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Sustainable Reclamation of Salt-Affected Rice Schemes around Lake Guiers through an Integrated and Climate-Resilient Approach

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Abstract

Soil salinity is a major constraint to the sustainability of rice cultivation in the Senegal River Valley, particularly around the Lake Guiers, where nearly 66% of irrigated land is affected. The reclamation of these salt-affected areas is therefore essential for improving rice productivity and strengthening national food security. This study evaluated an integrated strategy combining a salt-tolerant rice variety (ISRIZ 10), organo-mineral fertilization, and mechanized land preparation. The experiment was conducted in Mbane using a randomized complete block design with three treatments: T0 (farmer's practice: DAP + urea), T1 (T0 + compost + phosphogypsum + mechanized land preparation), and T2 (T0 + compost + mechanized land preparation). Soil physico-chemical analyses and agronomic observations showed that integrated reclamation practices significantly improved both soil quality and rice performance. Soil organic carbon and organic matter increased in the surface layer, whereas sodium content decreased by more than 92% in the 10 - 30 cm layer. Mechanized land preparation also reduced weed pressure and improved seedbed quality. Treatment T1 showed the best agronomic performance, with grain yield exceeding that of the farmer's practice by more than 15%. These results demonstrate that the combined use of a salt-tolerant variety, compost, phosphogypsum, and small-scale mechanization is an effective strategy for rehabilitating salt-affected rice fields around the Lake Guiers. Because this approach is sustainable, replicable, and climate-resilient, it has strong potential to improve rice productivity and enhance food security in West Africa.

Keywords

Integrated Management, Salinity, Rice, Phosphogypsum, Compost, Small-Scale Mechanization, The Lake Guiers, Senegal, Soil Restoration

1. Introduction

Senegal is one of the largest rice-consuming countries in West Africa [1]. Rice has become the main staple cereal, surpassing millet and maize. National cereal crops cover 1,895,834 ha, of which 20% is devoted to rice, with an estimated production of 842,819 tons of milled rice [2] and [3]. However, this output meets only 52% of national demand, estimated at 117 kg per capita per year [3]. Despite major government efforts, the country continues to rely heavily on imports, which average 1,327,775 tons of milled rice and represent 3033 billion CFA francs [2]. This structural gap between domestic production and consumption underpins the national food sovereignty strategy, which targets 3,678,313 tons of paddy rice by 2029, corresponding to a coverage rate of 108% [2].

Irrigated rice cultivation occupies a strategic position in achieving national rice self-sufficiency in Senegal. Irrigated rice cultivation is a major pillar of food security, particularly in the Senegal River Valley and around the Lake Guiers, where a substantial share of national production is concentrated. This area benefits from direct access to lake water, hydro-agricultural infrastructure, and a semi-arid Sahelian climate that allows two rice-growing seasons per year. However, this production dynamic is increasingly threatened by progressive soil degradation, mainly due to salinization, which currently affects about 66% of irrigated land around the lake [4].

Soil salinity is widely recognized as one of the most serious threats to the sustainability of irrigated systems in arid and semi-arid regions. According [5], more than 20% of irrigated land worldwide is affected by salinity, and this proportion is increasing because of climate change, capillary rise, high evaporation rates, and inappropriate irrigation practices. In the Senegal River Valley, several studies [6] have shown that salinization is due to inadequate drainage, to salt accumulation in deeper soil horizons, and to irregular and poor water management.

Around the Lake Guiers, the salinization is particularly severe. Studies [7] and [8] indicate that increasing pressure on water resources, climate variability, and the lack of efficient drainage systems have contributed to salt accumulation in irrigated soils. The soils in this area, which are mainly sandy to sandy-loam in texture, have low cation exchange capacity, limiting nutrient retention and making them highly vulnerable to salinity [8].

In this context, identifying sustainable and locally adapted solutions is essential for restoring the productivity of salt-affected land. Integrated soil reclamation approaches combining mechanized land preparation, organic amendments, judicious use of mineral inputs, and salt-tolerant rice varieties appear to be promising and durable options. Such strategies could improve the properties of saline soils while strengthening the resilience of rice production systems to environmental and climatic stresses.

1.1. Objectives of the Study

This study was to contribute to the reclamation and sustainable use of salt-affected rice fields in the Mbane area around the Lake Guiers.

