

COMPARATIVE EFFECTS OF ORGANIC AND INORGANIC FERTILIZERS ON PHENOLOGY AND YIELD STABILITY OF IRRIGATED RICE IN KANO, NIGERIA

*¹Abubakar M. Saleh, ²Shamsu A. Zakari and ³Afiya K. Lamido

¹Soil and Land Management Department, Sule Lamido University, Kafin Hausa, Jigawa, Nigeria

²Crop Science Department, Sule Lamido University, Kafin Hausa, Jigawa, Nigeria

³Soil Science Department, Aliko Dagote University of Science and Technology, Wudil, Kano State, Nigeria

*Corresponding Author: abubakarmsaleh@gmail.com

Abstract

Efficient fertilizer management remains critical for improving the productivity and sustainability of irrigated rice systems in sub-Saharan Africa. This study evaluated the performance, canopy dynamics, and yield stability of irrigated rice (*Oryza sativa* L.) under inorganic and organic fertilizer regimes within the Kano River Irrigation Scheme (KRIS), northern Nigeria. On-farm experiments were conducted across three local government areas during the 2020 and 2021 dry seasons using a randomized complete block design on farmers' fields. Four fertilizer treatments were assessed: farmer practice, recommended NPK-Urea application, poultry manure, and cow manure, using FARO 44 as the test variety. Results showed that organic amendments, particularly poultry and cow manure, enhanced tillering efficiency and canopy development compared with inorganic fertilizer and farmer practice. Poultry manure recorded the highest leaf area index (LAI) and grain yield, while cow manure exhibited superior biomass partitioning to grain, as revealed by the highest harvest index. In contrast, inorganic fertilizer and farmer practice demonstrated greater year-to-year yield stability. Relative yield advantage analysis indicated a yield gain of 6.4% under poultry manure compared with farmer practice, whereas cow manure resulted in a slight yield reduction. These findings highlight trade-offs between yield maximization, canopy persistence, and yield stability among fertilizer regimes. Suggesting that integrating organic nutrient sources with improved fertilizer management can improve rice productivity while promoting sustainable intensification in irrigated systems of northern Nigeria.

Keywords: Canopy dynamics; Fertilizer management; Irrigated rice; Yield stability, Organic manure, Nigeria

Introduction

Rice (*Oryza sativa* L.) is a globally staple crop, supporting food security and rural livelihoods for billions of people, particularly across sub-Saharan Africa (Zakari *et al.*, 2021), where dietary reliance on rice continues to grow. Despite increased area expansion, yield gaps persist in many production systems, especially in irrigated lowlands of West Africa, due in part to

suboptimal nutrient management practices and soil nutrient depletion (Cassman *et al.*, 1998; Chivenge *et al.*, 2022). Previous studies show that inorganic fertilizer application, particularly of nitrogen (N), phosphorus (P), and potassium (K), remains a dominant strategy for enhancing rice yields (Wopereis *et al.*, 1999; Haefele *et al.*, 2013; Tsujimoto *et al.*, 2019). Still, its effectiveness is often constrained by inefficiencies,

environmental concerns, and diminishing soil fertility when used without complementary organic inputs. Intensive reliance on mineral fertilizers without adequate organic amendments has been linked to soil quality deterioration and reduced long-term sustainability of cropping systems (Tsujimoto *et al.*, 2019; Yi *et al.*, 2022).

Organic nutrient sources, such as cow and poultry manures, offer a range of benefits, including improved soil physical condition, increased soil organic carbon, enhanced nutrient retention, and more balanced nutrient release through mineralization (Ouyang *et al.*, 2022). These attributes can contribute to improved growth and yield in rice by supporting physiological processes such as nutrient uptake and biomass accumulation (Zakari *et al.*, 2020). Meta-analyses and field trials have shown that organic fertilization can significantly increase leaf area index (LAI), chlorophyll content, total biomass, and ultimately grain yield through enhanced nutrient uptake and physiological efficiency (Liu *et al.*, 2021).

