https://dx.doi.org/10.4314/dujopas.v11i4a.1
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 11 No. 4a December 2025*

A Study of the Effects of Site, Variety, and Fertilizer Application on Rice Agronomic Traits Using Least Squares Mean Plots (LSMP)

[1*]Alfa, M. B, [2*]A. Usman,[3*]Y. Yakubu,[4*]Moses, S.B,[5*]Kalabu, S.A

[1&5]Department of Mathematics and Statistics,
Faculty of Science,
Federal Polytechnic,
Bauchi.

[2&3]Department of Statistics,
Faculty of Physical Science,
Federal University of Technology,
Minna.

[4*]National Cereals Research Institute,
Minna.

Email: alfamb@fptb.edu.ng

Abstract
This study aimed to examine the effects of site, variety, and fertilizer application on rice growth and that of their interaction that produce the highest average response of plant height, tiller height, and grain yield of rice production using Least Square Means Plot. The experiment was conducted across multiple sites with different soil types and environmental conditions. Four distinct crop varieties were selected and three different fertilizer treatment were applied. Data on various agronomic traits, including plant height, tiller height, and yield were collected to assess the interactions between the factors. Results among the three variables revealed that plant height has the highest mean value indicating robust vegetative growth, site1 demonstrated the most favorable conditions overall with the tallest plant. The result among the four tasted rice varieties faro49, faro55, faro57 and Nerica7 in terms of plant height, tiller height, and yield, Faro49 emerged as the most vigorous and productive variety, exhibiting the tallest plants. The results among the three different responses plant height, tiller height, and grain yield under three fertilizer treatments; control, inorganic fertilizer and poultry manure, the control group exhibits the highest average. The study highlights the critical influence of site and variety on rice growth and yield with site – specific environmental rice conditions proving to be the most significant factor in determining overall performance. Emphasize the need for integrated decision-making in rice cultivation, where agronomic practices should align with both environmental conditions and genetic characteristics for improved productivity.

Keywords: Site, Variety, Fertilizer and least means plot.

INTRODUCTION

Rice (Oryza sativa L.) remains one of the most important cereal crops worldwide, providing staple food for over half of the global population. The productivity of rice is profoundly influenced by environmental factors, genetic diversity among varieties, and nutrient

**Author for Correspondence*

management practices. Site-specific parameters including soil fertility, water availability, and microclimate create variability in rice growth and yield outcomes, necessitating adaptive and location-tailored agronomic practices (Girsang *et al.*, 2025). Different rice varieties exhibit distinct physiological and morphological traits that determine their adaptability and yield potential under varying environmental and management conditions (Wang *et al.*, 2025). Moreover, fertilizer application plays a critical role in improving rice yield by supplying essential nutrients; however, the type, rate, and timing of fertilizer applications must be optimized to maximize benefits while minimizing environmental impacts (Slameto *et al.*, 2024).

Depending on the needs of the specific variety, rice is one of the main grains that are grown extensively for food in Nigeria. It can be grown in paddies or on upland fields. Nigeria was the world's second-largest importer of rice as of December 2016, according to the Punch newspaper. Nigeria's high rate of rice importation has compelled the government to adopt a number of measures to reverse the trend, including outright banning rice imports and launching a new rice project aimed at boosting domestic output. All of these occur despite the nation's vast potential for rice production and its capacity for self-sufficiency in this area (Akinbile *et al.*, 2018).

A study by Emeana *et al.* (2019) showed that less than12% of organic farmers surveyed in a community in Southeast Nigeria engage incomplete organic farming. Organic certification and government subsidies might provide vital mechanisms that can significantly contribute to expanding organic production among farmers in Nigeria (Ume and Bahta, 2024). Priya and Singh (2024), who studied the market dynamics and potential for organic agriculture in the global South. Despite these valuable contributions, there remains a significant gap in the literature regarding comprehensive investigations into the economic incentives and government support systems, including certifications and subsidies that are instrumental in scaling up organic agriculture within the global South. Verburg *et al.* (2022) studied the case of organic dairy farming in the Netherland sand reported that government subsidies bolstered the economic feasibility of organic farming by offering financial support for organic certification fees, organic inputs, and infrastructure development. According to their findings, these subsidies reduce the financial barriers that farmers may face when considering expanding.

