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Farmers' Perceptions of Saline-Sodic Soil Impacts on Rice Production in Navotas, Balayan, Batangas, Philippines

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Abstract: Soil salinization is a critical global issue that undermines agricultural productivity, threatens food security, and compromises the sustainability of farming systems. In the coastal region of Navotas, Balayan, Batangas, Philippines, the increasing salinization of irrigated rice farmlands due to saline-sodic soils has become a pressing concern. The understanding of farmers' perceptions regarding the risks associated with soil salinity, as well as their insights into the causes, consequences, and coping mechanisms, remains inadequately explored. This gap in knowledge may hinder the development of effective countermeasures and appropriate policy interventions. In this study, farmers' perceptions of saline-sodic soils were assessed through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs), which were analysed using thematic analysis and Causal Loop Diagrams (CLDs). Saltwater intrusion was consistently identified as the primary cause of soil salinization, with subsequent reductions in rice yields ranging from 60% to 100%, depending on the growth stage of the crop. The most vulnerable periods were identified as June to August, particularly during the vegetative and flowering stages of rice. Farmers reported coping strategies such as irrigation with freshwater and the cultivation of salt-tolerant rice varieties; however, challenges related to delayed access to freshwater and seeds were frequently mentioned. The expansion of saline-sodic areas was identified as the most significant threat to rice production, with the condition of saline-sodic soils in lowland rice paddies increasingly viewed as a worsening problem. These findings underscore the severe impact of saline-sodic soils on both agricultural productivity and farmers' livelihoods, providing valuable insights that can inform the development of tailored management strategies and mitigation measures.

Keywords: Soil salinization; Salinity; Saline-sodic; Farmers' perceptions; Rice farmers; Causal Loop Diagrams; Word clouds

1. Introduction

Soil salinization is said to affect approximately 33% of all irrigated lands and 20% of the total croplands worldwide. By the year 2050, salinization is estimated to affect 50% of the world's total croplands, with a steady growth rate of 10% per year (Nachshon, 2018). The Food and Agriculture Organization (FAO) and Intergovernmental Technical Panel on Soils (ITPS) estimated that the problem of soil salinity is diminishing 0.3 to 1.5 million ha out of production worldwide each year with a potential to further decline agricultural output of 20 to 40 million ha (FAO & ITPS, 2015). In the Philippines, the coastal saline soil has a total area of 400,000 ha, comprising 175,000 ha of fishponds, 100,000 ha of mangrove forests, and 125,000 ha of mostly idle land (Naungayan et al., 2021). In addition, the sources of salinization in the country include seepage, creeks, groundwater, and, most importantly, seawater, where low-lying coastal areas are affected (Asio et al., 2009). The problem with salinity, especially in coastal areas, is caused by high levels of Na^+, Cl^- and other related ions, resulting in salt stress to plants by disrupting plant cellular functions, leading to shrinkage and dehydration of cells known as the osmotic effect. Consequently, the plants' vital processes, such as seed germination, photosynthesis, and water absorption, decrease, leading to tissue damage or even plant death (Balasubramaniam et al., 2023). In a previous study by Labios et al. (2020) in Navotas, Balayan, Batangas, rice farmlands were tested to contain high amounts of sodium due to saltwater intrusion from the nearby swamp. Due to the lowland coastal rice farmlands and Type I climatic condition where the community is located, the dry season results in the accumulation of salts due to low rainfall, and the wet season results in saltwater intrusion due to high tide (Corporal-Lodangco & Leslie, 2017; Tan et al., 2019). Although there has been a study on the characterization of the physical and chemical properties of salt-affected soil in Navotas, Balayan, Batangas, previous investigators noted the lack of information that can provide a thorough understanding of the extent and severity of saline-sodic soil in the area, including the effects on the productivity of rice production (Labios et al., 2020). The lack of information regarding people's perceptions of the risks of saline-sodic soil on rice production may result in ineffective adaptation measures by an individual or group, and it is vital in formulating policies and suitable interventions (Khong et al., 2020; Omar et al., 2022). This aligns with the observation that, despite global advancements in understanding salinity, data on the localized socio-economic and environmental contexts of salinity's effects on agricultural communities remains limited. Thus, considering that the perception of farmers and their knowledge of the problem can help in deciding on employing local adaptation and mitigation practices, which could also be further improved (Qureshi et al., 2019), understanding these perspectives is essential for designing interventions tailored to local conditions, especially in resource-limited settings such as Navotas, Balayan, Batangas. In this type of locality where farmers largely rely on rice cultivation as a source of income and food security (Municipality of Balayan, 2024), farmers' perception of the problem of salinization is important to improve their rice production.

