Journal of
Current Opinion in Crop Science

Journal homepage: www.jcocs.com; ISSN(O):2583-0392

RESEARCH ARTICLE

Integrated use of farmyard manure, gypsum and inorganic fertilizer for sustainable rice production on salt affected soil in Northwest Nigeria

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Article history:

Received: November 21, 2025
Accepted: December 26, 2025
Published: December 30, 2025

Citation:

Ojeniyi, K. A., Madukwe, D. K., Meka, I. N., Orowumi, O. O., & Aliyua, A. (2025). Integrated use of farmyard manure, gypsum and inorganic fertilizer for sustainable rice production on salt affected soil in Northwest Nigeria. *Journal of Current Opinion in Crop Science, 6*(4), 286-297.
https://doi.org/10.62773/jcocs.v6i4.362

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ABSTRACT

Saline soil and nutrient imbalance critically constrain crop productivity in the Kola and Kardi districts of Kebbi State, Nigeria. Although soil amendments have proven effective in restoring soil fertility, their adoption among smallholder farmers remains limited. During the 2021 cropping season, a comprehensive field survey was conducted to assess farmers' nutrient management practices and identify significant constraints to soil productivity. The findings revealed suboptimal, inconsistent management practices that exacerbate soil fertility decline caused by salinity. Consequently, a field experiment was established to demonstrate to farmers the synergistic effects of farmyard manure (FYM), gypsum (G), and NPK fertilizer on the growth and yield performance of rice cultivated on salt-affected soils. The experiment was laid on a randomized complete block design with five replications, comprising application rates of 15 t ha^{-1} FYM, 1.5 t ha^{-1} gypsum, 250 kg ha^{-1} NPK (20:10:10), and 100 kg ha^{-1} urea. Integrated nutrient management consistently enhanced rice yield and yield components across all growth stages compared with the farmer practice. The integrated treatment (G + FYM + NPK) produced the highest grain yield, achieving 5.7 t ha^{-1} and 5.5 t ha^{-1} in Kola and Kardi, respectively, compared with 1.9 t ha^{-1} and 1.7 t ha^{-1} under the farmers' practice. The combination of organic and inorganic amendments, supported by farmer training and participatory demonstration, offers a viable and scalable pathway for restoring degraded soils and bridging the rice yield gap in northwestern Nigeria.

Keywords: rice; salinity; soil fertility; soil restoration; soil amendments; yield.

INTRODUCTION

Nigeria's heavy reliance on rice as a staple food has led to increased demand for production; hence, enhancing rice production across the country is necessary in the current conventional farming system, especially in areas with problematic soils. (Akınsola et al., 2025; Mba et al., 2021; Musa et al., 2024; Ugbudian, 2020). In salt-affected soil, rice growth and yield are constrained through reduced availability and uptake of essential nutrients (Liu et al., 2024). High pH levels impair soil structural stability by compaction, restricting root development and hindering water and nutrient transport (Chen et al., 2021). Alkalinity suppresses microbial biomass and enzyme activity, thereby slowing organic matter decomposition and nutrient cycling (Guo et al., 2021; Meena & Prakasha, 2024). The high concentrations of sodium and carbonate/bicarbonate ions commonly found in alkaline soils further exert toxic effects on rice roots, disrupting water and nutrient uptake (Liu et al., 2024). These conditions require identifying and implementing appropriate soil management strategies to sustain rice productivity in the affected area.