Specifically, the study aimed to:

- Evaluate the effects of combining a salt-tolerant rice variety, compost application, phosphogypsum, and mechanized land preparation on soil salinity dynamics and rice productivity;
- Identify the most effective a best-adapted agronomic practices under saline conditions in order to sustainably improve rice production performance in the study area.

1.2. Research Hypotheses

This study was based on the following hypotheses:

- Integrated soil management practices, combining mechanized land preparation with the use of organo-mineral fertilizers, improve the physico-chemical properties of saline soils and increase the productivity of salt-affected rice fields.
- An optimal combination of agronomic practices adapted to the pedoclimatic conditions of the commune of Mbane that can maximize both rice production performance and the sustainability of cropping systems in saline environments.

2. Materials and Methods

2.1. Study Area

The experiment was conducted in the 2024 rainy season in Mbane, located in the Lake Guiers region of northern Senegal. The area is characterized by a semi-arid Sahelian climate with low and irregular rainfall, mainly concentrated between August and October. Annual temperatures vary widely, ranging from about 15˚C during the cool season to more than 40˚C during the hot season, thereby strongly influencing crop growth conditions.

The soils in the area are predominantly sandy to sandy-loam in texture, with varying levels of salinity depending on the plots. Rice field irrigation is supplied by water from the Lake Guiers, distributed through a gravity-fed canal network, which constitutes the main water source for rice production in the area.

2.2. Plant Material

The rice variety used in this study was ISRIZ 10, a salt-tolerant variety developed by the Senegalese Institute of Agricultural Research (ISRA). This variety is well adapted to irrigated systems and to environments affected by soil salinity. Under optimal growing conditions, ISRIZ 10 has a yield potential of up to 11 $t \cdot ha^{-1}$.

2.3. Experimental Design and Treatments

The experiment was set up using a randomized complete block design (RCBD) with three treatments and three replications.

The treatments were as follows:

- T0 (farmer's practice): DAP + urea (100 kg/ha DAP; 300 kg/ha urea);

- T1: T0 +1t/ha compost + 500 kg/ha phosphogypsum + mechanized land preparation (offset discing, puddling, and leveling);
- T2: T0 + 1t/ha compost + mechanized land preparation.

Each experimental plot measured 22 m × 17 m (374 m^2).

2.4. Soil Preparation and Crop Management

Mechanized land preparation was performed using a motorized tiller equipped with an offset disc harrow and a puddling attachment under flooded conditions. The operations included (Photo 1 and Photo 2):

1) Offset discing to break soil clods and uproot weeds;

2) Puddling to homogenize the soil and incorporate amendments;

3) Leveling to establish a uniform seedbed and ensure proper water distribution.

Rice seedlings were transplanted at a spacing of 20 cm × 20 cm after a 21-day nursery period.

Compost and phosphogypsum were applied during puddling to improve nutrient availability and soil structure. Urea was applied in two split doses: at tillering and at panicle initiation.

The compost used was obtained from the AGRINOVA product, derived from the composting-based valorization of agricultural residues, agro-industrial by-products, and livestock manure. It is produced by Elephant Vert, a company specializing in fertilizer production.

The composition of the compost was as follows: dry matter: 70%; organic matter: 30%; moisture content: 35% (±5%); C/N ratio: 12 - 15; N-P-K-Ca: 1-1-1-1. The compost was free from pathogenic germs, weed seeds, and heavy metals.

Table 1. Chemical composition of phosphogypsum produced in Senegal.

Components	CaO%	SO_3%	P_2O_5%	F%	FE_2O_3	Al_2O_3
Composition	32.0	18.0	1.7	1.20	Trace amounts	Trace amounts

2.5. Soil Sampling and Analysis

Soil samples were collected before trial establishment as composite samples from three sampling points selected along the diagonal in order to establish the baseline conditions and after harvest at two depths: 0 - 10 cm and 10 - 30 cm for each block.

- Soil pH was measured in a 1:5 suspension (10 g of air-dried fine soil in 50 mL of boiled and cooled distilled water) using a direct-reading pH meter;
- Electrical conductivity (EC 1:2.5) was measured by mixing 20 g of unground dry soil with 50 mL of distilled water, followed by direct reading after 2 hours of agitation on a rotary shaker;
- Soil carbon was determined using the modified Walkley-Black method;
- Total nitrogen was determined using the Kjeldahl method;
- Available phosphorus was determined using the Olsen P method, modified according to Dabin;

- Cation exchange capacity and exchangeable bases were determined by leaching the soil with an ammonium acetate solution;
- Exchangeable sodium percentage was calculated using the following formula: ESP = Na+/CEC × 100;
- Organic matter (OM %) was calculated using the following formula: organic carbon (%) × 1.72;
- The C/N ratio was calculated as the ratio of soil carbon to soil nitrogen.

