG 52	NPK + Urea	61.76	12.34	86.21	106.34	38.01	3.43	
	Poultry manure	56.76	11.43	85.35	105.08	36.00	3.12	
	Goat manure	52.76	9.23	83.23	101.34	34.32	3.01	
	Control	50.76	8.00	80.56	100.98	25.89	2.90	
SAMSORG 53	NPK + Urea	68.43	11.35	85.01	101.12	35.18	2.28	
	Poultry manure	54.87	10.34	84.43	100.32	32.16	2.43	
	Goat manure	50.43	9.11	82.34	97.34	30.76	2.21	
	Control	48.98	8.23	80.23	94.89	22.54	2.00	
SAMSORG 41	NPK + Urea	96.56	16.34	97.54	97.12	26.18	1.88	
	Poultry manure	90.64	14.45	96.12	95.32	22.16	1.43	
	Goat manure	85.76	12.15	94.43	93.23	20.32	1.23	
	Control	75.76	10.23	102.21	90.89	19.54	1.04	
	F-LSD (0.05)	3.54	2.11	70.10	1.11	1.12	0.01	

PW= Panicle weight, NO.SH= Number of seed per head, 100 SW= 100 seed weight, LSD= Least Significant Differences at 5% Level of Probability

Table 5 is the interaction between nutrient sources and sorghum varieties on yield-related characters in Makurdi, Nigeria. Three sorghum varieties (SAMSORG 52, SAMSORG 53, and SAMSORG 41) were subjected to four nutrient treatments: NPK + Urea, poultry manure, goat manure, and a control. Growth and yield parameters assessed included plant height (PH), number of leaves (NL), days to maturity (DM), number of seeds per head (NO/S/H), 100 seed weight (100 SW), and grain yield (t/ha). Results indicated significant varietal and nutrient effects. SAMSORG 41 recorded the highest vegetative growth (plant height and number of leaves), particularly under NPK + Urea treatment Brady & Weil (2016) support the finding stating that cultural practice such as spacing, genetically improve variety and nutrients affect vegetative growth positively. On contrary Madina *et al.*, 2024 reported that inorganic nutrients are unlike the organic source who release nutrients more slowly due to gradual microbial decomposition, this slower release may initially limit plant height but improve sustained growth later in the season. A significant interaction between nutrient source (NPK/urea, poultry litter, goat manure) and varieties (SAMSORG 41, SAMSORG 52 and SAMSORG 53) suggests that the varieties responded differently to the different nutrient sources. This is primarily due to physiological, genetic, and soil-plant dynamics. However, SAMSORG 52 produced the highest grain yield (3.43 t/ha) when treated with NPK + Urea, followed by poultry manure (3.12 t/ha). Across varieties, NPK + Urea consistently enhanced yield and yield components compared to organic manures and the control. The control treatment recorded the lowest values for most parameters. A perfect combination is at a par with the finding of IFA 2019 who report the use of good variety and nutrient source had increase yield. The significant interaction between nutrient sources and sorghum varieties indicates differential varietal responses to nutrient availability and release patterns. Variations in nutrient use efficiency, root architecture, and growth duration among SAMSORG 41, SAMSORG 52 and SAMSORG 53 may have influenced their ability to utilize nutrients from both inorganic (NPK/urea) and organic (poultry manure and goat manure) sources. Differences in nutrient release synchrony, particularly the rapid availability from mineral fertilizers versus gradual mineralization from organic manures, may have further contributed to the observed interaction (Fageria, 2009; Brady & Weil, 2016; Vanlauwe *et al.*, 2010). The interaction between variety and nutrient source significantly influenced yield performance, with SAMSORG 52 combined with NPK + Urea emerging as the most productive treatment. These findings suggest that integrated nutrient management, particularly inorganic fertilizer application, optimizes sorghum productivity under the agro-ecological conditions of Makurdi.

CONCLUSION AND RECOMMENDATION

The study assessed the effects of different nutrient sources on the growth and yield performance of SAMSORG 41, SAMSORG 52 and SAMSORG 53, with a view to identifying suitable nutrient management strategies for enhanced sorghum production in the study area. Significant difference was observed in both variety and nutrient sources, where the use of NPK/Urea outperformed the other nutrient sources and the use of SAMSORG 52 did better than SAMSORG 41 and SAMSORG 53. Based on this work it can be recommended that the use of NPK/Urea N120kg/ha, P60kg/ha and K60kg/ha and the use of SAMSORG 52 be recommended for framers in Makurdi for optimum yield and animal feed since it produced higher Stover yield. The application of 5t/ha poultry litter, goat manure and SAMSORG 53, can be used for farmers who want organic production of sorghum.