Dollison (2023). Carried out analysis of inorganic and organic fertilizers application/hectare of rice production particular quantity unit cost, based on the results of the study, it can be concluded that the growth performance tested was not significantly affected by the kind and amount of inorganic and organic fertilizer application. Andriatmoko (2020) analyzed the effect of the use of organic rice and inorganic rice production factors in Sambirejo sub-district, Sragen Regency, analyzed the level of efficiency in organic and inorganic rice farming production and compared the level of production benefits between organic and paddy rice inorganic in the study area.

Recent research has shown that fertilizer regimes combining inorganic and organic sources can significantly improve rice growth parameters such as plant height, tiller number, panicle length, and grain filling, resulting in higher grain yields (Slameto *et al.*, 2024). Site and genotype interactions also influence nutrient use efficiency, emphasizing the necessity for site-specific nutrient management approaches (Girsang *et al.*, 2025). To accurately decipher the complex interactions between site conditions, variety genetics, and fertilizer application on rice traits, advanced statistical tools like Least Squares Mean Plots (LSMP) allow for unbiased estimation of treatment effects, adjusting for covariates and experimental imbalances. This study employs LSMP to assess the individual and interactive effects of site, variety, and fertilizer application on rice agronomic traits, aiming to provide actionable insights to improve rice yield and sustainability across diverse production environments.

Fertilizer Use, Soil Health, and Yield Performance

Organic fertilizers have garnered significant attention in sustainable agriculture due to their environmental benefits and potential to improve soil health. In rice cultivation, the use of organic fertilizers has shown both positive and variable impacts on yield, depending on soil conditions, climatic factors, and the type and quantity of organic inputs used. It including compost, farmyard manure, green manure, and bio-fertilizers, improve soil structure, water retention, and microbial activity. These factors contribute to better root development and nutrient uptake by rice plants. According to Wang *et al.* (2023), the application of organic manure increased soil organic matter and microbial biomass, which enhanced nitrogen mineralization and availability, ultimately boosting rice yield. "Application of organic fertilizers significantly improved soil fertility and microbial activity, leading to an average yield increase of 12.5% compared to control plots."

While organic fertilizers improve long-term soil fertility, they may not always match the immediate nutrient availability of synthetic fertilizers. However, integrated nutrient management (INM) combining organic and inorganic fertilizers has proven effective. Kumar *et al.* (2022) found that rice yields under INM systems were significantly higher than those with organic or chemical fertilizers alone. "The combined use of organic and inorganic fertilizers produced the highest yields (6.4 t/ha), outperforming both sole organic (5.2 t/ha) and chemical fertilizer treatments (5.8 t/ha)."

Environmental, Economic, and Long-Term Considerations

Organic fertilizers reduce dependency on synthetic inputs and mitigate environmental issues such as nitrate leaching and greenhouse gas emissions. However, their effectiveness is influenced by decomposition rates and nutrient release, which are slower compared to chemical fertilizers. Rahman *et al.* (2024) emphasized that while organic fertilizers are environmentally friendly, their widespread adoption among rice farmers requires cost-effective production and policy support. "Organic inputs contribute to sustainable intensification, but scaling up adoption needs economic incentives and awareness among farmers."

Longitudinal studies show that continuous application of organic fertilizers improves yield stability and soil resilience. Chen *et al.* (2021) reported that a 10-year organic amendment program increased rice yields by 15–20% compared to conventional systems under stress-prone environments. "Sustained organic amendments enhanced soil buffering capacity and provided yield stability under abiotic stress conditions."

METHODOLOGY

Experimental Design and Site

A factorial experiment combining multiple factors such as rice varieties, fertilizer types, and planting methods is typically set up (e.g., dibbling, transplanting, broadcasting) to capture their individual and interaction effects on rice traits (Haruna *et al.*, 2023). Key agronomic traits evaluated include plant height, tiller number, panicle length, grain yield per plant, 1000-seed weight, and yield per hectare. Data are collected periodically during the growth stages to monitor development over time. Random sampling of plants within plots is employed to ensure unbiased representation for trait measurements.

The experiment was conducted at the National Cereal Research Institute (NCRI), Badeggi, Niger State, Nigeria, during the 2022–2023 cropping season. The experimental design was a randomized complete block design (RCBD) with three replications. Three experimental sites with differing environmental conditions were used to capture variation in soil and climate. Each site featured identical plot dimensions (16 m^2) and was separated by 1-meter spacing.