2.6. Observations and Measurements of Agronomic Parameters

At maturity, three 1 m^2 yield quadrats were established in each plot. The mean value obtained from the three quadrats was considered to represent the yield per 1 m^2.

The number of panicles was determined by direct counting within the three yield quadrats, and the resulting mean was retained as the representative value per square meter.

The number of unfilled grains was assessed from a sample of 1000 grains, in which unfilled grains were counted using a CONTADOR grain counter.

Within each quadrat, plants were harvested and then sun-dried for 15 days. The grains were subsequently separated from the straw. The mean value obtained from the three quadrats was considered to represent the yield per 1 m^2, as shown in Photo 3, which illustrates the layout of the yield squares. Paddy yield was calculated by adjusting the values to the standard moisture content of 14%.

Weed infestation was estimated by visual assessment using a scale from 0 to 10, where a score of 10 corresponded to a completely weed-free plot and a score of 0 to a fully weed-infested plot.

Equipment and accessories used

Photo 1. Motorized tiller, or walking tractor, equipped with a disc plough. The accessories included an offset disc harrow for land preparation and a puddling attachment for soil leveling and puddling operations.

2.7. Statistical Analysis

Data were analyzed using R software (version 4.5.0). An analysis of variance (ANOVA) was performed to assess significant differences between treatments. When significant effects were detected, means were compared using Tukey's test at the 5% significance level. In addition, correlation analyses and Principal Component Analysis (PCA) were conducted to explore the relationships between agronomic variables and soil parameters.

Photo 2. Walking tractor operation with the puddling chain.

3. Results

3.1. Initial Soil Characteristics

The physicochemical properties of the soil collected from the experimental site before treatment application are presented in Table 1. Textural analysis showed that the soil was sandy in both depth intervals. Clay content was slightly higher in the deeper layer, whereas silt content was higher in the surface layer. Bulk density was slightly lower at depth than in layer, but values in both horizons remained within the normal range for sandy soils, indicating the texture generally favorable to for root development. Chemical analyses revealed a near-neutral pH (Table 2) in both layers. Electrical conductivity (EC), which exceeded 2000 $\mu S \cdot cm^{-1}$ at depth, indicated moderate salinity. The low organic carbon and organic matter contents in both layers pointed to poor organic status, while a C/N ratio below 8 suggested low biological activity and limited fertility. Among the exchangeable bases, calcium and potassium concentrations remained below recommended agronomic thresholds, whereas magnesium exceeded expected values. Sodium was absent in the surface layer but exceeded the suggested threshold at the 10 - 30 cm layer by about 40%, indicating marked sodium accumulation at depth; the exchangeable sodium percentage further confirmed soil solidity in this layer. The sandy texture was also consistent with the low cation exchange capacity (CEC) observed in both horizons, reflecting the inherently low cation retention capacity of porous sandy soils.

Table 2. Results of soil analyses before the implementation of the different practices.

Physico-chemical characteristics	Depths (cm)	
	0 - 10	10 - 30
Clay (%)	3	5.5
Silt (%)	2.5	1.25
Sand (%)	94.5	93.25
Bulk density (g/cm^3)	1.61	1.59

Continued

pH water (1/5)	6.54	6.92
EC (μs·cm^{-1}) (1/5)	1143	2590
C (%)	0.189	0.399
N (%)	0.031	0.058
C/N	6.043	6.899
OM (%)	0.326	0.686
Available P (ppm)	22.174	30.686
Na (meq/100g)	0	1.468
K (meq/100g)	0.043	0.576
Ca (meq/100g)	0.941	2.22
Mg (meq/100g)	0.552	1.17
CEC (meq/100g)	2.602	5.806
ESP (%)	0	25

3.2. Effects of Integrated Practices on Soil Chemical Properties

Post-harvest variations in soil physicochemical properties under the different treatments (T0, T1, and T2) are presented in **Table 3**. To assess treatment effects more accurately within the portion of the soil profile corresponding to the rice root zone, the analysis focused on the 0 - 10 cm and 10 - 30 cm layers.