Using participatory rural appraisal (PRA) tools such as KIIs and FGDs, the opportunities and constraints could be investigated and evaluated to facilitate timely decisions by the participating community members (Singh & Dubey, 2021), which is useful in understanding the perceptions of farmers regarding their affected saline-sodic soil. The PRA tools encourage members of the community in sharing their opinions, experiences, and ideas, which can be achieved through interviews and group discussions (Omar et al., 2022). Some studies have used PRA tools in assessing the farmers' perception of soil salinization. In particular, Min (2017) found out that salinization was one of the perceived causes of agricultural loss. Similarly, Khong et al. (2020) utilized PRA tools to collect data on farmers' awareness, adaptation measures, intention, and proposed public intervention regarding salinization, which resulted in four adaptation strategy groups. The identification of salinization as a problem through PRA tools led to the recommendation of major mitigation policy (Reddy et al., 2016). Further, PRA tools can also show the dynamic interplay and feedback of different drivers of change, such as technological development, policy intervention, profit maximization, and changing the condition of salinization, which could shape agricultural systems (Nguyen et al., 2019). Given the nature of the location of the community, PRA tools could provide an in-depth understanding of saline-sodic lowland rice soils since it is best done with small groups of people (Nyumba et al., 2018).

This study aims to address this knowledge gap by using PRA tools to investigate farmers' awareness of salinity, their adaptation measures, and the socio-economic impacts of salinity on their livelihoods. PRA tools such as KIIs and FGDs are especially valuable for capturing qualitative insights into local adaptation practices. Given the gaps in understanding local-level impacts of salinity, this study continues to contribute both theoretical and practical knowledge by focusing on the specific context of Navotas, Balayan, Batangas. Thus, this study seeks to answer several questions: (a) How do farmers perceive the salinity problem and its impact on their livelihood? (b) What strategies are currently employed to mitigate salinity? (c) What additional interventions or policies can address these challenges effectively?

2. Methodology

2.1 Study Area and Research Duration

Balayan, a coastal first-class municipality in Batangas Province in the Philippines, is characterized by a humid tropical climate and an economy predominantly driven by agriculture, fishing, and small-scale industries. It is bounded by the municipality of Tuy on the north, Calaca on the east, Calatagan and Lian on the west, and Balayan Bay on the south (Municipality of Balayan, 2024). One of the communities in Balayan, barangay Navotas (13°55'48.72"N, 120°43'7.32"E) is a coastal community in the municipality, with a total land area of 129.39 ha and a population of 4,113 as of 2020 (Figure 1). The study was conducted in the community from April 12 to June 15, 2023. According to the key informants, nine of 53 members of the Navotas Farmers' Association in the barangay were said to have saline-sodic lowland rice soils. According to the president of the association, 3.45 ha of the total rice farmlands (48 ha) overseen were said to be affected.

Figure 1. Administrative boundary of Navotas, Balayan, Batangas
Source: The Municipal Agriculture Office (MAO).

2.2 Coordination

Prior to the KIIs with the MAO officer and Farmers' Association President and FGDs with officials and rice farmers with saline-sodic lowland rice soils, a request letter and information sheet about the study were sent to the respective offices of the Balayan municipal agriculture and municipal administration, and farmers' association for proper introduction of the study.

2.3 KII

The KII is a method used to obtain information, especially from experts or individuals with a deep understanding of a given topic (Taylor & Blake, 2015). Two KIIs were conducted to gather information about farmers' profiles in barangay Navotas, Balayan, Batangas, by interviewing the MAO officer (Palanca-Tan & Gio, 2021) and the president of one farmers' association. The interviewees were purposively selected due to their roles in their respective agency and association, including their access to information (Agu et al., 2022). In addition, their years of experience and familiarity with the area were considered knowledgeable about the ecological and socioeconomic aspects of the community (Marie et al., 2024). Additionally, due to the nature of the study area where there is only one MAO officer and one president for the farmers' association in the community, this makes them automatically selected as interviewees. The interviewees were contacted and informed one week before the planned schedule for the visit to give them time to prepare and make necessary adjustments to the activity. The set of questions was devised from the study of Labios et al. (2020), which focused on several aspects, such as the number of farmers, the presence of farmers' association, the number of members in the association, the total area of farmlands, production, cropping season or pattern, the incidence of natural calamities (drought, flood, typhoon), the incidence of salinization, government and non-government linkages, policies, and programs relevant to saline-sodic soil management. Relevant secondary data were also retrieved from the MAO of Balayan, barangay Navotas, and farmers' associations (Melodillar et al., 2018). The KIIs were conducted with a duration of at least 30 minutes during the free time of the interviewees at a chosen location.