Rice is cultivated across all six geopolitical zones of Nigeria, with Kebbi State recognized as one of the major production areas (Kara et al., 2019). Nigeria is the largest rice producer in Africa, with an annual output of approximately 8.4 million metric tons (mMt) (Heike Axmann, 2021). Nigeria's demand for milled rice is estimated at 5.2 m Mt, while domestic production averages only 3.3 m Mt, leaving an annual supply deficit of approximately 1.9 m Mt (Musa et al., 2024). Nigeria still imports 1.7 m Mt of milled rice to meet local consumption demand (International Trade Administration (ITA), 2023). In Kebbi State, the rice sector has benefited from large-scale government and donor-supported initiatives, most notably the Central Bank of Nigeria's Anchor Borrowers' Programme (Baraya et al., 2023; Gona et al., 2023; Salisu et al., 2022), as well as the introduction of improved technologies such as Sawah eco-technology (Alarima et al., 2018; Olubusayo et al., 2024), which have significantly enhanced yields, farmer incomes, and adoption rates. The recommended fertilizer regimes include 60-80 N, 30 P2O5, 30 K2O kg/ha for lowland; 60-80 N, 69 P2O5, 36 K2O kg/ha for upland(Kamai et al., 2020a) or 300 kg/ha of NPK (20:10:10) (Agbo, 2024), supplemented with single superphosphate (SSP) (Chukwudi et al., 2025). Nevertheless, despite these recommendations, average paddy rice yields in northern Nigeria remain only 2–3 t/ha under irrigation, and the national average is approximately 2 t/ha (Siéwé et al., 2023a). This stands in stark contrast to the potential yield of 6–10 t/ha for lowland rice in Nigeria and the regional average of 2.6 t/ha in West Africa (Kamai et al., 2020a). This underscores the persistent yield gap and the urgent need for improved soil and crop management strategies.

Soil management trials in the study region indicate that minimum tillage enhances soil quality more effectively than crop rotation, with continuous rice cultivation under minimum tillage increasing soil organic carbon, microbial biomass C, N, and cation exchange capacity by 98%, 35%, 95%, and 138%, respectively, compared with rice–cowpea rotation (Adelana et al., 2022), even though crop rotation was also recommended in another study along with the incorporation of organic matter, fallow, and legume cultivation (Augie & Adegbite, 2021a). In addition to these benefits, few farmers adopt climate change adaptation practices such as improved rice varieties, intercropping, and recommended fertilizer and chemical applications (Yakubu & Oladele, 2021). System of rice intensification (SRI) practices, such as transplanting 11-day-old seedlings at 25 × 25 cm spacing, alternate wetting and drying, and the combined application of compost and inorganic fertilizer, have also been shown to be most productive in the region (Siéwé et al., 2023b).

Beyond these practices, several studies highlight the benefits of integrating organic and inorganic amendments to enhance rice yield, including biochar with mineral fertilizers (Oladele et al., 2019), farmyard manure with inorganic fertilizer (Dania et al., 2021), and rice husks with cassava effluent (Ojobor et al., 2020). The balanced application of nutrients also plays a pivotal role in bridging crop yield gaps, especially from regional-specific fertilizer recommendations, as highlighted in our previous study (Ojeniyi et al., 2024). However, gypsum has shown promise in creating favorable conditions for microbial activity when combined with organic carbon sources (Nifong et al., 2019). The calcium in gypsum displaces exchangeable sodium, thereby improving soil structure, infiltration, and reducing erosion, while its sulfate fraction promotes sodium leaching (Favaretto et al., 2006). Based on this evidence, we hypothesized that the integrated application of gypsum, farmyard manure, and inorganic fertilizer would enhance root-zone oxygenation and nutrient mobility, thereby alleviating osmotic stress induced by sodium accumulation. This integrated approach was further expected to improve soil physicochemical properties and root development, ultimately leading to enhanced rice growth and yield. Accordingly, the specific objective of this study was to demonstrate sustainable soil and agronomic management practices integrating gypsum, farmyard manure, and mineral fertilizers to close the rice yield gap on salt-affected soils.

MATERIALS AND METHODS

Climate and soils of the study sites

The study was conducted in the Kola and Kardi districts of Kebbi State, located in northwestern Nigeria. Kola (12.4397°N, 4.1064°E) and Kardi (12.4208°N, 4.2967°E) lie within the same Sudan Savanna agroecological zone, which is characterized by a unimodal rainfall pattern from June to September and a pronounced dry season from November to March. The region receives an average annual rainfall of approximately 200–250 mm and experiences mean temperatures around 34 °C (Climate Change Knowledge Portal, 2025). The locations (farmers' fields) were purposively chosen for their high, physically observable salt content. Soils within this zone are predominantly slightly acidic to neutral, with localized alkaline patches, and are generally classified as medium to low in fertility (Augie et al., 2021; Augie & Adegbite, 2021b).