Analysis of variance showed significant treatment effects on carbon (C), organic matter (OM), and cation exchange capacity (CEC) in the 0 - 10 cm layer. In the 10 - 30 cm layer, the only significant effect was observed for electrical conductivity (EC), indicating substantial variation between the initial condition and post-harvest status, as well as among treatments, with the highest mean value recorded under T0, the farmer's practice. Furthermore, the salinity observed after harvest, coinciding with the end of the rainy season, appears to have been influenced by rainfall through groundwater recharge processes that leached salts into deeper soil layers. An increase in pH toward slightly alkaline values was also observed after intervention, indicating a shift from an initially neutral soil condition to moderate alkalinity. This change appears to be related to the combined application of phosphogypsum, compost, DAP fertilizer, and urea, which altered the soil physicochemical balance, particularly through effects on exchangeable cation dynamics and organic matter mineralization.

Indeed, the results showed substantial variability in exchangeable cations between the baseline condition and the post-intervention (**Photo 4**) state. Furthermore, soil electrical conductivity decreased significantly under the integrated treatments compared to the farmer's practice, indicating a reduction in salinity in the treated plots. Exchangeable sodium concentrations in the 10 - 30 cm layer also decreased markedly, with reductions exceeding 92% compared to initial conditions. This substantial decline demonstrates the effectiveness of the treatments in reducing soil solidity.

Under treatments T1 and T2, sodium content changed in both the surface and subsurface layers relative to the initial condition. In the 10 - 30 cm layer, sodium concentration declined markedly, with a reduction of more than 92% under T1 and an approximately fourfold decrease under T2. For the other exchangeable cations, namely magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^{+}), lower concentrations were generally observed at depth across all treatments. In contrast, available phosphorus increased, particularly under T0 and T2, whereas nitrogen (N) followed the same general trend as the other exchangeable cations. The C/N ratio, which reflects the degree of organic matter transformation, indicated rapid decomposition and accelerated nitrogen release in both the surface and deeper layers. Among the different options tested, treatment T1, combining compost and phosphogypsum application, proved to be the most effective, showing a pronounced reduction in sodium content at depth.

Photo 3. Illustration of aborted grains caused by salt stress.

Photo 4. Establishment of yield quadrats and measurement of growth parameters.

Table 3. Effect of different practices on post-harvest soil chemistry.

Site	Depths	Treatments	Ph	CE	C	N	MO	C/N	P ass	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC
			eau (1/5)	(µs·cm^{-1}) (1/5)	(%)				ppm	meq/100g				
Mbane	0 - 10	T0	7.60	89.66	0.47^{a}	0.065	0.80^{a}	6.52	14.73	0.161	0.116	1.45	0.912	4.316 a
		T1	7.56	78.70	0.40^{ab}	0.053	0.70^{ab}	6.83	18.98	0.140	0.078	1.28	0.712	4.019 b
		T2	7.62	78.93	0.29^{b}	0.042	0.50^{b}	6.28	14.60	0.004	0.092	1.02	0.575	3.058 b
		Mean	**7.59**	**82.43**	**0.39**	**0.053**	**0.67**	**6.54**	**16.11**	**0.102**	**0.095**	**1.25**	**0.733**	**3.798**
		Coef of variation	**2.13**	**24.34**	**16.26**	**16.11**	**16.30**	**7.26**	**17.95**	**144.76**	**75.37**	**23.70**	**19.46**	**12.41**
		Probability	**0.904**	**0.761**	***0.0519****	**0.0808**	***0.0527****	**0.444**	**0.224**	**0.444**	**0.814**	**0.321**	**0.1035**	***0.0552****
	10 - 30	T0	7.63	57.46^{a}	0.30	0.044	0.52	6.58	14.80	0.240	0.094	1.081	0.64	3.56
		T1	7.71	44.36^{b}	0.29	0.040	0.50	6.78	17.47	0.075	0.067	1.030	0.58	3.77
		T2	7.60	53.7^{ab}	0.30	0.041	0.52	6.28	14.67	0.00	0.062	0.92	0.53	3.00
		Mean	**7.64**	**51.86**	**0.992**	**0.041**	**0.51**	**6.55**	**15.64**	**0.105**	**0.074**	**1.011**	**0.586**	**3.44**
		Coef of variation	**1.89**	**9.70**	**45.32**	**43.3**	**45.38**	**6.65**	**24.29**	**202.06**	**51.41**	**33.67**	**32.92**	**21.34**
		Probability	**0.668**	***0.053****	**0.992**	**0.960**	**0.993**	**0.444**	**0.630**	**0.444**	**0.587**	**0.849**	**0.786**	**0.483**