Canopy development and persistence are central determinants of crop productivity in irrigated rice systems. Leaf area index (LAI) has long been used to assess canopy size and light interception potential, but dynamic canopy metrics such as leaf area persistence index (LAPI) provide additional insights into how canopy function evolves through critical growth stages (Dammer *et al.*, 2008). Efficient canopy persistence supports prolonged photosynthetic activity during reproductive and grain-filling phases, which in turn influences assimilate partitioning and yield outcomes. Likewise, indices such as

tillering efficiency reflect how effectively plants convert vegetative growth into yield-forming structures under different nutrient regimes (Shang *et al.*, 2023). While inorganic fertilizers often stimulate rapid vegetative growth, integrating organic amendments may enhance physiological functioning over longer periods, thereby potentially stabilizing yield outcomes across seasons. Beyond yield magnitude, stability and efficiency metrics such as harvest index (HI) and yield stability index (YSI) provide critical information on how reliably a fertilizer strategy performs under interannual variability. Harvest index quantifies the efficiency of biomass partitioning into grain. In contrast, the yield stability index is a useful measure of consistency across seasons and environmental attributes, especially important in environments where climatic and management conditions vary year to year (Han *et al.*, 2020). Assessing relative yield advantage (RYA) against farmer practice further frames research outcomes in terms of practical agronomic benefit.

Despite extensive research on fertilizer effects in controlled settings, there is limited empirical evidence that integrates canopy dynamics, physiological efficiency indices, and yield stability under contrasting organic and inorganic fertilizer regimes within farmer-managed irrigated rice systems in Nigeria. Moreover, comparative evaluations of organic amendments such as poultry and cow manures alongside recommended mineral fertilizer rates remain sparse, particularly in the context of irrigated rice schemes where water and nutrient interactions are especially influential.

The Kano River Irrigation Scheme (KRIS) represents one of northern Nigeria's most significant irrigation infrastructures, supporting thousands of rice farmers and contributing substantially to national rice productivity (Oluniyi and Bala, 2021). Understanding how inorganic and organic fertilizer regimes influence rice performance, canopy development, and yield stability in this real-world setting is critical for optimizing nutrient management strategies that enhance productivity without compromising environmental and soil health. Therefore, this study evaluated the performance, canopy dynamics, and yield stability of irrigated rice under inorganic and organic fertilizer regimes within the Kano River Irrigation Scheme, Nigeria, integrating growth traits, yield components, and derived performance indices across multiple seasons and on-farm environments.

Materials and Methods

Study Area

The study was conducted within the Kano River Irrigation Scheme (KRIS), situated between latitudes 11°35'00" and 12°50'06"N, and longitudes 08°20'45" and 09°40'05"E, approximately 25 km south of Kano city in Nigeria. KRIS is a government-managed scheme designed to provide irrigation to about 22,000 hectares of land using water released from the Tiga Dam via the Ruwan Kanya Reservoir (Hadejia-Jama'are River Basin Development Authority [HJRBD], 1999). The project area spans multiple local government areas (LGAs), namely Kura,

Garun Malam, and Bunkure, covering fields on both sides of the Kano-Zaria and Karfi-Rano highways.

Experimental Design and Treatments

The experiments were conducted using a Randomized Complete Block Design (RCBD) on farmers' fields, which served as pseudo-replicates to reflect real-life farming variability. A total of 34 farmers participated in the study across the three LGAs. Data were collected over two seasons (2020 and 2021); however, due to the COVID-19 pandemic, only limited data were collected in 2020. The experiment was expanded in 2021 to compensate.

Each experimental plot measured 10 m × 10 m (100 m²). The four fertilizer treatments included: T1: Control (Farmer Practice), Inorganic fertilizers (NPK 20-10-10 and Urea 46%) applied without adherence to recommended rates. T2: Recommended Fertilizer Application 200 kg/ha of NPK 15-15-15 applied two weeks after transplanting and 100 kg/ha of Urea (46%) applied four weeks after transplanting. T3: Poultry Manure 6 tons/ha incorporated at basin leveling. T4: Cow Manure 6 tons/ha incorporated at basin leveling. The rice variety used was FARO 44. Farmers in the control treatment (T1) applied fertilizers according to their usual practices. None of the farmers used organic fertilizers in their traditional methods. Table 1 summarizes the average quantity of fertilizer applied in the farmer practice plots.

Table 1: Average nutrient application rates under farmer practice across study locations and seasons (2020–2021).