2.4 FGD

FGDs provide a platform for gathering diverse perspectives and validating themes from the KIIs. Two FGDs were conducted with a total of 14 participants with a duration of 1.5-2.0 hours. The first FGD consisted of five officials from the MAO, farmers' association, and barangay who served at least one year in the office. The second FGD consisted of nine rice farmers with saline-sodic lowland rice soils in the community, who were purposively selected and invited to participate in the study (Wynn et al., 2013). However, only six of the nine farmers were able to answer the questionnaire (Table 1). Among the 53 members of the farmers' association, the selection of farmers during purposive sampling was based on these criteria: (a) ownership or management of saline-sodic lowland rice fields, (b) membership in the Navotas Farmers' Association, and (c) willingness to participate in discussions and share experiences. Due to the location of rice farmlands, the limited number of farmers cultivating rice near the swamp was also few, which led to a small sample size. Affected farmers have a total of 3.45 ha of saline-sodic soil, from which they harvest 30 to more than 90 sacks of rice depending on their individual area (Table 2). All participants were invited one week ahead of the scheduled interviews and the FGDs were conducted on Fridays for the officials to attend. The investigator facilitated the discussion for a smooth flow of the study to ensure that all topics were discussed. The FGDs were conducted in a neutral place, such as under a tree and at a farmer's house, during the activities.

Prior to information gathering for the questionnaire (Table 1) based on the study by Islam et al. (2022), the sociodemographic profiles of farmers (Table 2) were also obtained in the study. In addition, problem ranking and cropping calendar were also used in the study following the International Institute of Rural Reconstruction (IIRR) methods (IIRR, 1998) as follows:

- Problem ranking: The participants were asked to list down their major problems and compare each one of them in a table using the two-way matrix method. Afterwards, the participants ranked these problems based on the score given to each problem.
- Cropping calendar: The participants were asked to describe their rice production. They were also tasked to provide details about their farm activities and the worst occurrence of the saline-sodic soil within a year by drawing an outline of their local annual calendar on a whiteboard. In addition, the participants were asked to describe and list their strategies for minimizing the impacts of saline-sodic soil.

Table 1. Guiding questions of the questionnaire used in FGD

No.	Questions
1	How has saline-sodic affected your rice production? Describe the effects.
2	How do you describe the current level of salinity (saline-sodic soil) in your rice farmlands?
3	Can you determine the different causes of saline-sodic soil in your rice farmlands?
4	Can you determine the cropping season when saline-sodic soil is more pronounced?
5	Can you determine the stage of your rice crop that is most affected by saline-sodic soil?
6	What are your strategies for managing your saline-sodic soil?
7	How has saline-sodic soil impacted your livelihood?

Table 2. Socio-demographic profile of rice farmers with saline-sodic lowland rice soils

Farmers	Sex	Age	Education	Primary Occupation	Area Affected with Saline-Sodic Soil (ha)
1	Female	45	High school	Farming	0.60
2	Female	65	Grade 1	Farming	0.20
3	Male	67	No formal education	Farming	0.40
4	Male	51	Elementary	Farming	0.60
5	Male	64	Elementary	Farming	0.30
6	Male	54	High school	Farming	0.15
7	Male	48	High school	Farming	0.30
8	Male	47	Vocational	Farming	0.50
9	Female	47	High school	Farming	0.40

2.5 Quality Control Measures

The materials and methods used in this study were employed following the standard procedures from previous studies in the community and similar studies. Then they were reviewed by experts for appropriateness and refined for clarity and comprehensibility based on the recommendations from the University of the Philippines Los Baños (UPLB) Research Ethics Board. In addition, note-taking, audio recording, and cross-validation were employed to ensure data reliability.