3.3. Effects on Weed Infestation and Seedbed Quality

Mechanized land preparation significantly ($P < 0.05$) contributed to reducing weed pressure in the experimental plots (Figure 1). Compared to the control treatment (T0), the level of weed infestation decreased by approximately 15% under treatment T1 and by 5% under treatment T2, demonstrating the effectiveness of mechanical operations in weed control. Disc harrowing and puddling operations also improved soil physical conditions. These practices promoted better soil loosening, greater seedbed uniformity, and improved water distribution within the plots, which in turn contributed to better rice growth and development under saline conditions.

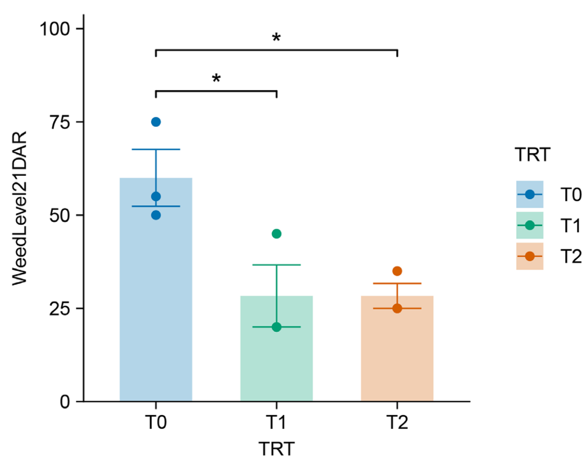

Figure 1. Influence of tillage on weed infestation levels at 21 days across the different plots (treatments).

3.4. Effects on Rice Yield Components

3.4.1. Formation of Empty Grains

Plots managed under the farmer's practice (T0) recorded a higher number of empty grains compared to the integrated treatments T1 and T2, as shown in **Figure 2**. This situation reflects the negative effect of salinity on the physiological processes involved in grain formation and filling in rice (as shown in **Photo 3**). Indeed, the high occurrence of empty grains observed in the T0 plots may partly reflect the effects of salinity on the grain-filling process in rice, leading to grain abortion. Conversely, treatments incorporating compost and phosphogypsum appear to have helped mitigate the impact of salinity on this grain-filling process.

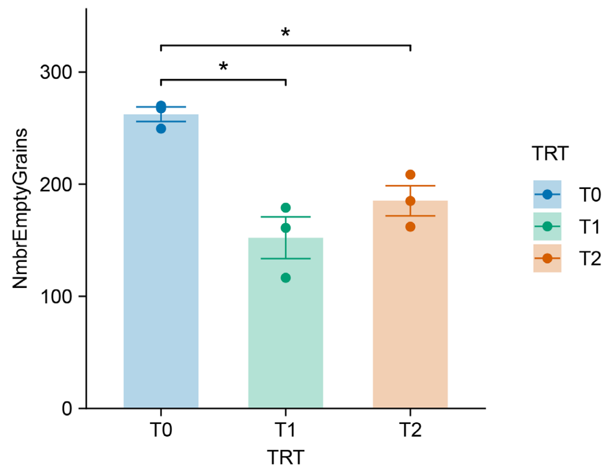

Figure 2. Effect of different practices on the number of empty grains (m^2).

3.4.2. Number of Panicles

Integrated treatments led to a significant ($P < 0.05$) increase in the number of panicles compared to the farmer's practice (T0) (**Figure 3**). Treatments T1 and T2 recorded increases of 50% and 45%, respectively, reflecting a notable improvement in rice plant growth and development even under saline conditions.

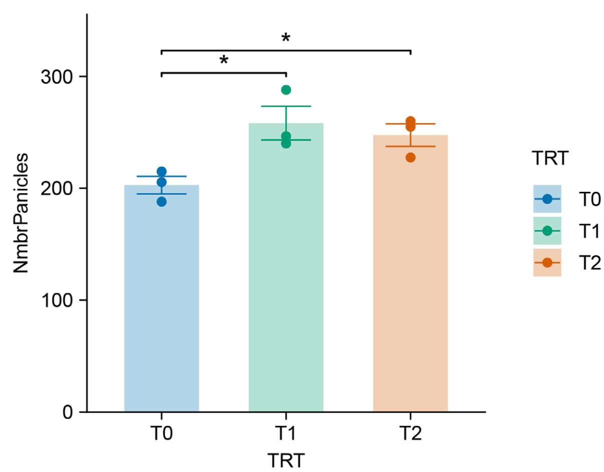

Figure 3. Effect of different practices on the number of panicles (m^2).

