Journal of Agricultural Chemistry and Environment, 2025, 14(2), 202-216
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Phosphogypsum and Organic Matter: Sustainable Solution for the Rehabilitation of Saline Lands in the Saloum Delta, Senegal

Boubacar Sagna[1*], Adama Ndiaye[2], Ibrahima Thiam[1], Kéba Thiam[1], Aby Kane Diallo Sow[1]

[1]Wetlands International West Africa and Gulf of Guinea, Dakar, Senegal
[2]National Institute of Pedology (INP), Kaolack, Senegal
Email: *bsagna@wetlands-africa.org, boubacarsagna22@gmail.com

How to cite this paper: Sagna, B., Ndiaye, A., Thiam, I., Thiam, K. and Sow, A.K.D. (2025) Phosphogypsum and Organic Matter: Sustainable Solution for the Rehabilitation of Saline Lands in the Saloum Delta, Senegal. *Journal of Agricultural Chemistry and Environment*, **14**, 202-216.
https://doi.org/10.4236/jacen.2025.142014

Received: February 25, 2025
Accepted: April 15, 2025
Published: April 18, 2025

Abstract

Constituting the northern margin of all the "*rivers of the South*" which extend continuously on the Atlantic coast of West Africa, the Saloum Delta is full of important economic, cultural and ecotourist potentialities. Despite its importance, the area faces a variety of threats from a combination of natural and anthropogenic factors. The most important being the worrying phenomenon of salinization of agricultural land, which is seriously affecting the livelihoods of communities in the area. Faced with this situation, a technique for recovering salted rice land based on the use of phosphogypsum and organic matter such as cow dung and/or groundnut shell and poultry manure was tested at the level of abandoned production lands. This is composed of different stages such as the identification and characterization of the soils of the sites, the input supply, the ploughing and the monitoring of the evolution of the physico-chemical and agronomic parameters. The analysis of the results of the monitoring shows a high degree of effectiveness of the system for the recovery of rice-growing lands. Indeed, the electrical conductivity which is the main physico-chemical parameter followed has seen a very positive evolution. The seeded soils have been upgraded from class III to V of saline soils, to extremely saline, with electrical conductivity greater than 2000 µS/cm before the installation of the device in class I of unsaline soils with values well below 500 µS/cm. This decrease in salinity has generated very interesting yields, the average of which is estimated at 6.17 t/ha paddy rice for the variety Sahel 108. This, in relation to the 58 ha planted in the intervention area leads us to estimate the total production at 357.58 t. Given these spectacular results of the scheme on salt land abandoned for several decades, the need to develop a strategy for popularizing technology and building the capacity of actors in order to recover abandoned rice fields.

Keywords

Phosphogypsum, Livestock Manure, Saloum Delta, Wetlands International, Salinization

1. Introduction

The Saloum Delta is the northern margin of all the "southern rivers" that extend continuously along the Atlantic coast of West Africa. This delta is composed of many islands of varying sizes, shapes and altitudes separated by sea inlets or bolongs [1]. Designated as a UNESCO biosphere reserve since 1980 and as a World Heritage site since 2011. It is mainly composed of tropical mangrove ecosystems, rich in biodiversity which provide livelihoods for more than 100,000 people [2]. These ecosystems are currently under pressure due to climate change and the unsustainable use of mangrove forests by the population [3]. More than 50% of the population in the area lives in poverty, which explains why 80% of energy needs are covered by biomass. This anthropogenic pressure is marked by excessive cutting for wood supply for cooking, processing of fish products, fencing, habitat construction, extension of cultivation areas, etc. [4] and [5]. This combination of natural and anthropogenic factors has caused negative impacts threatening local development in the region. These include sea advance, coastal erosion, loss of beaches, desertification, reduction of mangroves and other spawning grounds, loss of arable land and other grazing lands, salinization of water and soil, Alteration of the water table, reduction or insufficiency of water availability for irrigation and drinking and other productive activities. The phenomenon of salinization of land has taken a very worrying pace in recent years, causing a strong conversion of agricultural production areas, especially rice, into tanneries and other bare spaces, salted or acidic, which are not suitable for any economic activity and thus aggravate poverty, rural exodus and illegal emigration. Indeed, the Saloum estuary is the area most affected by this phenomenon, where more than 50% of cultivated land is threatened [6] and [7].