Year	LGA	Type of Fertilizer	N/Kg/ha	P ₂ O ₅ /kg/ha	K ₂ O/kg/ha
2020	Kura	NPK (20-10-10)/Urea (46%)	263.3	25	25
	Garun Malam	NPK (20-10-10)/Urea (46%)	163.3	15.5	15.5
	Across LG	NPK (20-10-10)/Urea (46%)	213.3	20.25	20.25
2021	Kura	NPK (20-10-10)/Urea (46%)	155.5	26.10	26.10
	Garun Malam	NPK (20-10-10)/Urea (46%)	167	37.5	37.5
	Bunkure	NPK (20-10-10)/Urea (46%)	202.8	93.75	93.75
	Across LG	NPK (20-10-10)/Urea (46%)	175.1	52.45	52.45

Soil Sampling and Analysis

Soil samples were collected at the beginning and end of the experiment to evaluate changes in soil physicochemical properties. Sampling was done at a depth of 0–30 cm before transplanting and after harvest. The samples were air-dried, sieved using a 2-mm mesh, and analyzed according to standard laboratory protocols. Parameters measured included pH (1:2.5 soil-water ratio), electrical conductivity (EC), total nitrogen (Kjeldahl method), available phosphorus (Bray-1 method), and exchangeable cations (Ca, Mg, K, Na) using ammonium acetate extraction (Black, 1965; Udo *et al.*, 2009). Results from this analysis were presented in a separate conference paper (Saleh *et al.*, 2025).

Phenology and Yield Data Collection

Phenological and yield parameters were recorded at various stages of the rice crop growth: Plant height was measured at maturity from four randomly selected spots

per plot using a meter rule. Leaf Area Index (LAI) was recorded at 6 and 9 weeks after transplanting using a Ceptometer. Panicle length was measured from harvested samples collected within a 2 × 2 m² quadrat. The number of productive tillers was counted within each quadrat. Grain and stalk yields were recorded at harvest using a weighing scale.

Data Analysis

The collected data were statistically analyzed using JMP statistical software.

Mapping of Experimental Plots

The geographical distribution of the experimental sites across the study area was mapped using the geocoordinates provided for each farmer's field. A satellite-derived base map was generated from Sentinel-2A imagery, overlaid with village locations and experimental plots (Fig. 1). This spatial visualization enhances understanding of the spatial layout of the research and the connectivity of the irrigation infrastructure.

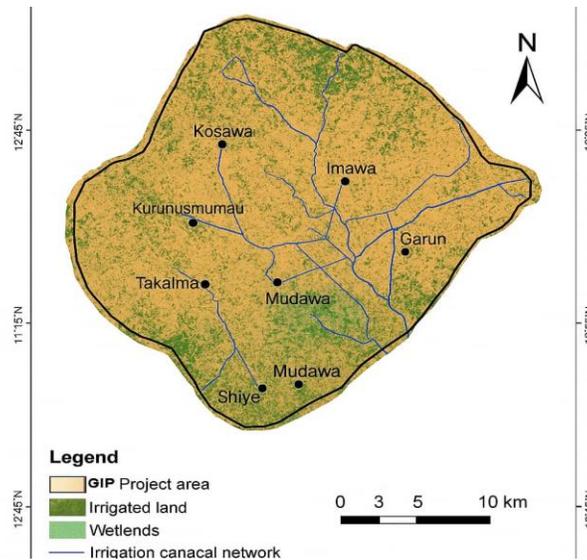


Fig 1.: Geographical map of the study area showing farm locations within KRIS (source: Sentinel-2A Imagery)

Results and discussion

Leaf area index (LAI) differed among fertilizer regimes at both 6 and 9 weeks after transplanting (WAT) (Table 2). Poultry manure recorded the highest LAI at both stages, indicating vigorous canopy development, while cow manure and inorganic fertilizer treatments produced intermediate values. Enhanced LAI under poultry manure reflects improved nutrient availability during early vegetative growth, particularly nitrogen, which promotes leaf expansion and photosynthetic surface area. Organic amendments are known to improve soil structure and nutrient supply, thereby supporting robust canopy formation (Agegnehu *et al.*, 2017). Farmer practice consistently showed lower LAI. The derived leaf area persistence index (LAPI) ranged from 1.29 to 1.44, with inorganic fertilizer and cow manure exhibiting higher canopy

persistence than poultry manure. However, the lower LAPI observed under poultry manure suggests faster canopy turnover, likely due to rapid mineralization and early nutrient release, which can accelerate leaf senescence once readily available nutrients decline. In contrast, higher LAPI values under inorganic fertilizer and cow manure indicate greater canopy persistence, which is critical for sustained photosynthesis during reproductive stages, as previously reported that canopy persistence is a key determinant of grain filling efficiency in rice, particularly under irrigated conditions where light interception drives biomass accumulation (Peng *et al.*, 1998; Yoshida, 1981). These findings demonstrate that fertilizer source not only influences canopy size but also its temporal stability, with implications for assimilate supply during grain development.