3.4.3. Grain Yield

Figure 4 highlights grain yield according to the different treatments. Rice grain yield was significantly ($P < 0.05$) improved under integrated practices compared with the farmer's practice. Consistent with the results observed for grain filling and panicle number, grain yield followed the same trend, with markedly higher values under treatments T1 and T2. The yield recorded under the farmer's practice (T0) was 15% lower than that obtained under T1 and T2, highlighting the effectiveness of improved rice management practices on salt-affected soils. This integrated approach appears to contribute to productivity enhancement by strengthening the productive capacity of the soil and optimizing its management.

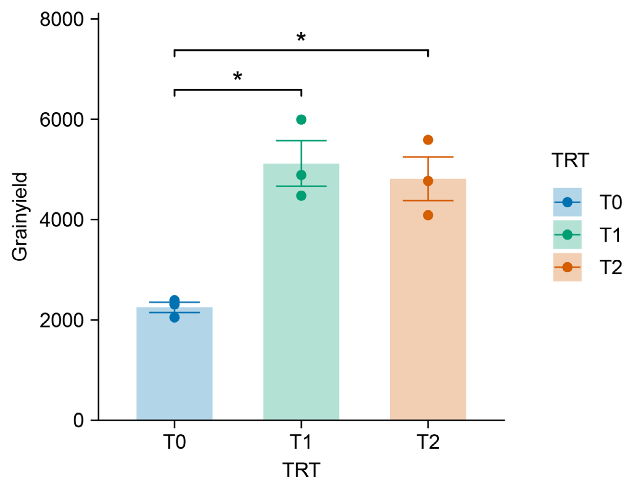

Figure 4. Effect of different practices on grain yield ($kg \cdot ha^{-1}$).

3.5. Correlation Analysis and Principal Component Analysis

Figure 5 shows the biplot obtained from the Principal Component Analysis (PCA) performed on rice growth and yield variables together with post-harvest soil chemical parameters measured in the experimental plot. This graphical representation enables simultaneous visualization of the relationships among quantitative variables and treatments (T0 to T2). The analysis was projected onto the first two principal components: Dimension 1 (horizontal axis) explained 64.4% of the total variance, whereas Dimension 2 (vertical axis) accounted for 35.6%, resulting in a cumulative explanation of 100% of the initial variability.

This very high proportion of explained variance indicates that the factorial plane provides an accurate representation of the overall structure of the dataset. The biplot therefore reveals two agronomically meaningful dimensions: Dimension 1 is primarily associated with agronomic performance, including yield and its components, whereas Dimension 2 is more closely related to soil fertility and quality, particularly organic matter, cation exchange capacity (CEC), and exchangeable bases.

Dimension 1 (Dim1), which captured the largest share of the total variance, grouped variables directly related to crop productivity, including grain yield, number of filled grains, filled grain weight, panicle number, panicle length, and panicle weight. By contrast, Dimension 2 (Dim2), which contributed less to total variance, was mainly associated with soil-related variables such as organic matter, cation exchange capacity, magnesium, calcium, and weed infestation at 21 days after establishment. The orthogonal orientation of these variables relative to the yield-related traits suggests a partial independence between productive performance and improvements in soil quality.

The distribution of treatments on the factorial plane showed a clear separation among management practices. Treatment T0, located in the positive quadrant of Dim2, was associated with high electrical conductivity (EC) and with a greater number and weight of empty grains. In contrast, T1 was positioned opposite T0 and showed a strong association with key yield-related variables, particularly filled grain weight, thousand-grain weight, and panicle number. This treatment, that is comprised of mechanized tillage, compost application, and phosphogypsum amendment, appeared to provide both enhanced productivity and progressive improvement in soil fertility. These results suggest that the combined application of compost and phosphogypsum was particularly favorable to rice growth and development, with a marked positive effect on grain yield.

Treatment T2, located in the positive quadrant of both Dim1 and Dim2, was strongly associated with several yield components, notably the number of filled grains, panicle weight, and panicle length. However, it was more clearly opposed to soil fertility indicators, particularly organic matter, CEC, and exchangeable bases. Although T2 differed markedly from T0, it remained relatively close to T1 because both treatments shared similar crop management practices, with the main distinction being the absence of phosphogypsum application in T2.