Aware of the seriousness of this phenomenon in the area, Wetlands International West Africa Coast and Gulf of Guinea (WIACO), whose mission is to conserve and restore wetlands for nature and human beings, considered it necessary to undertake actions for the recovery of degraded land based on the use of phosphogypsum and organic amendment with technical support from the National Institute of Pedology (INP). In order to evaluate the relevance and effectiveness of this experimental system for the recovery of saline lands, monitoring of the evolution of soil and agronomic parameters was carried out. This article presents the main results obtained.

2. Methodological Approach

2.1. Study Area Presentation

2.1.1. Biosphere Reserve of the Saloum Delta

Composed of a variety of islands separated by inlets, the Saloum Delta Biosphere Reserve is located in west-central Senegal between the city of Joal-Fadiouth to the north, the Republic of Gambia to the south and the Atlantic Ocean to the west. Formed by the confluence of the Sine and Saloum rivers, it is a rich natural ecosystem with an area of 232,500 hectares, including 58,300 hectares of mangroves [8] and [9]. It includes (11) classified forests, four (04) marine protected areas (Joal-Fadiouth, Sangomar, Gandoul and Bamboung) and one (01) community nature reserve (Palmarin). **Figure 1** shows a presentation of the Saloum Delta Biosphere Reserve.

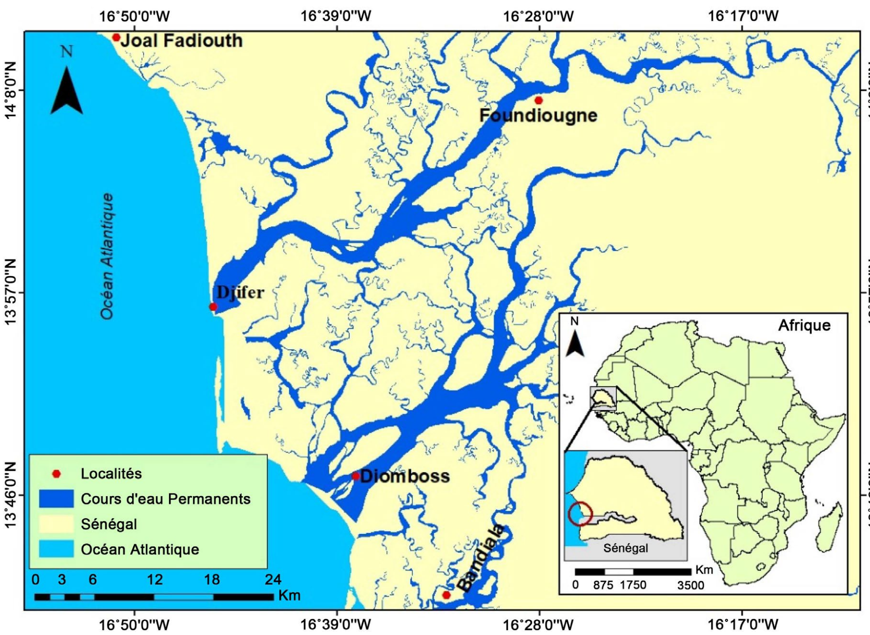


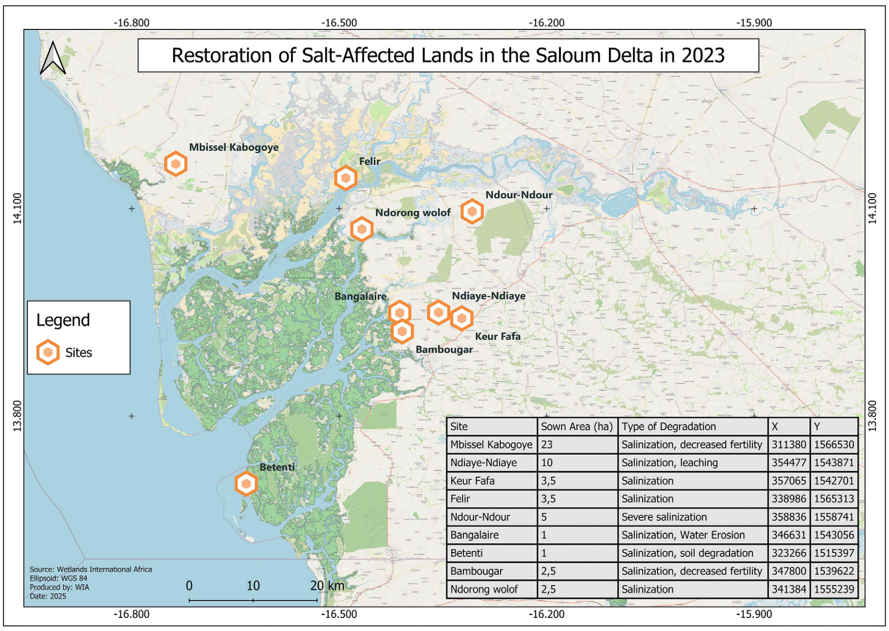
Figure 1. Presentation of the saloum delta biosphere reserve.