2.6 Triangulation of Data

Triangulation of data across the study was conducted with the KIIs, officials' FGD, and the farmers' FGD. To increase the validity of the obtained results, data were combined to support and clarify the farmers' perceptions of saline-sodic soil. Additionally, fundamental biases during data collection were overcome (Omar et al., 2022).

2.7 Data Analysis

2.7.1 Thematic analysis

The data collected from the KIIs and FGDs were subjected to thematic analysis (Clarke & Braun, 2016) using NVivo 12 Pro Qualitative Data Analysis Software version 12.6. NVivo 12 Pro is a powerful qualitative analysis software that allows users to easily code, classify, and map the data across the data set of multiple sources such as interviews, documents, audio and video transcriptions, and even images. The nodes, also known as coded data, can be classified, allowing users to create data categories from one source or multiple cases with similar attributes and values, thereby enabling the thematic mapping of data to specific cases (Dhakal, 2022). The thematic analysis resulted in the identification of themes and subthemes from hierarchical coding that enables the analysis of various texts at different levels of specification (Nowell et al., 2017). Coded data in themes were presented in word clouds, which helped in explaining the perceptions of the rice farmers. Using a word cloud, keywords that occurred frequently across the coded data from the documents were identified. These keywords presented the most relevant topics to the theme of the study (Ritter et al., 2020).

2.7.2 CLD

The CLDs were generated using Vensim PLE version 10.1.3. The identification of the factors affecting and effecting the saline-sodic soil in thematic analysis was used to visualize the positive and negative relationships of different variables and how they causally relate with each other (Lindawati et al., 2022). Hence, more details and information on the perceptions of rice farmers with saline-sodic lowland rice soils were provided. Polarities "+" and "-" were indicated to identify reinforcing loops and balancing loops in the diagram. In addition, when the "‖" sign is used in the center of the arrow, a delay can be expected as it may take time for the factor to take effect on another factor (Esfandabadi et al., 2022).

3. Results

3.1 Perceptions of Farmers with Saline-Sodic Lowland Rice Soils

3.1.1 Perceived causes of saline-sodic lowland rice soils (Theme 1)

The word cloud in subgraph (a) of Figure 2 stresses these concerns, with "saltwater" being the most prominent word, reflecting that it is the perceived main cause of saline-sodic soil in the area, which all farmers agreed to be the main cause of salinity. Other related terms, such as "intrusion," "rises," and "tide," further emphasize the farmers' understanding that natural forces, particularly those influenced by climate change and rising sea levels, exacerbate the problem. One farmer stated "pag naabot ng tubig alat ang lupa ay mag-aasin ang lupa," which in context can be translated to "When saltwater reaches the land, it will lead to soil salinization." This sentiment echoes the prevalent concerns among the farmers regarding the persistent intrusion of saltwater into their farmlands, which has led to the degradation of soil quality and decreased agricultural productivity.

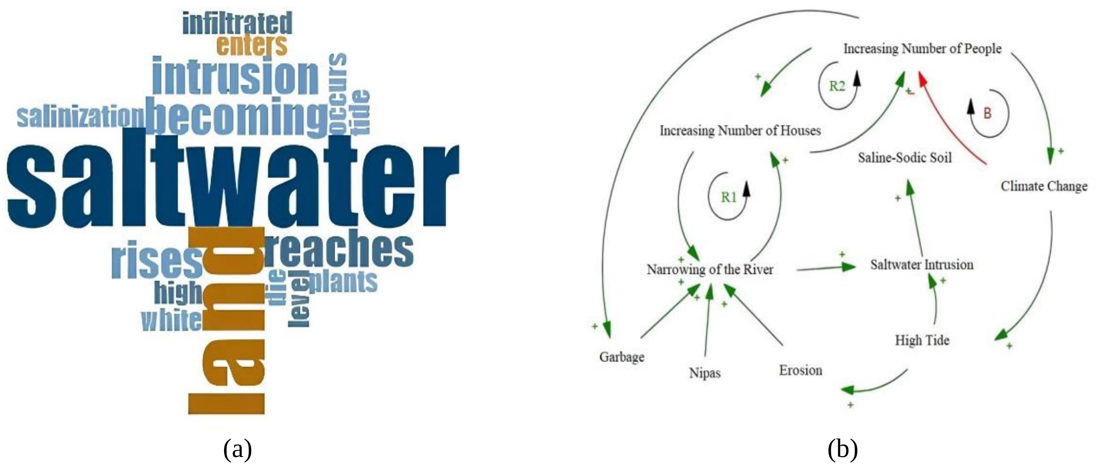


Figure 2. Word cloud of perceived causes of saline-sodic lowland rice soils: a) interviewed farmers, b) CLD of the causes of saline-sodic lowland rice soils