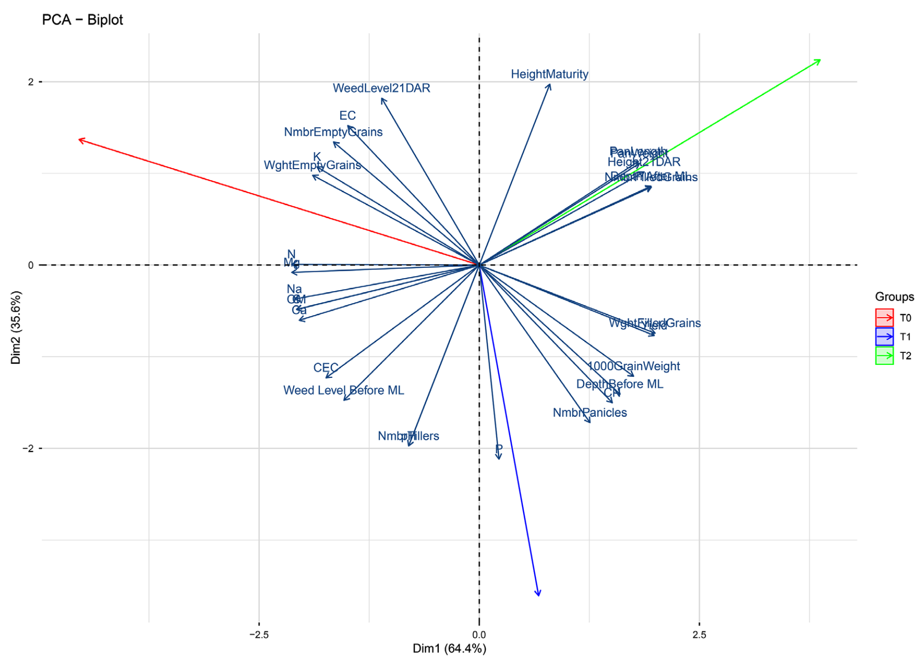

Figure 5. Principal Component Analysis (PCA) biplot of the measured variables.

4. Discussion

This study showed that integrated soil management practices significantly improved the physicochemical properties of saline soils and enhanced rice productivity under irrigated conditions. Overall, the findings confirm the relevance of combining mechanized land preparation, organic amendments, and mineral inputs for the sustainable rehabilitation of salt-affected land.

It is important to note that this study, conducted during the rainy season, once again highlighted the dissolution and downward leaching of soluble salts by rainwater, as reported [9]. This process partly explains the electrical conductivity values measured after harvest relative to the initial baseline conditions.

The strong reduction in sodium concentrations observed under treatments T1 and T2 indicates that compost and phosphogypsum contributed to improving soil structure and reducing solidity. This reduction, exceeding 92% in the 10–30 cm layer, can be explained by well-documented physicochemical mechanisms. According [10]; calcium contained in phosphogypsum replaces sodium on the exchange complex, promoting clay flocculation, improving soil structure, and reducing electrical conductivity.

The application of compost also played a key role in improving soil fertility. [11] and [12], show that organic matter increases cation exchange capacity, enhances water retention, and stimulates microbial activity, thereby improving nutrient availability. In the sandy soils of Mbane, these effects are particularly important for stabilizing soil aggregates and limiting salt mobility.

Mechanized land preparation also had a marked effect on weed suppression and seedbed quality. Offset discing and puddling improved soil loosening, facilitated amendment incorporation, and enhanced water distribution across the plots. These findings are consistent with those [13] and [14], who reported that puddling reduces infiltration losses, limits weed growth, and promotes deeper root development. The position of T2 on the factorial plane further highlights the contribution of mechanized tillage. Its strong association with panicle traits and filled grain number suggests that, even with organic matter input alone, tillage operations improved seedbed conditions and root exploration, thereby enhancing water uptake and grain filling. A similar pattern was observed for T1, but in this treatment phosphogypsum emerged as the key differentiating factor. Taken together, these results indicate that the combination of mechanized tillage (offset discing, puddling, and leveling), organic amendment (compost), inorganic amendment (phosphogypsum), and recommended mineral fertilization provides the most effective strategy for the rehabilitation and productive use of salt-affected rice fields in Mbane.