The Saloum Delta is a ria that operates in an "inverse estuary", meaning that it increases rather than decreases by going up from the sea upstream. This hydrodynamic phenomenon is due to the large predominance of evaporation on very small and limited freshwater supplies during the rainy season, which leads to a reverse flow, with seawater replacing the volumes lost by evaporation, allowing salt water to enter deeper and deeper into the land, due in part to slow flow of both rivers [10].

Mangrove riparian communities are highly dependent on these ecosystems, both for their environment (protection from swells and the effects of climate change) and for their livelihoods (fishing, seafood harvesting, beekeeping, etc.) The Saloum Delta has been suffering for several years from the adverse effects of climate change and unsustainable practices. This has resulted in intense coastal erosion at some parts of the Delta's coastline and an increase in water salinization, which reaches 120 at the end of the dry season in the extreme upstream part of the Saloum 2. Furthermore, poor practices such as the unruly occupation of the coastline, deforestation, excessive cutting of mangrove forests for smoking and baking activities, overfishing and poor waste management, especially plastic, they are responsible for the degradation of ecosystems.

2.1.2. Presentation of Restoration Sites

As part of enhancing the livelihoods of local communities in the Saloum Delta, which are severely affected by the concerning phenomenon of land salinization, a campaign to recover abandoned rice valleys has been initiated across nine (9) villages in four communes. These include the large valley of Kabongoye-Mbissel in the commune of Fimela (23 ha), Ndiaye-Ndiaye (10 ha), Bangalaire (1 ha), Keur Fafa (3.5 ha), Ndorong Wolof (2.5 ha), and Bambougar (2.5 ha) in the commune of Diossong; Félir (3.5 ha) in the commune of Djirnda; Boli-Ndour-ndour (5 ha) in the commune of Djilor; and Bétenti (1 ha) in the commune of Toubacouta. The spatial distribution of these sites is detailed in the following **Figure 2**.



Site	Sown Area (ha)	Type of Degradation	X	Y
Mbissel Kabogoye	23	Salinization, decreased fertility	311380	1566530
Ndiaye-Ndiaye	10	Salinization, leaching	354477	1543871
Keur Fafa	3,5	Salinization	357065	1542701
Felir	3,5	Salinization	338986	1565313
Ndour-Ndour	5	Severe salinization	358836	1558741
Bangalaire	1	Salinization, Water Erosion	346631	1543056
Betenti	1	Salinization, soil degradation	323266	1515397
Bambougar	2,5	Salinization, decreased fertility	347800	1539622
Ndorong wolof	2,5	Salinization	341384	1555239

Figure 2. Map of the restoration sites (WIACO, 2023).

2.2. Land Recovery Technique

The strategy used for the recovery of salty land is mainly based on the use of phosphogypsum, organic matter (manure and/or groundnut shells, poultry dung) and the rice variety Sahel 108. From a practice point of vies, the activity is structured around the following main tasks:

- **Identification of Sites and Beneficiaries:** This involves meeting with affected producers to identify abandoned rice fields they wish to restore for community benefit. Collaboration modalities will also be defined during these meetings.

- **Characterization of the identified valleys:** At this stage, soil samples were taken from the identified valleys and submitted to laboratory analysis to determine soil parameters such as pH, electrical conductivity (EC) or salinity, organic matter (OM), nitrogen (N), C/N ratio and phosphorus (P), etc. These analyses are very important in the process because they allow us to define a reference situation by determining the quantity of calcium and organo-mineral (phosphogypsum and organic matter) required. During the harvest, other samples will be taken and analyzed to see the evolution of parameters and to evaluate the effectiveness of the device.
- **Implementation of the Land Recovery System:** This involves carrying out agricultural **operations** such as plowing and applying inputs like phosphogypsum, peanut shells, and/or cow dung, as well as seeding rice.

Plowing: Tillage is a method of turning the soil to bury plant debris and fertilizer, expose the deep part of the soil to the sun and facilitate gas exchanges between the soil and the atmosphere. It is often done with a tractor or trolley. As part of this scheme, we have carried out a tri-cross ploughing; first a cross plough before spreading the inputs at a depth of 15 cm then a third light ploughing to bury them. However, if there is not a large quantity of herbs, we were able to do a cross plough; Before and after application of inputs.