Table 2: Leaf area index (LAI) at 6 and 9 weeks after transplanting and derived leaf area persistence index (LAPI) of irrigated rice under different fertilizer regimes.

Treatment	LAI 6 WAT	LAI 9 WAT	Leaf Area Persistence Index
Farmer Practice	2.05b	2.82c	1.38a
NPK/Urea	1.98b	2.84b	1.43a
Poultry Manure	2.38a	3.06a	1.29a
Cow Manure	1.92b	2.77d	1.44a
P-Value	0.05	0.25	0.03
SE ±	0.173	0.149	0.193

Means in the same column with different letters are significantly different at ($P < 0.05$),

LAI = Leaf Area Index, WAT = Weeks After Transplanting. LAPI = LAI at 9 WAT / LAI at 6 WAT

Tillering efficiency reflects the plant's ability to convert vegetative growth into yield-bearing structures. Productive tiller number and tillering efficiency index (TEI) were higher under organic fertilizer treatments than under inorganic fertilizer or farmer practice (Table 3). Cow manure recorded the highest TEI, followed closely by poultry manure, while farmer practice showed the lowest value. The superior TEI under organic amendments suggests improved assimilate allocation and reduced competition between vegetative and reproductive sinks. Organic fertilizers improve soil physical conditions

and microbial activity, enhancing nutrient uptake efficiency and supporting sustained tiller survival (Ladha *et al.*, 2011).

Previous studies have reported that organic nutrient sources promote balanced growth and reduce excessive plant height, thereby improving tiller productivity rather than vegetative luxuriance (Cassman *et al.*, 2002). The results align with the concept that improvements in rice yield are more closely associated with the number of productive tillers than with total biomass alone. (Peng *et al.*, 1998).

Table 3: Productive tiller number, plant height, and tillering efficiency index of irrigated rice as influenced by fertilizer source.

Treatment	Productive Tillers	Plant Height (cm)	TEI
Farmer Practice	15.91	94.19	0.169
NPK/Urea	16.15	93.80	0.172
Poultry Manure	17.33	96.71	0.179
Cow Manure	16.88	93.45	0.180
P-Value	0.34	0.16	0.41
SE ±	0.81	1.60	1.25

Tillering efficiency index (TEI) = Number of productive tillers / Plant height

In the year 2021, grain yield was highest under poultry manure, followed by inorganic fertilizer and farmer practice, while cow manure produced the lowest yield (Table 4).

Poultry manure also resulted in the highest stalk yield, indicating greater total biomass production. In contrast, cow manure produced lower biomass but a relatively

higher harvest index. Explaining that the yield advantage of poultry manure is attributable to its relatively high nutrient content and rapid mineralization, which supports both vegetative growth and grain formation. Several studies have demonstrated that poultry manure can significantly enhance rice yield by improving nitrogen availability and soil fertility (Amanullah *et al.*, 2016; Liu *et al.*, 2020). However, higher biomass accumulation under poultry manure did not translate proportionally into grain yield, suggesting reduced partitioning efficiency.

Furthermore, cow manure produced lower total biomass and recorded a higher harvest index, indicating more efficient allocation of assimilates to grain (Table 4). Harvest index is a critical indicator of physiological efficiency and has been widely used to evaluate the effectiveness of management practices in rice systems (Yoshida, 1981; Sinclair, 1998). These results highlight trade-offs between total biomass production and grain partitioning under different fertilizer regimes.

Table 4: Grain yield, stalk yield, and harvest index (HI) of irrigated rice under inorganic and organic fertilizer regimes (2021 season).

Treatment	Grain Yield (ton/ha)	Stalk Yield	Harvest Index
Farmer Practice	6.87 ^{ab}	8.01 ^b	0.46 ^a
NPK/Urea	6.88 ^{ab}	8.04 ^b	0.46 ^a
Poultry Manure	7.31 ^a	9.20 ^a	0.44 ^a
Cow Manure	6.39 ^b	7.35 ^c	0.47 ^a
P-Value	0.05	0.02	0.07
SE±	0.51	0.58	0.61

Means in the same column with different superscripts are significantly different at ($P < 0.05$).