Treatments and Varieties
The treatments involved three fertilizer types: inorganic (NPK), poultry manure (organic), and control (no fertilizer), four rice varieties: FARO 49, FARO 55, FARO 57, and NERICA 7. A total of 36 treatment combinations were tested.

Data Collection
Data were collected on: Plant height (PH) at 4, 6, 8, and 10 weeks after planting, Tiller height (TH) at the same intervals, Grain yield (Y) at harvest. The average from ten representative plants per plot was recorded for PH and TH.

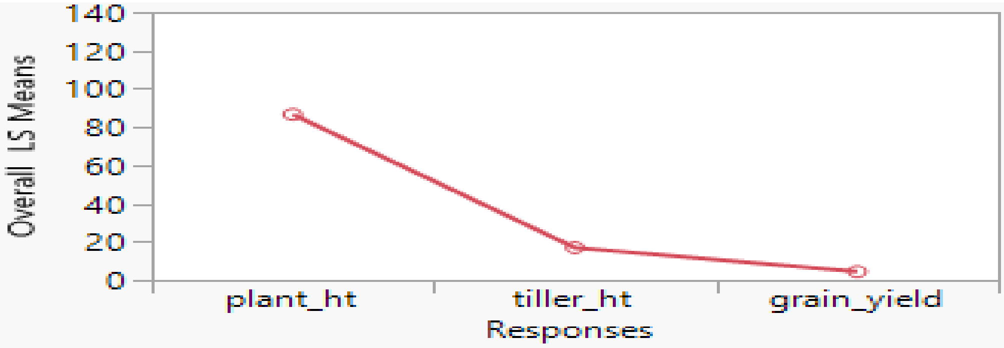
Statistical Analysis
Advanced modeling techniques such as modification of split-plot design Least Squares Mean Plots (LSMP) are used for estimating and comparing adjusted treatment means, controlling for covariates and unbalanced experimental designs. LSMP offers visual and statistical insights into how each factor and their interactions models (SPDM) combined with estimation methods like restricted maximum likelihood (REML) and estimated generalized least squares (EGLS) provide robust variance component estimates and improve fit for agronomic data analysis (Ijdm, 2024).
Least Squares Means (LS Means) plots were employed to visualize response trends and interaction patterns. Post hoc tests were performed at a 5% significance level.

Statistical Model and Notation
The 3-way MANOVA model below is used to describe the collected data used in this work.

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijkl} \qquad (3.1)$$

(Agbelie & Aliyu, 2022; Kovačić, Miloš, Kurkutović, Čelebić, & Petričević, 2024; Yıldızer & Munusturlar, 2022) where
y_{ijkl} denotes the observed value of the response variable for i^{th} level of site factor (factor A), j^{th} level of variety factor (factor B), k^{th} level of fertilizer factor (factor C) in the i^{th} replicate.
μ is the overall mean.
α_i is the effect of the ith level of the site factor.
β_j is the effect of the jth level of the variety factor.
γ_k is the effect of the kth level of the fertilizer factor.
$(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, $(\beta\gamma)_{jk}$and $(\alpha\beta\gamma)_{ijk}$ are the respective interaction terms.
ϵ_{ijkl} is the random error term.

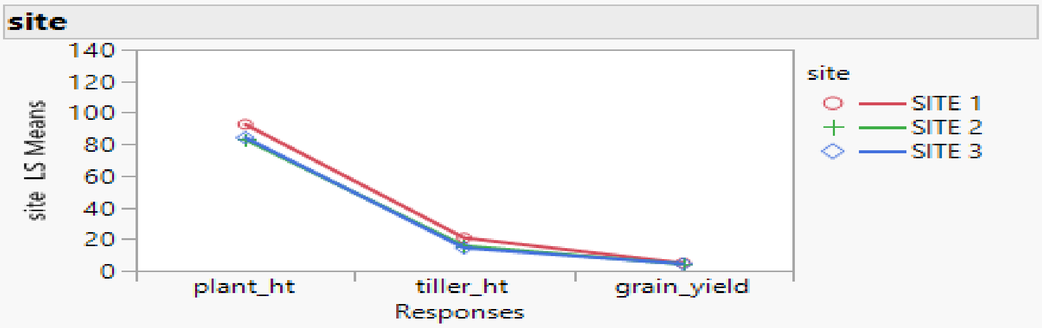
Results: Least Squares Mean Plots
The analysis results are presented here to evaluate the effects of the plant height, tilling height and yield of rice production.