Note: R means reinforcing; B indicates balancing; the "+" sign at the end of the arrows indicates (x ↑→ y ↑); and the "-" sign at the end of the arrows indicates (x ↑→ y ↓).

Subgraph (b) of Figure 2 shows the farmers' perceptions that the narrowing of the river and high tide are directly linked to the increase in saltwater intrusion. In addition, all factors affect one another, which eventually results in saline-sodic soil. One official also noted that the improper waste disposal in the river, including the growth of nipa palm (*Nipa fruticans*), contributed to the blockage of riverways, further heightening the risk of saltwater intrusion. This observation adds a layer of human-induced impact to the natural processes identified by the farmers.

The CLD in subgraph (b) of Figure 2 reflects two reinforcing loops (R1 and R2) that amplify the problem of saline-sodic soils. Human activity and narrowing of the river (R1) relate to increasing population driving housing construction. As housing expands, it contributes to the narrowing of rivers, which restricts water flow and exacerbates saltwater intrusion into lowland rice fields. Additionally, garbage disposal and the growth of nipa palm further obstruct riverways, intensifying erosion and contributing to river narrowing. This restricted river flow aggravates saline-sodic soil conditions, which in turn drives the need for housing adjustments, creating a self-reinforcing feedback cycle.

Population growth and housing demand (R2) demonstrate the direct relationship between population growth and the demand for housing, which further narrows rivers and contributes to the formation of saline-sodic soils. This process reduces the availability of arable land, forcing populations to expand housing into new areas, thereby worsening the problem. This reinforcing cycle amplifies the interconnected issues of housing expansion, river narrowing, and soil salinization, making mitigation efforts increasingly challenging without breaking the loop.

Meanwhile, a balancing loop (B) incorporates the impact of climate change, which exacerbates high tides and saltwater intrusion, further deteriorating soil conditions. However, these environmental changes also introduce a natural limit to population growth. As saline soils render areas less hospitable for habitation and agriculture, population expansion is hindered, creating a counterforce to the reinforcing loops. This loop illustrates how climate change and salinity impacts balance out population pressures, though they do so at the cost of environmental and agricultural degradation.

These dynamic interactions illustrate the self-perpetuating nature of the reinforcing loops (R1 and R2), where socio-environmental challenges compound over time. The balancing loop (B) highlights the system's natural limitations, where the effects of salinity and climate change act as counterforces to unchecked growth and human activity. These findings emphasize the importance of integrated interventions to address both natural and anthropogenic drivers. Improving river management, regulating housing development, and promoting sustainable waste disposal are critical to breaking the reinforcing loops and halting the cycle of degradation. Simultaneously, adaptive measures should enhance resilience to climate change impacts, ensuring that affected communities can cope with the challenges posed by saline-sodic soils. The reinforcing loops demonstrate the compounding effects of human and environmental factors, while the balancing loop reflects the interplay between socio-economic stressors and environmental impacts. These findings show the multifaceted causes of saline-sodic soils and highlight the importance of integrated interventions to address both natural and anthropogenic drivers.