Phosphogypsum: Phosphogypsum is a by-product of synthesizing fluorapatite and sulfuric acid. Its composition varies significantly depending on the natural phosphates from which it is derived. It mainly serves as a source of calcium (CaO) and sulfur (S). It is particularly effective in reducing soil salinity due to its desalination properties. The application of phosphogypsum (Figure 3) provides the soil with sufficient calcium sulfate to flocculate clay, improving its workability. Its addition to saline lands allows the calcium it contains to gradually replace sodium in the exchange complex, thereby reducing soil salinity in the presence of water. As a source of calcium and sulfur, phosphogypsum can logically be considered a product with some fertilizing value, improving soil structure and facilitating water infiltration.

Figure 3. Application of phosphogypsum.

Organic Matter: When used appropriately, manures help maintain fertility and enrich the soil by providing nitrogen, carbon, phosphorus, magnesium, and calcium, increasing the availability of nutrients, improving soil structure (aggregate formation), biological activity, and water retention capacity. Cow manure is a mixture of cow dung and bedding straw. As large herbivores, cattle contribute significant amounts of humus to the soil, which is essential for healthy plant growth. It strengthens light soils, improves soil fertility, enhances crop quality, and boosts yields. However, it is not advisable to use fresh cow manure, as it can harm human health and plant growth; the decomposition of fresh cow manure generates high-temperature fermentation (over 55˚C) that can burn roots and plants. For this reason, it is recommended to wait at least one year before applying cow manure as shown in Figure 4. This type of organic matter is used in this experimental phase because of its availability in the area, to facilitate the appropriation of the technique by the communities.

Figure 4. Application of organic matter.

Plant Material: The Sahel 108 variety selected is suitable for winter cultivation (early and late sowing, 110 days and 125 days, respectively); it has good grain quality (thin and long, mutique), a potential yield of 10 tons per hectare, and is favored for its taste and culinary qualities by homemakers. This variety was chosen for the trial because it is the most commonly used in the delta and is notably sensitive yet tolerant to salinity. Figure 5 below shows the rice application system.

Figure 5. Application of sahel 108 rice.

2.3. Monitoring the Land Recovery System

The monitoring and evaluation of the experimental land recovery system focused on several soil and agronomic parameters.

Soil Parameters: Composite soil samples (from the surface and 20 cm depth) were collected at the study sites for analysis. A total of 89 sampling points were taken in the managed area and 10 in the unmanaged area to serve as controls. The selection of points was done randomly and stratified, ensuring they were at least 20 meters from the edge to minimize border effects. The collected soil samples (**Figure 6**) allowed for the determination of nutrient content, soil structure, soil texture, and soil salinity and acidity, among other factors.

Figure 6. Soil sampling.

Agronomic Parameters: Regarding agronomic parameters, 10 yield plots of 1 m^2 each were established in the managed area. Within these plots, organic matter samples were collected (**Figure 7**) to define a set of agronomic parameters, including production yield, number of grains per panicle, mass of 1000 grains, average height of ears, and average tillering of the rice. These biological parameters, compared to those of the variety grown under normal conditions, allowed for the assessment of the system's effectiveness. To minimize border effects, the yield plots were also placed at a minimum distance of 20 meters from the edge.

Figure 7. Agronomic parameters monitoring.

Semi-Structured Interviews: In addition to the collected samples, producers' opinions on the system were gathered through a mixed focus group of producers and five individual interviews. These exercises allowed beneficiaries to express their views on the system's effectiveness. They also provided insights into current needs, which will serve as a foundation for developing a future valley management plan.

3. Results and Discussion

3.1. Results

3.1.1. Technique for Applying Inputs for Recovering Saline Lands

The application of phosphogypsum and manure must be tailored to the soil characteristics and cultivation objectives. Phosphogypsum can be spread uniformly over the soil surface or incorporated using cross or triple plowing. Manure can be applied on the surface or buried to facilitate its incorporation into the soil. Ideally, a cross plow should be done first to bury straw and weeds, whose decomposition also enhances soil fertility. Following this, inputs such as phosphogypsum, rice seeds, manure, and/or peanut shells should be applied before performing a final light plowing. Besides cow dung and peanut shells, other types of organic materials such as poultry litter and goat or sheep droppings can be used with similar effects. The application rate should be adjusted based on the specific soil characteristics and crops. In the Saloum Delta, site characterization for rice production has established a standard dosage that can be followed in the absence of physical-chemical soil analysis. This is set at 0.5 tons/ha for phosphogypsum and 2 tons/ha for organic matter, with the type and proportions depending on availability.