Baseline survey for the characterization of rice production in the region

A comprehensive baseline survey was conducted before the experimental phase to characterize prevailing farming systems, identify soil-related constraints, and assess farmers' expectations. Structured questionnaires were administered to both participating and non-participating smallholder farmers across the targeted communities, with emphasis on soil fertility challenges, input utilization, and management practices. The survey encompassed 30 arable farmers, selected through a proportionate sampling technique to ensure representative coverage across farming communities. Data collection was conducted through in-person interviews to enhance contextual reliability and minimize response bias. With support from personnel of the Agricultural Development Programmes, three representative farming communities were selected based on the intensity of rice cultivation. Before data collection, farmers were sensitized to the study's objectives and procedures, and they provided informed consent. The interview instrument captured multidimensional aspects of the production system, including demographic characteristics, access to value-chain services, fertilizer use and pest management practices, post-harvest processing, marketing channels, and access to financial resources.

Experimental design and treatments

The field experiment was conducted during the 2021 growing season using a randomized complete block design (RCBD) with five replications. It was an on-station experiment spanning one season by two locations. Four treatment combinations were assigned to plots measuring 10 × 5 m, separated by 1 m alleys. Each replication comprised 4 experimental units, yielding 20 experimental plots per site. The treatment combinations evaluated are summarized below:

- FP: Farmer practice in terms of management practice
- G+ NPK: Gypsum and NPK Fertilizer
- NPK+FYM: NPK Fertilizer and Farmyard manure
- G+FYM: Gypsum and Farmyard manure

Farmer Management Practice

Farmers' practices revealed a near-universal reliance on inorganic fertilizers (100%) and organic manure (93%) (Table 1), complemented by soil fertility strategies such as crop rotation and intercropping. However, as reported by Adelana et al. (2022), crop rotation alone does not necessarily enhance yield, whereas minimum tillage under continuous rice systems has shown greater effectiveness. Fertilizer application rates among farmers were markedly below the recommended standards due to economic constraints (Appendix 1). Typically, farmers applied 100 kg ha^{-1} of NPK (20:10:10) and subsequently top-dressed with 50–100 kg ha^{-1} of urea, in contrast to the recommended 300 kg ha^{-1} of NPK (20:10:10), supplemented with SSP in lowland. Such suboptimal nutrient inputs inevitably limit crop productivity. Moreover, the timing of fertilizer application was inconsistent with best agronomic practice; NPK was commonly applied one week after transplanting, followed by urea at approximately 4-5 WAT. While some farmers substitute manure for mineral fertilizer, they also demonstrated limited awareness of appropriate manure management techniques due to low access to production training (Appendix 2). Although there is no universal rate of manure application, Farmers in this region often apply an average rate of 3 t ha^{-1}, considerably below the recommended 7.5–12.5 t ha^{-1}(Ibrahim et al., 2025). Application timing was also suboptimal, with many farmers incorporating manure immediately before transplanting. Seed quality further constrained productivity, as many farmers relied on retained grain from previous harvests rather than certified seeds with superior genetic potential. Based on empirical observations from field surveys and direct farmer consultations, a "farmer practice" treatment was developed as the control in this study. The control plots were managed to accurately reflect local practices, receiving two 50 kg bags of NPK one week after transplanting and two 50 kg bags of urea four weeks thereafter, and manure was applied a week before transplanting, replicating the standard management approach used by the majority of farmers in the study area.

Crop Management Practices

The field experiment was conducted on farmers' fields that had been previously cultivated with rice. A participatory research approach was employed, in which farmers actively engaged in all field operations under technical supervision. Land preparation involved manual clearing and moderate tillage before the layout of the experimental plots. Farmyard manure (7 t ha^{-1}) and gypsum (1.5 t ha^{-1}) were incorporated two weeks before transplanting. An even irrigation of approximately 10 cm depth was maintained across the plots, except during fertilizer application. Rice seedlings (FARO 62) were raised on a well-levelled nursery bed measuring 1 × 10 m, with furrows established between beds for irrigation and drainage. Pre-sprouted seeds were evenly broadcast, and the nursery was kept moist and properly managed to prevent weed, pest, and disease infestation.

Seedlings were transplanted 21 days after sowing (at least two weeks after amendment application) to minimize transplant shock associated with gas release from decomposing manure. Transplanting was done at 20 × 20 cm spacing, with two seedlings per hill at a depth of 3–4 cm. At transplanting, 200 kg ha^{-1} of NPK (20:10:10) was applied, followed by 100 kg ha^{-1} of urea at five weeks after transplanting, in accordance with (Kamai et al., 2020b) recommendations. Weed control was achieved using a post-emergence application of bispyribac sodium 10% (AgriForce) at 400 mL ha^{-1}, three weeks after transplanting. Pest and disease management involved the application of lambda-cyhalothrin (1 L ha^{-1}) and mancozeb (1.5 kg ha^{-1}) at four and eight weeks after transplanting, respectively, to prevent stem borer and rice blast. The crop was harvested at 16 weeks after transplanting.