Overall Means

plant_ht	tiller_ht	grain_yield
86.6272222	16.9018519	4.41639815

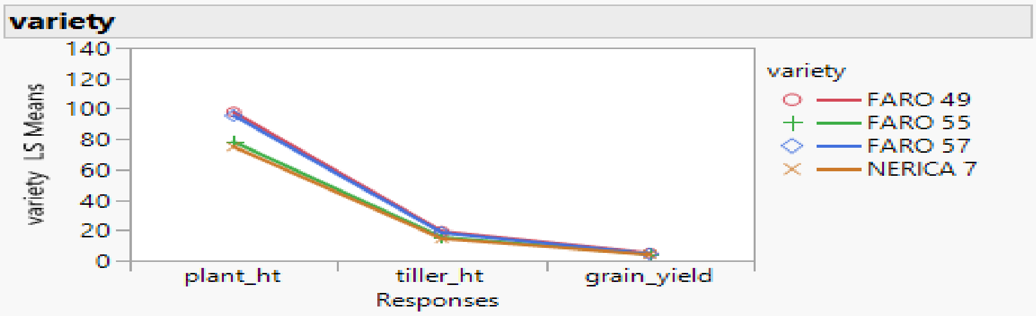
Figure 1: Overall Means Plot for the Response Variables.



site

	plant_ht	tiller_ht	grain_yield
SITE 1	92.6222222	20.6888889	4.80391667
SITE 2	83.0522222	15.6527778	4.12491667
SITE 3	84.2072222	14.3638889	4.32036111

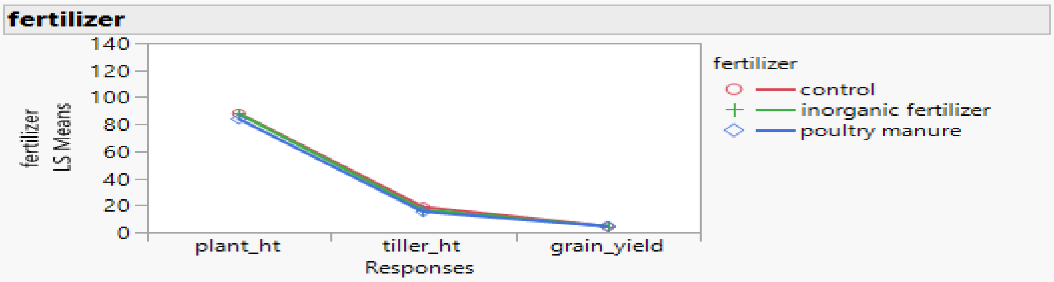
Figure 2: Mean Plot for the Response Variables with Respect to the Site Factor.



variety

	plant_ht	tiller_ht	grain_yield
FARO 49	97.7962963	19.3148148	4.89655556
FARO 55	78.2125926	15.4037037	4.32722222
FARO 57	95.5333333	18.4	4.41637037
NERICA 7	74.9666667	14.4888889	4.02544444

Figure 3: Means Plot for the Response Variables with Respect to the Variety Factor.



fertilizer

	plant_ht	tiller_ht	grain_yield
control	88.02	18.7805556	4.39752778
inorganic fertilizer	87.9172222	16.7222222	4.46441667
poultry manure	83.9444444	15.2027778	4.38725

Figure 4: Means Plot for the Response Variables with Respect to the Fertilizer

DISCUSSION

Figure 1 illustrates the overall least squares (LS) means for three traits plant height (86.63 cm), tiller height (16.90 cm), and grain yield (4.42 units). The trend shows a sharp decline from plant height to tiller height, and a further decline to grain yield. This pattern suggests that while plants achieved substantial vegetative growth (tall plant height), this growth did not proportionally translate into reproductive output (grain yield). The relatively low tiller height and grain yield indicate a possible allocation imbalance between vegetative and reproductive growth.

Tall plant height (mean ≈ 86.6 cm) indicates good vegetative vigor, which is often associated with strong photosynthetic capacity. However, excessive vegetative growth can sometimes compete with reproductive development, reducing assimilate partitioning to grains (Khush, 2013; Fageria *et al.*, 2014). This aligns with the observed low grain yield despite tall plants. Tiller height (mean ≈ 16.9 cm) is an important trait influencing tillering capacity and subsequent panicle or ear development. Shorter tiller height may reduce the plant's capacity to produce effective tillers that contribute to yield (Peng *et al.*, 2008). This may explain why the observed grain yield is low relative to plant height.