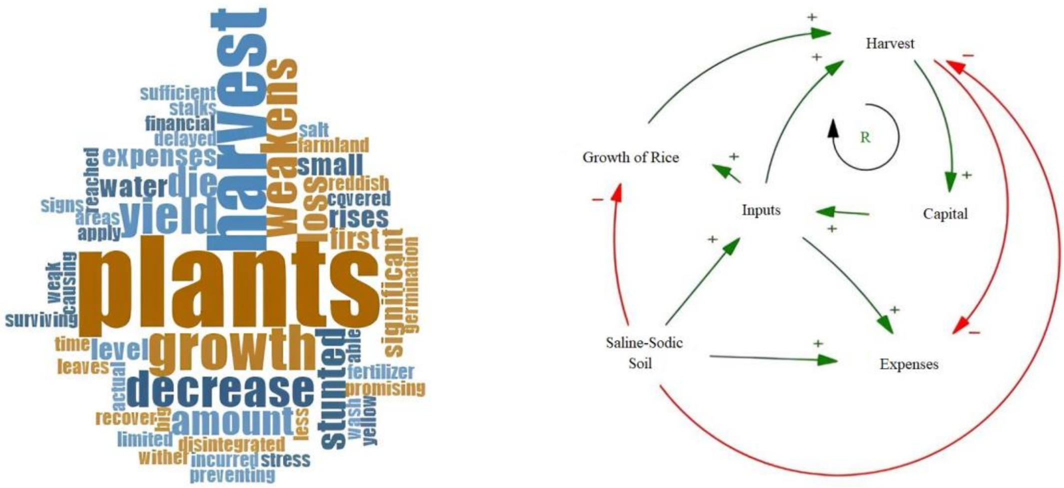
Interventions targeting the reinforcing loops could include improving river management to prevent blockages and erosion, regulating housing development to limit river narrowing and promoting sustainable waste disposal practices to reduce riverway obstructions caused by garbage and nipa palms. Simultaneously, measures to address the balancing loop should focus on building resilience to climate change impacts, such as investing in salt-tolerant crops, enhancing irrigation systems, and providing alternative livelihoods for affected communities.

Similar studies also reported at least one of the same identified causes of saline-sodic soil in their agricultural lands (Islam et al., 2020; Islam et al., 2021; Islam et al., 2022; Roy et al., 2022). These studies affirm that the perceived causes of saline-sodic soils in Navotas, Balayan, Batangas are not unique; they mirror the experiences of other rice farmers facing similar challenges with saline-sodic lowland soils in various regions in the Philippines. Such findings strengthen the argument that saline-sodic conditions in rice fields are a widespread issue driven by both environmental and anthropogenic factors. The findings of this study align with the broader literature, suggesting that the primary cause of saline-sodic soils is multifaceted, involving both natural processes (such as saltwater intrusion due to rising tides and climate change) and human activities (such as improper waste disposal, urban expansion, and riverway obstruction). These reinforce the need for comprehensive interventions that address both the environmental and socio-economic dimensions of saline-sodic soil formation.

In a broader agricultural and soil management context, these results underline the need for integrating soil and water management strategies into regional planning. Addressing human-induced drivers such as urban expansion and waste disposal is essential for reducing saltwater intrusion. Moreover, these insights highlight a growing global challenge of balancing urban development and agricultural sustainability, which has significant implications for policy frameworks and land-use planning in coastal agricultural areas.

3.1.2 Perceived effects of saline-sodic lowland rice soils (Theme 2)

Figure 3 identifies the different effects of saline-sodic soil perceived by rice farmers with saline-sodic lowland rice soils. In subgraph (a) of Figure 3, the perceptions of saline-sodic soil mainly focus on the plants, followed by harvest. Important terms such as "plants," "growth," "harvest," and "decrease" dominate, emphasizing the severe impact of saline-sodic conditions on plant health and agricultural output, which they estimated that 100 sacks of rice harvest could decrease to only 60 sacks. In addition, depending on the stage of rice plants, a 100% crop failure can happen during the vegetative stage. The frequency of terms like "weaken," "loss," "expenses," and "stunted" specifies the economic burdens caused by the degraded soil, as farmers struggle with lower yields and increased costs. These perceptions align with the descriptions provided by farmers, who frequently reported seeing disintegrated, dead, or stunted rice plants due to saline-sodic soil. The damage extends beyond physical plant conditions, leading to decreased productivity, delayed harvests, and additional costs. Moreover, the rice farmers with saline-sodic lowland rice soils describe the effects as “tunaw ang palay” (“rice plants disintegrated”), “washout” (“washed out”), “patay ang palay” (“rice plants were dead”), and “namumula ang palay” (“rice plants turned reddish”).



(a) (b)

Figure 3. Word cloud of perceived effects of saline-sodic lowland rice soils: a) interviewed rice farmers, b) CLD of the effects of saline-sodic lowland rice soils

Note: R means reinforcing; the “+” sign at the end of the arrows indicates (x↑→ y↑); and the “-” sign at the end of the arrows indicates (x ↑→ y ↓).