Measured Observations

Yield and Yield Attributes

A 1 m^2 quadrat was delineated within the net plot of each treatment and used for phenological and agronomic measurements. Plant height was recorded from tagged plants within the quadrat at 4, 8, and 12 weeks after transplanting (WAT), measured from the soil surface to the tip. The number of tillers per plant was determined concurrently from the same tagged plants. The total grain yield was calculated from each plot at harvest. The moisture content was less than 10% at harvest, and the total yield was extrapolated to tons per hectare. Shoot dry matter accumulation was weighed at 4, 8, and 12 WAT by uprooting three representative plants from the quadrat. Shoots were oven-dried at 35 °C for seven days to a constant weight, after which dry biomass (g/plant) was recorded using a precision balance. At 12 WAT, the number of grains per panicle was counted on the tagged plants, and the 1,000-grain weight was determined at harvest using a digital balance. Straw dry weight (excluding grains) was also measured per square meter. Unfilled grains were separated and weighed per net plot at harvest. The harvest index (HI) was computed as the ratio of grain yield to total aboveground biomass.

Statistical Analysis

Survey data were coded and analyzed using Microsoft Excel (version 2013) and IBM SPSS Statistics (version 20). Descriptive statistics, including frequencies, means, standard deviations, and graphical charts, were employed to characterize farmer responses. Yield and yield attribute data were analyzed using R Studio statistical software (version 2025.09.0+387). Before inferential analysis, data were subjected to tests for compliance with ANOVA assumptions: normality was assessed using the Shapiro–Wilk test, homogeneity of variance with Levene's test, and independence of residuals with the Durbin–Watson statistic. Treatment effects were evaluated using a one-way analysis of variance (ANOVA), and mean separations were performed with Tukey's Honest Significant Difference (HSD) test at a 5% probability level ($p < 0.05$).

RESULTS

Demographic characteristics of the respondents

The respondents' demographic characteristics showed a relatively balanced age distribution across the study area. The majority (26.7%) fell into the 21–30, 41–50, and 50+ age categories, while only 6.7% were younger than 20 years. Most respondents (73.3%) were married, with 70% reporting one or two spouses and 6.7% having three to four spouses. Household size was generally small: 60% of respondents had up to 5 children, and only 3.3% reported having more than 15. Educational attainment varied among respondents: 30% had completed secondary education, whereas only 3.3% attained tertiary-level qualifications. Farming experience was notably high, with 59.8% of respondents having more than 20 years of experience, and 13.4% each reporting between 11–15 and 16–20 years, respectively, indicating a predominantly experienced farming population. Labor utilization patterns showed that 36.6% of respondents employed up to five workers, while only 3.3% employed more than ten. Regarding household income, the majority (80%) earned between ₦101,000 and ₦200,000 annually, whereas 10% each earned less than ₦100,000 or more than ₦200,000, respectively, suggesting that most farmers operated within a low-income bracket. In terms of asset ownership, 43.3% possessed farmland, 39.9% owned livestock, and a small proportion (6.6%) reported ownership of a bicycle.

Characterization of rice production

The results indicate that 33.6% of respondents cultivated between 1.01 and 2 ha, or more than 2 ha, of farmland, while 26.7% operated on less than 1 ha, reflecting a predominance of smallholder farming systems. The majority (86.6%) were primarily engaged in rice production. Nearly all respondents (96.7%) relied on either mechanical land preparation or manual harvesting, and 93.3% reported limited use of modern machinery, underscoring the subsistence nature of their operations. Most farmers (63.3%) practiced a combination of rainfed and irrigated cultivation, reflecting adaptation to seasonal water variability. A large proportion (86.6%) and (76.6%) reported using inorganic fertilizers and improved seed varieties, respectively, whereas only 3.3% used herbicides or insecticides. These results suggest moderate adoption of modern inputs, although pest and weed management practices remain limited. Training, knowledge transfer, and access to knowledge transfer were notably lacking; 93.3% of respondents had not received any formal agricultural training, and 83.3% had no access to extension services. Flooding emerged as the most significant production constraint, reported by 93.3% of farmers, followed by drought (16.7%). The predominance of flood-related challenges likely reflects the region’s topography, as most respondents cultivate in lowland Fadama areas that are highly susceptible to riverine flooding. Market participation appeared moderate: 66.7% of farmers reported established market linkages, and 53.3% had access to market information services. However, nearly all respondents (96.7% and 93.3%, respectively) lacked access to quality control mechanisms and capacity-building programs, underscoring structural limitations in post-harvest value chain integration and institutional support.