3.1.2. Relevance of the Saline Land Recovery System

The support provided to producers is unanimously appreciated. In fact, 100% of producers surveyed in the perception study affirm that the system based on the application of phosphogypsum and organic matter, such as manure and/or peanut shells, is very profitable. It has given a second life to lands abandoned due to salinity, resulting in very satisfactory outcomes. These are primarily marked by a significant reduction in salinity, leading to highly favorable yields. The evolution of salinity before and after the intervention, evaluated through electrical conductivity, is represented in the following Figure 8.

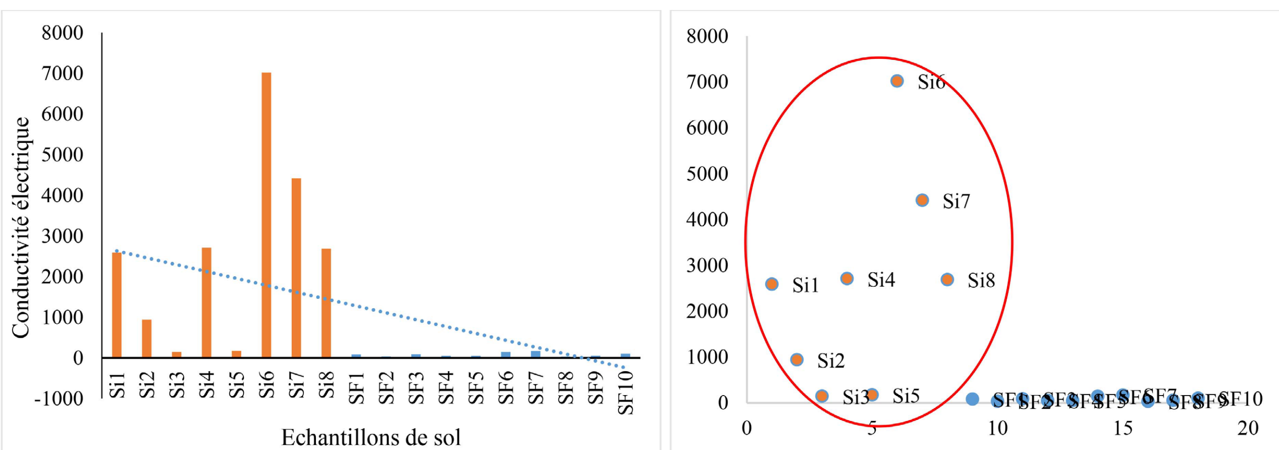


Figure 8. Evolution of soil electrical conductivity in the managed valley of Mbissel (Before & After).

The analysis of the above figures indicates a significant decrease in electrical conductivity after the implementation of the land recovery system. The electrical conductivity of soils determines their level of salinity. Before the system was established, this variable had very high values typically ranging from 1000 to 7000 µS/cm. In fact, most of the rice-growing lands in the Saloum Delta fall between class III and class V, which does not support crop development in the area. Productivity of most rice crops begins to be negatively affected at levels starting from 1000 µS/cm. The following **Table 1** provides information on the classification of soils and the behavior of rice crops based on variations in electrical conductivity.

Table 1. Variation of crop yields based on electrical conductivity.

Soil class	EC at 25˚C (µS/cm)	Soil quality	Effect on yield
Class I	0 - 500	Non-saline	Negligible effect
Class II	500 - 1000	Slightly saline	Decreased yield for varieties sensitive to salinity
Class III	1000 - 2000	Saline	Decreased yields for most varieties
Class IV	2000 - 4000	Very saline	Only a few resistant varieties can achieve satisfactory yields
Class V	4000 and above	Extremely saline	Only very resistant varieties can survive and produce a passable yield

As observed in **Figure 3** and **Figure 4**, the land recovery system implemented has successfully brought soils previously classified between Class III and Class V back to Class I, indicating non-saline soils. In addition to electrical conductivity, other soil parameters such as pH and soil fertility have shown very positive changes. Indeed, the soils were slightly acidic, with pH levels around 6 or lower across all sites, and the C/N ratio was very low due to minimal or absent mineralization of organic matter before the system was implemented. By the end of the agricultural season, acidity had significantly decreased, resulting in nearly neutral pH levels. There was also a substantial increase in soil fertility, reflected by a significant rise in the C/N ratio. These results are partly confirmed by those from the agronomic monitoring summarized in the following **Table 2**.

Table 2. Summary of agronomic monitoring results.