Low Grain Yield: The grain yield (mean ≈ 4.42) is comparatively small, which highlights the challenge of converting vegetative growth into reproductive output. Grain yield is a complex trait affected by genetic, physiological, and environmental factors (Tester & Langridge, 2010). Improving yield requires not just taller plants but optimized tiller and panicle development, as well as efficient assimilate translocation to grains.

The results suggest that selection should balance plant height with effective tillering and reproductive efficiency. Semi-dwarf varieties, for example, have been shown to reduce lodging risk while improving harvest index and yield stability (Hedden, 2003). Incorporating robust tiller development and stress-resilient genetics may further enhance yield outcomes.

Figure 2 depicts the effects of site on rice growth and yield components presents a comparative analysis of plant height, tiller height, and grain yield across three experimental sites. SITE 1 has the highest mean plant height at approximately 92.62 cm, followed by SITE 2 at around 83.05 cm, and SITE 3 at about 84.21 cm. This suggests that the conditions at SITE 1 are more favorable for plant growth compared to the other sites. The mean tiller height shows a similar trend. SITE 1 again has the highest mean (20.69 cm), while SITE 2 and SITE 3 have lower means (15.63 cm and 15.62 cm respectively). This indicates that SITE 1 might have better management practices or environmental conditions that promote tiller growth. For grain yield, SITE 1 also leads with a mean of 4.80 tons per hectare, significantly higher than SITE 2 (4.12 tons per hectare) and SITE 3 (4.12 tons per hectare). This trend reinforces the idea that SITE 1 is the most productive site among the three.

SITE 1's superior performance in all three metrics may be attributed to optimal factors such as soil fertility, moisture levels, and climate conditions. Research indicates that environmental factors significantly influence plant growth and yield (Wang *et al.*, 2021). Differences in management practices, such as fertilization, irrigation, and pest control, could also contribute to the observed outcomes. For instance, precision agriculture techniques can enhance crop productivity and resource use efficiency (Zhang *et al.*, 2020). Soil health plays a crucial role in determining plant performance. Factors such as pH, nutrient availability, and organic matter content could explain the variations in yield among sites (Lal, 2022).

Figure 3 represents the effects of variety on rice growth and yield components highlights significant differences among the four tested rice varieties. FARO 49 shows the highest mean plant height at approximately 97.80 cm, followed by FARO 55 (92.51 cm), FARO 57 (95.53 cm), and NERICA 7 (74.97 cm). This indicates that FARO 49 has superior growth characteristics compared to the others. In terms of tiller height, FARO 49 again leads with a mean of around 19.31 cm. FARO 55 and FARO 57 have similar tiller heights (15.40 cm and 14.81 cm, respectively), while NERICA 7 has the lowest mean at approximately 11.38 cm. This suggests that FARO 49 is better suited for producing taller tillers. For grain yield, FARO 49 continues to outperform the others with a mean yield of about 4.90 tons per hectare. FARO 55 has a yield of 4.32 tons per hectare, FARO 57 at 4.14 tons, and NERICA 7 at 4.03 tons. This pattern indicates that FARO 49 is the most productive variety among those evaluated.

The observed differences in LS means among the varieties highlight the importance of genetic traits and adaptability in crop performance. Varietal differences in growth and yield can be attributed to genetic variations that influence traits such as height and tillering ability. Research suggests that specific genetic traits can significantly enhance performance under varying environmental conditions (Yadav *et al.*, 2020). The superior performance of FARO 49 might indicate its better adaptability to local environmental conditions, including soil type and climate. Understanding how different varieties respond to such factors is crucial for optimizing crop selection (Baker *et al.*, 2021). Agronomic practices, such as fertilization and irrigation, can also influence the effectiveness of each variety. Tailoring management strategies to specific varieties can enhance their performance (Jat *et al.*, 2019).

Figure 4 presents the Least Squares (LS) Means of three different responses—plant height, tiller height, and grain yield. The control group has the lowest mean plant height at approximately 88.02 cm. Inorganic fertilizer shows a slightly higher mean of about 87.97 cm, while poultry manure leads with a mean of approximately 83.94 cm. This indicates that the use of inorganic fertilizer slightly improves plant height compared to control and poultry manure. For tiller height, the control group again exhibits the highest mean at approximately 18.78 cm, followed closely by inorganic fertilizer (16.72 cm). Poultry manure shows the lowest mean tiller height of about 15.27 cm. This suggests that the control and inorganic treatments are more effective in promoting tiller growth compared to poultry manure.