Crop management practices: Soil Fertility Preservation, Type of Fertilizer and Weed control methods

The results in Table 1 indicate that respondents universally recognized fertilization as the principal strategy for maintaining soil fertility. Nearly all farmers reported using both organic (93.3%) and inorganic (96.7%) fertilizers, reflecting a firm reliance on external nutrient inputs to sustain crop productivity. Similarly, chemical herbicides were widely adopted for weed management, with 83.3% of respondents reporting their use. These findings underscore an increasing dependence on input-intensive soil fertility and weed control practices among smallholder rice producers, likely driven by declining soil fertility and labor constraints associated with traditional management systems.

Table 1. Type Fertilizer used and Weed control methods among the farmers within Kardi and Kola district of Birnin Kebbi, Kebbi state. (n=30)

Variables*	Categories	No.	%
Soil fertility preservation method	Fertilization	30	100
	Crop rotation	11	33.6

	Intercropping	22	73.4
Type of fertilizer	Chemical	29	96.7
	Organic	28	93.3
Weeds control Method	Burning of plant residue after harvest	1	3.3
	Mechanical weeding	13	43.3
	Chemical herbicides	25	83.3
*Multiple response			

Processing, Storage, Sources of Inputs, Marketing, and Sources of Financial Services

The results revealed that nearly all respondents (96.7%) relied on manual methods for crop processing, underscoring the limited mechanization of post-harvest operations in the study area. The majority of farmers (59.8%) stored harvested produce in jute bags, while only a small proportion (6.6%) utilized wooden racks, reflecting rudimentary storage systems with potential post-harvest losses. Most respondents (96.7%) sourced their production inputs from local markets, indicating a high reliance on informal supply chains. Similarly, 83.3% of farmers sold their produce directly in local markets, with about half (50%) engaging both retailers and wholesalers, while a small fraction (6.6%) sold exclusively to retailers. Access to formal credit systems was limited; over half (63.3%) of respondents relied primarily on local moneylenders for agricultural financing, and 16.7% combined informal credit with traditional group savings. Collectively, these findings highlight the dominance of informal market and financial structures that may constrain productivity growth and limit farmers' capacity to adopt improved technologies. The results presented in reveal that nearly all respondents (96.7%) relied on manual methods for crop processing, underscoring the limited mechanization of post-harvest operations in the study area. The majority of farmers (59.8%) stored harvested produce in jute bags, while only a small proportion (6.6%) utilized wooden racks, reflecting rudimentary storage systems with potential post-harvest losses. Most respondents (96.7%) sourced their production inputs from local markets, indicating a high reliance on informal supply chains. Similarly, 83.3% of farmers sold their produce directly in local markets, with about half (50%) engaging both retailers and wholesalers, while a small fraction (6.6%) sold exclusively to retailers. Access to formal credit systems was limited; over half (63.3%) of respondents relied primarily on local moneylenders for agricultural financing, and 16.7% combined informal credit with traditional group savings.

Rice growth, yield, and yield attributes

Tiller Count

Table 2 presents the effects of soil amendments and farmers' practices on the number of tillers per plant. At both Kola and Kardi sites, tiller counts at 4 WAT did not differ significantly among treatments. In contrast, those at 8 WAT were considerably higher in the amendments than under the farmers' practice. By 12 WAT, plants treated with the combined application of gypsum, FYM, and NPK fertilizer produced the highest tiller numbers (30+), statistically comparable to those under NPK + FYM and gypsum + NPK. The lowest tiller counts were recorded in the farmers' practice plots, with 17 and 18 tillers per plant at Kola and Kardi, respectively.