Parameter	Unit	Value	Assessment
Average tillering	Tillers/plant	3	Good
Number of rice plants per m^2	Plants/m^2	46	
Average height	cm	93.4	Good
Number of branches per panicle	Branches/panicle	11	Good
Average length of panicles	cm	22.6	Good
Average weight of grains per panicle	g	4.1	Good

Continued

Average number of grains per panicle	Grains/panicle	151	Good
Weight of 1000 grains	g	23	Good
Average yield	t/ha	6.17	Satisfactory
Quantity of rice produced in the cultivated area	t	357.58	Satisfactory

- **Average Tillering**

This refers to the formation of tillers located at the same level of the stem, at the base of the plant, creating a tuft characteristic of grasses. The number of tillers per plant is closely related to the spacing observed during sowing. In the managed valleys, the average tillering is estimated at 3 tillers per plant, demonstrating adherence to proper spacing during sowing, which allows for good vegetative development of the crops.

- **Average Height**

Average height is an excellent indicator of the vegetative development of rice. The height of the tillers at the managed sites ranges from 72.32 to 114.48 cm, with an average of 93.4 cm, slightly above the average listed for the Sahel 108 variety used, estimated at 90 cm. This robust growth is linked to the ample water supply in certain valleys during a favorable period.

- **Average Number of Grains per Panicle**

The number of grains per panicle is significant, varying between 101 and 201 grains/panicle, with an average of 151 grains/panicle. This relatively high value has contributed to satisfactory productivity. Figure 9 below shows some of the rice panicles produced.

Figure 9. Rice panicles produced.

- **Weight of 1000 Grains**

This variable provides insights into the quality of the production and is heavily influenced by the quality of the grains obtained. In the managed valleys, 1000 grains of produced rice weigh on average 23 g, indicating very good quality, even though this value is slightly below the potential of the Sahel 108 variety, estimated at 24 g.

- **Average Yield and Production**

The yield plots established in the managed areas allowed for an estimation of the average yield at 6.17 t/ha. This value may seem low compared to the potential of Sahel 108, estimated at 10 t/ha. However, the yields for this variety vary between 6 and 7 t/ha in the Senegal River valley. It should be noted that producers reported a significant presence of weeds, which slightly impacted production, highlighting the need to improve the tillage system to reduce weed growth.

All these factors collectively indicate that the yields obtained are very satisfactory. Moreover, all producers surveyed during the last monitoring mission confirmed that with the addition of phosphogypsum and dried cow manure and/or peanut shells, the yields are very good. This has led to a strong demand for participation in the upcoming campaign, even from neighboring villages.

The extrapolation of the average yield obtained over the entire 58 ha managed area allowed for an estimation of total production at 357.58 tons of rice. This has significantly contributed to improving the livelihoods of local communities, while reducing the risk of food in security in the area. Figure 10 shows rice production.

Figure 10. Photos of the harvested rice.

3.1.3. Economic Profitability Analysis of the Recovery System

To analyze the economic profitability of the salt land recovery system, an estimation of the production cost per hectare has been summarized in the following Table 3.

Table 3. Analysis of the recovery.

Item	Year 1			Year 2		
	Quantity	Unit Price	Total (frs)	Quantity	Unit Price (frs)	Total (frs)
Phosphogypsum	1 t	60,000	60,000	0	60,000	0
Cow manure	1 t	60,000	60,000	0	60,000	0
Peanuts shells	1 t	50,000	50,000	0	50,000	0
Labor	3 times	30,000	90,000	2 times	30,000	60,000
Seed	40 kg	7000	7000	40 kg	7000	7000
Labor for spreading and harvesting	2	50,000	100,000	2	50,000	100,000
Transport of Inputs	Flat rate	100,000	100,000	0	100,000	0
Total			**437,000**			**167,000**

The largest investment in the salt land recovery technique occurs in the first year, primarily due to the costs associated with mobilizing inputs such as phosphogypsum and organic matter. During this initial campaign, the investment cost can reach up to 437,000 CFA francs. In subsequent seasons, investments will significantly decrease as there is no longer a need for additional input; the decomposition of rice straw residues alone suffices to maintain soil fertility. Thus, a flat amount of 167,000 CFA francs could facilitate good production.

Considering the average yield of 6.17 t/ha or 6170 kg/ha, with a selling price of 7000 CFA francs per 40 kg sack of paddy, the total revenue is estimated at 1,079,750 CFA francs. This results in a profit of 247% in the first year and 646% in the following years.