REFERENCES

1. Acquah. (2012). *Principles of Plant Genetics and Breeding*.
2. Ajeigbe, H. A. (2018). Sorghum yield and water use under Phosphorus fertilization applications in the Sudan savanna of Nigeria. *Open Access Repository of ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)*.
3. Ajeigbe, H. A., Akinseye, F. M., Kuniya, A., & Jonah, J. (2018). Productivity and Water Use Efficiency of Sorghum [Sorghum bicolor (L.) Moench] Grown under Different Nitrogen Applications in Sudan Savanna Zone, Nigeria. *International Journal of Agronomy*, 2018, 1. <https://doi.org/10.1155/2018/7676058>
4. Fageria, N. K., Baligar, V. C., & Y, L. (2008). *The Role of Nutrient Efficient Plants in Improving Crop Yields in the Twenty First Century*. <https://doi.org/10.1080/01904160802116068>
5. FAO. (2022). *FAOSTAT Statistical Database*. Food and Agriculture Organization of the United Nations.
6. Food and Agriculture Organization. (1995). *Sorghum and Millets in Human Nutrition*.
7. Food and Agriculture Organization. (2006). *Plant Nutrition for Food Security*.
8. Havlin, J. L. (2014). *Soil: Fertility and Nutrient Management* (p. 460). <https://doi.org/10.1081/e-enr-120047493>
9. ICRISAT, I. C. R. I. for the S.-A. T. (2025). *Sorghum breeding reports*.
10. Ignatius, A. I., Leiser, W. L., Nebié, B., Mary, Y., Daniel, A. A., Lawali, A., A, A. H., & Jerome, J. (2019). Morphological Diversity Assessment of Nigeria Sorghum Landraces for Utilization in Hybrid Parent Development. *Universal Journal of Agricultural Research*, 7(6), 221. <https://doi.org/10.13189/ujar.2019.070604>
11. International Fertilizer Association. (2019). *Nutrient management handbook*.
12. Madina, P., A, M. O., & Iyough, D. D. (2023). Productivity of cabbage (*Brassica oleracea* L.) as affected by organic manure and varieties grown in Jos Plateau State, Nigeria. *Journal of Agricultural Science and Food Technology*, 9(1), 1. https://doi.org/10.36630/jasft_22001
13. Madina, P., Esang, D. M., & Yunusa, A. (2023). Effect of Variety and Organic Manure on the Growth and Yield of Pepper Grown in Makurdi Benue State, Nigeria. *International Journal of Agriculture and Earth Science (IJAES)*, 9(7). www.iiardjournals.org
14. Nenkam, A. M., Wadoux, A. M. J. -C., Minasny, B., McBratney, A. B., Traoré, P., & Whitbread, A. (2023). Using homosols to enrich sparse soil data infrastructure: An example from Mali. *CATENA*, 223, 106862. <https://doi.org/10.1016/j.catena.2022.106862>
15. Palm, C., Gachengo, C. N., Delve, R. J., Cadisch, G., & Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture Ecosystems & Environment*, 83, 27. [https://doi.org/10.1016/s0167-8809\(00\)00267-x](https://doi.org/10.1016/s0167-8809(00)00267-x)

16. Shuaibu, Y. M., Bala, R. A., Kawure, S., & Shuaibu, Z. (2018). Effect of organic and inorganic fertilizer on the growth and yield of sorghum (*Sorghum bicolor* (L.) Moench) in Bauchi state, Nigeria. *GSC Biological and Pharmaceutical Sciences*, 2(1), 25. <https://doi.org/10.30574/gscbps.2018.2.1.0053>
17. Smith, C. W., Frederiksen, R. A., & Smith, W. C. (2000). Sorghum: origin, history, technology and production. In *John Wiley and Sons eBooks* (Issue 1). Wiley. <http://ci.nii.ac.jp/ncid/BA53801690>
18. The Use of Nutrients in Crop Plants by N. K. Fageria. (2009). *Cereal Research Communications*, 37(1), 149. <https://doi.org/10.1556/crc.37.2009.1.18>
19. Vanlauwe, B. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, 39(1), 17.
20. Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2010). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil*, 339, 35. <https://doi.org/10.1007/s11104-010-0462-7>
21. Weil, R. R., & Brady, N. C. (2016). *The Nature and Properties of Soils. 15th edition*. https://www.researchgate.net/profile/Raymond_Weil/publication/301200878_The_Nature_and_Properties_of_Soils_15th_edition/links/570bda8808aea660813b16f6.pdf