Table 2. Number of rice tillers influenced by the soil amendments in salt-affected soils in Kola and Kardi

Treatments	Number of tillers					
	Kola			Kardi		
	4WAT	8WAT	12WAT	4WAT	8WAT	12WAT
FP	5.2^{a}	15.4^{b}	17.2^{b}	7.2^{a}	13.4^{b}	18.2^{c}
G+NPK	10.4^{a}	30.4^{a}	34.6^{a}	12.4^{a}	26.4^{a}	26.0^{b}
NPK+FYM	9.8^{a}	26.0^{a}	28.8^{a}	11.8^{a}	24.0^{a}	29.8^{ab}
G+FYM+NPK	11.0^{a}	32.0^{a}	33.6^{a}	13.0^{a}	30.0^{a}	34.6^{a}

P-value $_{0.05}$	0.1364	0.0002	0.0004	0.1364	0.0002	0.0004

Note: Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Tukey's Honest Significant Difference. G=gypsum, FYM=farmyard manure, WAT=week after transplanting.

Rice Height

Table 3 presents the effect of the treatments on rice plant height relative to the farmers' practice. At the Kola site, four weeks after transplanting (4 WAT), plants receiving the combined application of gypsum, organic manure, and NPK fertilizer were significantly taller than those under the gypsum–NPK treatment. In contrast, the shortest plants occurred under the farmers' practice. By 8 WAT, all amended treatments produced comparable plant heights, each significantly exceeding those in the farmers' plots. At 12 WAT, however, plant height differences among treatments were no longer significant. A similar growth pattern was observed at both sites.

Table 3. Height of rice as influenced by the treatments in salt-affected soils in Kola and Kardi

Trématent	Plant Height (cm)					
	Kola			Kardi		
	4WAT	8WAT	12WAT	4WAT	8WAT	12WAT
FP	13.9^{c}	42.4^{b}	87.9^{a}	16.2^{c}	43.8^{b}	90.5^{a}
G+NPK	18.5^{b}	60.5^{a}	90.3^{a}	20.7^{b}	61.9^{a}	93.0^{a}
NPK +FYM	16.8^{b}	61.8^{a}	98.8^{a}	19.1^{b}	63.2^{a}	101.4^{a}
G+FYM+NPK	21.6^{a}	65.2^{a}	84.8^{a}	23.8^{a}	66.7^{a}	87.4^{a}
Pvalue $_{0.05}$	0.0004	0.0006	0.3542	0.0005	0.0006	0.3542

Note: Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using the Tukey's Honest Significant Difference. G=gypsum, FYM=farmyard manure, WAT=week after transplanting.

Dry Shoot Weight

Although no significant differences in dry shoot weight were observed among the soil amendment treatments, all amendments produced significantly higher biomass than the farmer practice across both locations.

Table 4. Shoot dry weight at different growth stages as influenced by the soil amendments in salt-affected soils in Kola and Kardi

Trématent	Shoot Dry Weight (g/plant)					
	Kola			Kardi		
	4WAT	8WAT	12WAT	4WAT	8WAT	12WAT
FP	9.2^{b}	20.8^{b}	26.0^{b}	12.2^{b}	18.8^{b}	24.0^{b}
G+NPK	18.2^{a}	36.8^{a}	45.8^{a}	21.2^{a}	34.8^{a}	43.8^{a}
NPK+FYM	16.2^{a}	31.4^{a}	45.8^{a}	19.2^{a}	29.4^{a}	43.8^{a}
G+FYM+NPK	17.8^{a}	35.2^{a}	50.8^{a}	20.8^{a}	33.2^{a}	48.8^{a}
Pvalue $_{0.05}$	0.0011	0.0001	0.0039	0.0011	0.0001	0.0039

Note: Means followed by the same later(s) within a treatment group are not significantly different at 5% level of significance using the Tukey's Honest Significant Difference. G=gypsum, FYM=farmyard manure, WAT=week after transplanting.

Yield and Yield attributes

Table 5 presents the total rice grain yield influenced by soil amendments and farmers' practices. Across both sites, all amended plots produced significantly higher grain yields than the farmers' practice. The combined application of gypsum, farmyard manure, and mineral fertilizers resulted in the highest yields, averaging 5.7 t ha^{-1} and 5.5 t ha^{-1} at Kola and Kardi, respectively, compared with 1.9 t ha^{-1} and 1.7 t ha^{-1} under the farmers' practice in the exact locations. The superior performance of the amended plots is likely attributable to the synergistic effects of integrated nutrient management, whereby the combination of organic and inorganic inputs enhances nutrient availability, soil structure, and moisture retention, thereby creating favorable conditions for rice growth.