3.2. Discussion

Relevance of the Salt Land Recovery System in the Delta du Saloum

Soil salinization is one of the most severe constraints in production systems across Sub-Saharan Africa [11]. In Senegal, many regions face the challenge of land salinization, particularly in the natural region of Sine Saloum, where the Saloum Delta biosphere reserve is located. Research conducted by the National Institute of Pedology (INP) in 2008 estimates that nearly 1,000,000 hectares of land are affected by salinity [12] and [13]. This phenomenon has led to the abandonment of vast areas of saline rice fields in favor of activities that are not necessarily beneficial to the environment because according to [14], the salinization negatively impacts the physical, chemical, and biological properties of the soil.

Fortunately, there is hope through the salt land recovery technique based on the use of phosphogypsum and organic matter, such as manure and/or peanut shells. This method has yielded very positive results, improving both the physico-chemical and agronomic parameters.

[15] reported that the improvement of physico-chemical parameters, phosphogypsum reduces the electrical conductivity (EC) or salinity of the soil, thus enhancing plant nutrition and leading to good yields. A similar finding was made [16] and [17], who points out that phosphogypsum combined with other organic amendments is effective in reducing the salinity of saline and sodic soils. These results also confirm those of [18] and [19], who found that gypsum significantly improves paddy yields. For [20] the combined phosphogypsum and cow dung treatment had the highest yield compared to the other treatments. Their study showed that, the treatment with phosphogypsum alone, obtained an average yield compared to the phosphogypsum + cow dung combination. Some researchers, such as [21] and [22] recommend the use of organic and mineral fertilisers, which would give a good yield compared with the control; this is not the case here, given the potential risk of these elements to the environment.

4. Conclusions and Recommendations

The Saloum Delta is severely threatened by the alarming phenomenon of agricultural land salinization, particularly in rice-growing valleys under significant marine influence. This issue leads to numerous adverse effects, such as decreased productivity and the abandonment of rice fields, exacerbating pressure on other production systems, including mangrove ecosystems. Additionally, it contributes to rural exodus, clandestine migration, increased risk of food insecurity, and dependency on external products.

Given these challenges, the proposed salt land recovery system aims to revitalize these agricultural spaces and significantly enhance the resilience of local communities in the Delta du Saloum. Follow-up results have revealed the system's great relevance, having nearly eradicated salinity in cultivated areas and achieved very satisfactory yields.

To support the adoption of this system by local communities in the Delta du Saloum, the following actions are necessary:

- **Production and dissemination of accessible tools** for capitalizing on the system, such as videos, brochures, or user manuals.
- **Capacity building for producers** to ensure proper mastery of the technique.
- **Support for the development of management plans** for certain valleys to diversify production and optimize productivity and profits.
- **Raising awareness among communities** about the origins of salinity in rice-growing valleys to help mitigate this phenomenon.
- **Supporting the rice value chain** to increase the economic profitability of the system

Acknowledgements

This work was carried out as part of the implementation of the Wetlands International Africa West Coast and Gulf of Guinea (WIACO) project portfolio in the Saloum Delta. We would like to thank the administration of the aforementioned structure for its trust and technical support, not forgetting its financial partners. Our thanks also go to the National Institute of Pedology, Kaolack office, for its technical support in this experimental process. We are also grateful to the people of the beneficiary villages for their welcome, their availability and their collaboration during data collection. Thanks are also due to our parents, wives, and any other people who have contributed directly or indirectly to the work.

Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] Wetlands International Afrique Côte Occidentale et Golfe de Guinée (2023) Appui à la Résilience communautaire dans le delta du saloum. Proposition Détaillée Soumise à la Swiss Philanthropy Foundation, 16 p.

[2] Bassi, A.M., Casier, L., Pallaske, G., Perera, O. and Bechauf, R. (2020) Evaluation des actifs durables (SAVI) du delta du saloum au Sénégal: Une évaluation économique de la contribution du delta du Saloum au développement durable, en se concentrant

sur les zones humides et les mangroves, 48 p.

[3] Dieye, E.B. (2007) Les ensembles littoraux de la lagune de Joal-Fadiouth et de l'estuaire du Saloum (Sénégal): Approche méthodologique de la dynamique de la mangrove entre 1972 et 2005 par télédétection et systèmes d'information géographique (SIG). Doctorat 3e Cycle, Université Cheikh Anta Diop de Dakar, 266 p.

[4] Ndour, N. (2005) Caractérisation et étude de la dynamique des peuplements de mangrove du Delta du Saloum (République du Sénégal). Thèse de Troisième Cycle, Université Cheikh Anta Diop, 180 p.