In terms of grain yield, the control group yields the highest at approximately 4.67 tons per hectare. Inorganic fertilizer follows with a mean yield of about 4.46 tons, while poultry manure has the lowest yield at approximately 4.38 tons per hectare. This indicates that the control treatment is most effective for grain yield, with inorganic fertilizer being slightly less effective and poultry manure showing the least effectiveness.

Inorganic fertilizers typically provide readily available nutrients, which can enhance plant growth and yield. However, the marginal difference in effectiveness compared to the control suggests that the environmental conditions may play a significant role (Barker *et al.*, 2021). While poultry manure is often valued for its organic matter content and potential to improve soil health, its lower performance in this instance may indicate a need for additional nutrients or a longer time frame for benefits to manifest (Miller *et al.*, 2021).
The efficacy of fertilizer treatments also depends on management practices such as application rates and timing. Tailoring these practices to the specific requirements of each treatment can enhance crop performance (Baker & Allen, 2019).

CONCLUSION AND RECOMMENDATIONS

This study reveals that both environmental (site) and genetic (variety) factors play pivotal roles in determining rice growth and yield parameters. The interaction between site and variety significantly influenced plant height, tiller height, and grain yield, emphasizing that varietal performance is highly site-dependent. Although fertilizer type had a moderate influence, particularly on tiller height and grain yield, its effect was not as pronounced as those of site and variety. These results underscore the necessity of adopting site-specific varietal recommendations to enhance productivity in rice farming systems. It is recommended that agricultural extension services should prioritize site-specific varietal trials before recommending rice varieties to farmers.
FARO 49 and FARO 57 should be considered for promotion in agro-ecological zones similar to Site 1 based on their superior performance. Fertilizer use strategies should be tailored to specific varietal responses, especially where tiller development is a limiting factor.

REFERENCES

Agbelie, D. S., & Aliyu, U. L. (2022). The effect of work experience on emotional intelligence among middle level managers in the Ghanaian insurance industry. *Journal homepage: www.ijrpr.com ISSN, 2582*, 7421.

Akinbile, A., Aminu, O., & Sokeye, I. (2018). Constraints encountered in rice production by farmers in Ogun State. *Nigerian Journal of Rural Sociology, 18*(1), 85–92.

Andriatmoko, N. D. (2020). Analysis of production factor efficiency in organic rice farming (*Oryza sativa*): A case in Sukorejo Village, Sambirejo Sub-district, Sragen District. *Habitat, 31*(1), 1–10.

Baker, J. T., & Allen, L. H. (2019). Fertilization strategies for enhancing crop yields: A review. *Agronomy Journal*, 111(5), 2230-2245.

Baker, J. T., Allen, L. H., & Boote, K. J. (2021). Crop responses to environmental conditions: A review of genetic and management interactions. *Field Crops Research*, 263, 108028.

Chen, J., Liu, X., Zheng, J., Zhang, B., Li, M., & Chen, X. (2021). Long-term organic amendments improve yield stability and soil resilience in rice-based systems. *Field Crops Research, 260,* 107982. https://doi.org/10.1016/j.fcr.2020.107982

Dollison, M. D. (2023). Comparative yield performance of rice production under organic and inorganic fertilizer application. *International Journal of Multidisciplinary: Applied Business and Education Research,* 4(7), 2173–2179. https://doi.org/10.11594/ijmaber.04.07.22

Emeana, E. M., Trenchard, L., Dehnen-Schmutz, K., & Shaikh, S. (2019). Evaluating the role of public agricultural extension and advisory services in promoting agroecology transition in Southeast Nigeria. *Agroecology and Sustainable Food Systems, 43*(2), 123–144. https://doi.org/10.1080/21683565.2018.1496071

Fageria, N. K., Baligar, V. C., & Jones, C. A. (2014). *Growth and Mineral Nutrition of Field Crops*. CRC Press.

Girsang, S. S., Nasution, Z., Lubis, I., & Rambe, P. (2025). Site-specific agronomic practices and their impact on rice yield variability. *Journal of Agronomy and Crop Science*, 211(2), 145–158.

Haruna, A., Bello, M., & Yusuf, A. (2023). Factorial experiments in rice agronomy: Variety, fertilizer, and planting method interactions. *Journal of Agricultural Science*, 15(4), 220–233.