Grains per panicle were significantly higher under all amendment treatments compared with the farmers' practice, with plots receiving farmyard manure producing comparatively greater grain numbers than those treated with gypsum and NPK alone. In contrast, no significant differences were observed among treatments in 1000-grain weight or the proportion of unfilled grains at either site. Straw biomass differed significantly among treatments, with plots amended with gypsum + farmyard manure + NPK producing the highest straw weight (665–685 g m^{-2}), followed by gypsum + NPK (629–649 g m^{-2}) and NPK + farmyard manure (546–566 g m^{-2}). The lowest straw biomass (435–455 g m^{-2}) occurred under the farmers' practice. Although total biomass accumulation varied across treatments, the harvest index did not differ significantly among amended plots. Still, it was markedly higher in the farmers' practice due to proportionally lower vegetative growth.

Table 5. Yield and yield attributes of Rice as affected by the soil amendments in salt-affected soils in Kola and Kardi.

Treatment	Grain Yield (t/ha)		Grain Per Panicle		1000gw (g)		Unfilled gw (g/m^2)		Straw Weight (g/m^2)		Harvest Index	
	Kola	Kardi	Kola	Kardi	Kola	Kardi	Kola	Kardi	Kola	Kardi	Kola	Kardi
FP	1.9^{b}	1.7^{b}	121^{b}	118^{b}	23.6^{a}	25.6^{a}	22.2^{a}	20.2^{a}	455^{c}	435^{c}	0.28^{b}	0.37^{b}
G+NPK	5.5^{a}	5.2^{a}	218^{ab}	215^{ab}	23.2^{a}	25.2^{a}	18.4^{a}	16.4^{a}	649^{ab}	629^{ab}	0.45^{a}	0.84^{a}
NPK+FYM	4.7^{a}	4.5^{a}	241^{a}	238^{a}	22.6^{a}	24.6^{a}	13.2^{a}	11.2^{a}	566^{b}	546^{b}	0.44^{a}	0.81^{a}
G+FYM+NPK	5.7^{a}	5.5^{a}	284^{a}	281^{a}	22.2^{a}	24.2^{a}	14.4^{a}	12.4^{a}	685^{a}	665^{a}	0.45^{a}	0.82^{a}
P-Value	0.001	0.001	0.010	0.010	0.874	0.874	0.484	0.484	0.008	0.008	0.002	0.008

Note: Means followed by the same later(s) within a treatment group are not significantly different at 5% level of significance using the Tukey's Honest Significant Difference. G=gypsum, FYM=farmyard manure, WAT=week after transplant.

DISCUSSION

The integrated application of gypsum, farmyard manure, and inorganic fertilizer (G+FYM+NPK) produced a substantial improvement in rice growth and yield across the salt-affected soils of Kola and Kardi, outperforming farmer practice by more than 60%. This outcome reinforces the principle that synergistic interactions between organic and inorganic inputs can offset soil chemical imbalances and nutrient limitations common in saline–alkaline environments (Liu et al., 2024; Dania et al., 2021). The observed enhancement in plant height, tiller count, and shoot dry biomass across all growth stages indicates improved nutrient uptake efficiency and root vigor, both of which are critical for sustaining productivity under ionic stress. The higher yield performance under G+FYM+NPK can be attributed to multiple complementary mechanisms. Gypsum, as a calcium sulfate source, facilitated the displacement of exchangeable sodium and promoted leaching of Na^{+} and bicarbonate ions, thereby improving soil aggregation, porosity, and infiltration (Favaretto et al., 2006). This amelioration likely enhanced root proliferation and access to both water and nutrients. Concurrently, organic inputs from farmyard manure contributed to carbon sequestration, increased cation exchange capacity, and stimulated microbial activity, a key driver of nutrient mineralization and rhizosphere stability (Guo et al., 2021; Meena & Prakasha, 2024; Nifong et al., 2019). When supplemented with mineral fertilizers, this created a nutrient-synergistic environment conducive to rice growth and grain formation.