[5] Ndour, N., Dieng, D.S. and Fall, M. (2016) Rôles des mangroves, modes et perspectives de gestion au Delta du Saloum (Sénégal). *VertigO—La revue électronique en sciences de l'environnement*, **11**, 11 p. https://journals.openedition.org/vertigo/11515#quotation

[6] Sadio, S. (2011) La connaissance des sols salés sulfatés acides des mangroves: Processus et mécanismes de pédogenèse, distribution spatiale et évolution. In: *Récupération et valorisation des terres salées en Afrique. Rapport général*, Atelier international préparatoire, Académie Nationale des sciences et Techniques du Sénégal.

[7] Faye, B., Tine, D., Ndiaye, D., Diop, C., Faye, G. and Ndiaye, A. (2019) Évolution des terres salées dans le nord de l'estuaire du Saloum (Sénégal). *Geomorphologie*, **25**, 15.

[8] Agence Japonaise de Coopération Internationale (JICA) (2005) Étude pour une gestion durable de la mangrove de la petite côte et du Delta du Saloum de la République du Sénégal. Plan de gestion durable de la mangrove. Rapport d'étude, 54 p.

[9] Samnick, E.L.N. (2021) Le delta du saloum au Sénégal, un écosystème d'exception. 6 p. https://www.researchgate.net/publication/350567969

[10] Barusseau, J.P., *et al.* (1985) Mise en évidence du fonctionnement inverse de certains estuaires tropicaux. Conséquences géomorphologiques et sédimentologiques (Saloum et Casamance) Sénégal. In: *Sedimentology*, No. 32, 543-551.

[11] Imane, H. (2012) Impact sur l'irrigation sur la salinisation des sols dans les palmeraies d'oueds. Mémoire de Fin d'éTude, Righ, 79 p.

[12] CSE-Centre de Suivi Ecologique (2010) Rapport sur l'état de l'environnement au Sénégal. 266 p.

[13] Sadio, S. (1989) Géomorphologie: Pédogénèse et potentialités forestières des sols sulfatés acides salés des tannes du Sine Saloum. Thèse d'état, Office de la recherche scientifique et technique outre-mer, 269 p.

[14] Dekhina, S. (2010) Apport des SIG pour la spatialisation de la salinité des sols irrigués en milieu aride (Relation CE et fraction fine). Laboratoire LAPA PEZA, Université de Batna, 13 p.

[15] Prapagar, K., Indraratne, S. and Premanandharajah, P. (2012) Effect of Soil Amendments on Reclamation of Saline-Sodic Soil. *Tropical Agricultural Research*, **23**, 168-176. https://doi.org/10.4038/tar.v23i2.4648

[16] Zia, M.H., Saifullah, Sabir, M., Ghafoor, A. and Murtaza, G. (2007) Effectiveness of Sulphuric Acid and Gypsum for the Reclamation of a Calcareous Saline-Sodic Soil under Four Crop Rotations. *Journal of Agronomy and Crop Science*, **193**, 262-269. https://doi.org/10.1111/j.1439-037x.2007.00262.x

[17] Ndiaye, R. (2009) Contribution to Understanding Salt and Sodium Affected soils in the Senegal River Valley. Geographic Information Sciences (GIS): Proquest/UMI, 18 p.

[18] Mutsaars, M. and Van Der Velden (1973) Le dessalement des terres du Delta du Fleuve Sénégal. Bilan de trois années d'expérimentations (70/73) et perspectives, FAO.

[19] Hassan, G., Sadiq, M., Jamil, M., Mehdi, S.M. and Sattar, A. (2001) Comparative Performance of RiceVarieties/Lines in Ameliorated and Non-Ameliorated Soils. *International Journal of Agriculture and Biology*, **3**, 286-288.

[20] Ba, D.D., Sow, A., Diop, T. and Ndiaye, R. (2019) Effets du phosphogypse et du fumier sur le rendement en riz dans les périmètres rizicoles affectés par la salinité: Cas de la cuvette de de Ndiol dans le Delta du fleuve Sénégal. Institut National de la Recherche Scientifique (INRS). *Revue Togolaise des Sciences*, **13**, 18 p.

[21] Shaaban, M., Abid, M. and Abou-Shanab, R.A.I. (2013) Amelioration of Salt Affected Soils in Rice Paddy System by Application of Organic and Inorganic Amendments. *Plant*, *Soil and Environment*, **59**, 227-233. https://doi.org/10.17221/881/2012-pse

[22] Matula, J. and Pechová, M. (2007) The Influence of Gypsum Treatment on the Acquirement of Nutrients from Soils by Barley. *Plant*, *Soil and Environment*, **53**, 89-96. https://doi.org/10.17221/2299-pse