Hedden, P. (2003). The genes of the Green Revolution. *Trends in Genetics*, 19(1), 5–9. https://doi.org/10.1016/S0168-9525(02)00009-4

Jat, H. S., Sahrawat, K. L., & Gupta, R. (2019). Enhancing crop productivity through improved management practices: A review. *Agricultural Systems*, 168, 8-20.

Kovačić, I., Miloš, M., Kurkutović, M., Čelebić, A., & Petričević, N. (2024). Influence of education level and gender of dental students on perception of dental aesthetics. *BMC Oral Health, 24*(1), 398.

Kumar, A., Sharma, R., Singh, J., & Yadav, S. (2022). Integrated nutrient management for enhanced rice yield and soil health. *Journal of Plant Nutrition, 45*(5), 715–728. https://doi.org/10.1080/01904167.2021.1941538

Khush, G. S. (2013). Strategies for increasing the yield potential of cereals: Case of rice as an example. *Plant Breeding*, 132(5), 433–436. https://doi.org/10.1111/pbr.1991

Lal, R. (2022). Soil health and sustainable agriculture. *Agriculture, Ecosystems & Environment*, 328, 107894.

Miller, R. O., *et al.* (2021). Organic amendments and their impacts on soil health and crop performance. *Soil Biology and Biochemistry*, 157, 108206.

Peng, S., Khush, G. S., Virk, P., Tang, Q., & Zou, Y. (2008). Progress in ideotype breeding to increase rice yield potential. *Field Crops Research*, 108(1), 32–38. https://doi.org/10.1016/j.fcr.2008.04.001

Priya, R., & Singh, S. (2024). Factors influencing the adoption of sustainable agricultural practices: A systematic literature review and lessons learned for India. *Forum for Social Economics, Advance online publication.* https://doi.org/10.1080/07360932.2024.2345678

Rahman, M., Alam, M., & Sultana, S. (2024). Policy and economic perspectives on organic fertilizer adoption in rice farming systems. *Sustainability, 16*(2), 889. https://doi.org/10.3390/su16020889

Slameto, S., Utomo, W. H., & Nugroho, D. (2024). Optimizing fertilizer use for sustainable rice production: Type, rate, and timing considerations. *Sustainability*, 16(12), 9542.

Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, 327(5967), 818–822. https://doi.org/10.1126/science.1183700

Ume, J., & Bahta, Y. T. (2024). Policy support strategies for organic farming extensification in Nigeria. *Organic Agriculture, 14*(3), 323–344. https://doi.org/10.1007/s13165-023-00494-1

Verburg, R. W., Verberne, E., & Negro, S. O. (2022). Accelerating the transition towards sustainable agriculture: The case of organic dairy farming in the Netherlands. *Agricultural Systems, 198,* 103368. https://doi.org/10.1016/j.agsy.2021.103368

Wang, Z., Li, H., & Zhang, Y. (2021). Environmental factors influencing crop yield: A comprehensive review. *Agronomy for Sustainable Development*, 41(2), 20.

Wang, Y., Zhang, X., Li, H., & Liu, B. (2023). Organic manure application improves soil fertility, microbial activity, and rice yield in subtropical paddy soils. *Soil & Tillage Research, 228,* 105657. https://doi.org/10.1016/j.still.2022.105657

Wang, Y., Zhang, L., Chen, H., & Li, J. (2025). Physiological and morphological diversity in rice varieties under varying environmental conditions. *Field Crops Research*, 302, 108945.

Yadav, O. P., Kumar, A., & Gupta, A. (2020). Genetic variations and their impact on yield traits in crops. *Plant Breeding and Biotechnology*, 8(2), 129-142.

Yıldızer, G., & Munusturlar, S. (2022). Differences in perceived physical literacy between teachers delivering physical education in schools: classroom teachers vs physical education teachers. *Physical Education and Sport Pedagogy, 27*(6), 626-639.

Zhang, X., Wang, J., & Liu, C. (2020). Precision agriculture technology for sustainable crop production: A review. *Journal of Cleaner Production*, 256, 120751.

Zhou, Z., Zhang, S., Jiang, N., Xiu, W., Zhao, J., & Yang, D. (2022). Effects of organic fertilizer incorporation practices on crop yield, soil quality, and soil fauna feeding activity in the wheat–maize rotation system. *Frontiers in Environmental Science, 10,* 1058071. https://doi.org/10.3389/fenvs.2022.1058071