HI = Grain yield / (Grain yield + Stalk yield).

Harvest index (HI) ranged from 0.44 to 0.47 across treatments, with cow manure recording the highest HI, while poultry manure had the lowest. Inorganic fertilizer and farmer practice exhibited similar HI values (Table 4). Higher harvest index under cow manure suggests improved biomass partitioning toward grain, which may result from moderated vegetative growth and sustained nutrient release throughout the crop cycle. Excessive vegetative growth, as observed under poultry manure, can reduce harvest index by diverting assimilates to

stems and leaves rather than grain (Sinclair, 1998). Comparable HI values between inorganic fertilizer and farmer practice indicate that unregulated fertilizer application does not necessarily improve physiological efficiency. This finding reinforces the importance of balanced nutrient management over sheer input quantity, consistent with observations from long-term rice experiments in Asia and Africa (Buresh *et al.*, 2004; Cassman *et al.*, 2002).

From Table 5, the yield stability index (YSI) values were highest under farmer practice

and inorganic fertilizer treatments, while the organic fertilizer treatments showed slightly lower stability. Relative yield advantage analysis revealed a 6.4% yield gain under poultry manure compared with farmer practice, whereas cow manure resulted in a yield reduction. Greater yield stability under inorganic fertilizer and farmer practice suggests a more predictable nutrient supply across seasons, particularly under irrigated conditions where management consistency is critical. Organic fertilizers, while beneficial for yield improvement, often exhibit variability due to differences in manure quality, decomposition rates, and

synchronization with crop demand (Liu *et al.*, 2020). Nevertheless, the positive relative yield advantage of poultry manure demonstrates its potential as a viable alternative to mineral fertilizer, especially when integrated with improved management practices. Yield stability is increasingly recognized as a core component of sustainable intensification, particularly in smallholder systems facing climatic and management variability (Tilman *et al.*, 2002). Thus, integrating organic inputs with inorganic fertilizers may provide a balanced strategy that enhances productivity while maintaining stability.

Table 5: Yield stability index (YSI) and relative yield advantage (RYA) of irrigated rice under contrasting fertilizer regimes across seasons

Treatment	2020 Yield	2021 Yield	YSI	RYA (%)
Farmer Practice	5.80c	6.87ab	1.18	-
NPK/Urea	6.02b	6.88ab	1.14	+0.15
Poultry Manure	6.56a	7.31a	1.11	+6.41
Cow Manure	5.79d	6.39b	1.10	-7.00
P-Value	0.41	0.046	0.65	-
SE±	0.53	0.50	0.91	-

Means in the same column with different superscripts are significantly different at ($P < 0.05$)

Yield Stability Index (YSI) $YSI = Y_{2021} / Y_{2020}$

Relative Yield Advantage (RYA) $= Y_t - Y_{FP} / Y_{FP} \times 100$ (Using 2021 yields)

Conclusion

This study provides an integrated assessment of rice performance, canopy dynamics, and yield stability under inorganic and organic fertilizer regimes within a major irrigated rice system of northern Nigeria. The results demonstrate that fertilizer source significantly influences not only grain yield but also canopy persistence, tillering efficiency, biomass partitioning, and yield

stability. Organic amendments, particularly poultry manure, enhanced canopy development and grain yield, resulting in a clear yield advantage over prevailing farmer practices. However, this yield gain was associated with faster canopy turnover and reduced harvest index, indicating lower efficiency of biomass partitioning to grain. In contrast, cow manure promoted higher harvest index and tillering efficiency,

reflecting improved physiological allocation despite lower total yield. Inorganic fertilizer and farmer practice exhibited greater yield stability across seasons, underscoring the role of predictable nutrient availability in maintaining consistent production under irrigated conditions. Thus, revealing the importance of trade-offs among yield maximization, physiological efficiency, and yield stability across fertilizer regimes. Consequently, reliance on a single nutrient source may not adequately address the

multiple dimensions of sustainable rice production. Such approaches are particularly relevant for farmer-managed irrigation schemes where productivity gains must be balanced with sustainability and resilience. The results provide empirical evidence to support context-specific fertilizer recommendations aimed at improving the performance and long-term sustainability of irrigated rice systems in the Sudan savanna zone of Nigeria.

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