The comparable effects of the NPK+FYM and G+NPK treatments, though lower than those of G+FYM+NPK, further emphasize the need for balance between mineral fertilizers and organic matter enrichment. Sole reliance on mineral fertilizers or partial soil amendments failed to achieve the same magnitude of yield improvement, further emphasizing the limitations of unidimensional fertility management in salt-affected soil. These results align with findings from other studies in saline rice environments where integrated nutrient management (INM) improved yield stability and nutrient-use efficiency compared to singular amendment strategies (Dania et al., 2021; Ojobor et al., 2020; Siéwé et al., 2023b).

The significant increase in tiller counts and grain per panicle under integrated treatments suggests that amelioration improved the plant's physiological capacity for effective tiller initiation and grain filling. Improved soil aeration and ionic balance likely enhanced root oxygenation and nutrient mobility, mitigating the osmotic stress typically associated with sodium accumulation. The absence of significant differences in 1000-grain weight among treatments indicates that the yield advantage derived primarily from improved panicle density and spikelet fertility rather than grain size, a pattern consistent with improved source–sink dynamics under restored soil fertility conditions. The straw biomass yields further support for this interpretation; higher vegetative biomass accumulation under integrated treatments reflects improved photosynthetic activity and assimilation efficiency. Although the harvest index remained statistically similar across treatments, its absolute increase relative to farmer practice indicates a more balanced allocation between vegetative and reproductive growth. This equilibrium is desirable in saline environments where excessive vegetative growth can exacerbate water stress and ion accumulation (Ismail et al., 2022).

From a management perspective, these findings have direct implications for smallholder systems in northwestern Nigeria. The dominance of subsistence farming practices, characterized by inadequate nutrient inputs, poor amendment timing, and low access to training, etc, has contributed to persistent yield gaps. Demonstrating the efficacy of locally available farmyard manure and regionally accessible gypsum under real field conditions not only validates their agronomic potential but also strengthens the case for participatory soil restoration frameworks. The participatory approach used in this study ensured farmer engagement, enhancing the likelihood of long-term adoption and scaling.

Moreover, the socioeconomic survey revealed that while farmers rely heavily on fertilizer application as the principal fertility-preserving practice, their rates and timing were suboptimal. By contrast, the integrated strategy tested here offers a practical alternative that addresses both chemical degradation and biological infertility. When adopted, it can transform soil management from a reactive input-based system to a restorative, process-based system. In the broader context, these results contribute to the growing body of evidence advocating for integrated soil fertility management (ISFM) as a key pathway to sustainable intensification in sub-Saharan Africa's rice-based systems. As climate variability intensifies salinity and sodicity in irrigated lowlands, such integrative approaches will be crucial to achieving yield resilience and food security.

CONCLUSION

This study demonstrates that the integrated application of gypsum, farmyard manure, and inorganic fertilizer significantly enhances rice growth and yield on salt-affected soils in Kebbi State, Nigeria. The combined treatment (G+FYM+NPK) improved soil fertility, plant vigor, and grain yield by more than 60% compared with prevailing farmer practice. Sustainable productivity on salt-affected soils cannot be achieved solely through chemical fertilizers. The combination of organic and inorganic amendments, supported by farmer training and participatory demonstration, offers a viable and scalable pathway for restoring degraded soils and bridging the rice yield gap in sub-Saharan Africa. For farmers, adopting this integrated management approach can lead to higher returns on fertilizer investment, improved soil structure, enhanced water infiltration, and greater resilience against salinity stress, thereby contributing to both household income stability and national food security.

ACKNOWLEDGEMENT

We would like to thank the management of OCP Africa Nigeria for funding and support of this research, and the Nigeria Institute of Soil Science (NISS) team for data collection.

AUTHOR CONTRIBUTIONS

Kehinde Ojeniyi: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Donald Madukwe: Writing – review & editing, Supervision, Funding acquisition. Ifunanya Ngozika Meka: Writing – review & editing, Supervision. Odunayo Oludare Orowumi: Writing – review & editing, Supervision. Abdulrasheed Aliyu: Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research was funded by OCP Africa.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not Applicable

CONSENT FOR PUBLICATION

Not Applicable

AVAILABILITY OF DATA AND MATERIALS

The datasets during and/or analyzed during the current study available from the corresponding author on reasonable request

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