The agronomic performance observed under treatment T1, particularly the increase in the number of panicles, the reduction in sterile grains, and the improvement in yield, confirms the synergistic effect of organic and mineral amendments. The salt-tolerant rice variety ISRIZ 10 also contributed to these results. [15] highlighted that salt tolerance in rice depends on the plant's ability to maintain a favorable K^+/Na^+ ratio, which is facilitated by improved soil structure and reduced solidity.

Principal Component Analysis (PCA) clearly differentiated the treatments according to their effects on soil fertility and agronomic performance. Treatment T1 emerged as the most effective option, in agreement [16], who emphasized the usefulness of PCA for analyzing complex systems and identifying the most influential variables. In the present study, the combined use of compost and phosphogypsum proved beneficial for rice growth and development, with a significant positive effect on grain yield. The higher mean grain yield recorded under T1, together with its strong association with both yield-related traits and soil fertility indicators, contrasts with the patterns observed for T0 and T2 and highlights the effectiveness of the synergistic interaction between organic matter input and phosphogypsum. This synergy likely improved soil structure, increased calcium availability on the exchange complex, and reduced ionic toxicity. These findings are consistent with the results reported by [17] and [18].

Finally, from a sustainability perspective, the results of this study are consistent with the findings of [19] and [20], who emphasize that ecological intensification based on the combined use of organic amendments, mineral inputs, and improved soil management practices represents a viable pathway for enhancing agricultural productivity while preserving natural resources.

5. Conclusions

This study demonstrated that integrated practices combining a salt-tolerant rice variety, mechanized land preparation, compost application, and phosphogypsum constitute an effective strategy for rehabilitating salt-affected rice fields around Lake Guiers.

The proposed approach significantly improved soil fertility, reduced sodium accumulation, limited weed infestation, and increased rice yield. These improvements reflect the synergistic effects of organic and mineral amendments combined with mechanical soil preparation in restoring the physical and chemical properties of saline soils. Among the treatments evaluated, treatment T1 stood out with the best agronomic performance as well as the most pronounced effects on soil rehabilitation.

Overall, the findings confirm that integrated approaches provide a sustainable and resilient pathway for restoring the productivity of degraded rice-growing land and improving the sustainability of irrigated production systems in the Senegal River Valley. They also show that integrated management of saline soils is a relevant option for the sustainable intensification of rice production and for strengthening food security in Senegal and other West African countries affected by salinity.

The dissemination of these practices is therefore essential to promote their adoption. Farmer field schools could provide an effective framework for training and demonstration under real farming conditions. In addition, improving farmers' access to mechanization services and to both organic and mineral amendments will be critical for facilitating implementation of the recommended practices.

Integrating saline soil rehabilitation strategies into national agricultural policies and programs would represent a major lever for promoting large-scale adoption while supporting the sustainability of rice production systems and strengthening farm resilience to environmental and climatic challenges.

Further research is needed to assess the long-term effects of this integrated approach on the sustainability of rice production systems. It will also be important to evaluate its economic profitability and cost–benefit ratio for farmers in order to determine its feasibility at scale.

A better understanding of the specific contribution of mechanized tillage under different salinity conditions also remains essential. Such work would help refine technical recommendations and adapt management practices to the diversity of agroecological conditions found in rice-growing areas.

Posthumously

We would like to pay tribute to our mentor and colleague, Dr Ramatoulaye Ndiaye, an outstanding scientist with a deep passion for soil science, who passed away far too early. We respectfully honor her memory and her valuable contribution to the scientific community. This article is dedicated to here. May her soul rest in peace.

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Authors contributions

Conceptualization, Babacar KANE and Papa Madiama DIOP; methodology, Babacar KANE and Papa Madiama DIOP; software, Babacar KANE; validation, Moussa DIENG, Mame Farma N'DIAYE; formal analysis, Babacar KANE; investigation, Babacar KANE; resources, Mame Farma N'DIAYE; data curation, Babacar KANE; writing—original draft preparation, Babacar KANE, Papa Madiama DIOP; writing—review and editing, Babacar KANE, Papa Madiama DIOP, Moussa Dieng, Mame Farma N'DIAYE; visualization, Moussa DIENG, Mame Farma N'DIAYE; supervision, Mame Farma N'DIAYE. project administration, Mame Farma N'DIAYE; funding acquisition, Mame Farma N'DIAYE.

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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