According to Hussain et al. (2017), the growth and development of rice plants are affected by salts by creating ionic, oxidative, and osmotic stresses, resulting in decreased photosynthetic activity and early leaf senescence. Additionally, Machado & Serralheiro (2017) stated that the high level of salt in the soil solution decreases the plant’s ability to absorb water, which is referred to as an osmotic or water-deficit effect, resembling water stress-induced “wilting.” Given this problem, the president of the farmers’ association stated during the KII that nine farmers were affected with saline-sodic soil and the MAO stated that one farmer was able to claim an indemnity from the Philippine Crop Insurance Corporation (PCIC) for 0.5 ha in 2022.

Subgraph (b) of Figure 3 provides a comprehensive model of the interactions and feedback mechanisms between saline-sodic soils, rice crop growth, and the economic decisions of farmers. It highlights the identification of one prominent reinforcing loop (R) and its associated dynamics, along with balancing feedback mechanisms that introduce systemic constraints.

The reinforcing loop begins with the growth of rice crops. Improved rice growth leads to better harvests, which in turn enhances farmers' capital availability. This increased capital allows for greater investments in inputs such as fertilizers, water, and soil amendments, further boosting rice growth and creating a cycle of productivity. However, saline-sodic soil conditions significantly disrupt this loop. As the severity of salinity increases, rice growth is negatively affected, leading to reduced harvests and lower capital availability. This reduction reduces farmers’ ability to invest in the necessary inputs to sustain or improve growth, perpetuating a downward spiral of declining productivity and worsening financial strain. This loop stresses the fragile nature of rice farming under saline-sodic conditions, where favorable circumstances can amplify growth and profitability, but adverse conditions can rapidly lead to financial instability and reduced productivity.

While the reinforcing loop highlights potential growth cycles, the dynamics involving expenses act as a balancing mechanism within the system. Due to increased costs of inputs required to counteract saline-sodic soil conditions, rising expenses reduce available capital. This, in turn, limits the reinvestment capacity of farmers, acting as a constraint on the reinforcing loop. These balancing dynamics highlight the economic trade-offs inherent in saline-sodic farming. While higher investments may mitigate salinity effects temporarily, escalating costs and diminishing returns pose long-term sustainability challenges.

The effect of saline-sodic soil on the growth of rice is the first to be perceived by rice farmers, followed by harvest, expenses, and inputs. During the FGD, one farmer stated “Hindi maka harvest. Kulang sa puhunan. Nalulugi sa gastos”, which can be translated to “Unable to harvest, lack of capital, and incurring loss from expenses.” In a similar study, Khanom (2016) reported that farmers incurred additional costs for inputs. Furthermore, the income from farming was not enough to cover the cost of buying agricultural inputs along with family expenses.

In the problem ranking (Figure 4), capital and finance both obtain a high score, indicating their importance in farmers' rice production. Financial constraints are said to be experienced by rice farmers from less harvest affecting the income, which is also the capital. In the problem ranking of officials, they stressed the importance of finance in farmers' rice production, which resulted in one of the first ranks among the identified major problems. Financial constraints to farmers could lead to limited inputs in their farming activities (Dewi et al., 2015) and decision-making in pursuing intensive rice cultivation (Van Aalst et al., 2023).

	Capital	Seed	Equipment	Manpower	Salinity	Score	Rank
Capital		Capital	Capital	Manpower	Salinity	2	2
Seed	Capital		Equipment	Machine	Salinity	0	4
Equipment	Capital	Equipment		Machine	Salinity	1	3
Manpower	Capital	Manpower	Manpower		Salinity	2	2
Salinity	Salinity	Seed	Salinity	Salinity		3	1

(a)

	Financial	Old Age	Manpower	Machine	Salinity	Selling Price of Rice	Score	Rank
Financial		Financial	Financial	Financial	Financial	Financial	5	1
Old Age	Financial		Manpower	Machine	Salinity	Selling Price of Rice	0	5
Manpower	Financial	Manpower		Machine	Salinity	Manpower	2	4
Machine	Machine	Machine	Machine		Salinity	Selling Price of Rice	3	3
Salinity	Financial	Salinity	Salinity	Salinity		Salinity	4	2
Selling Price of Rice	Selling Price of Rice	Selling Price of Rice	Selling Price of Rice	Selling Price of Rice	Selling Price of Rice		5	1

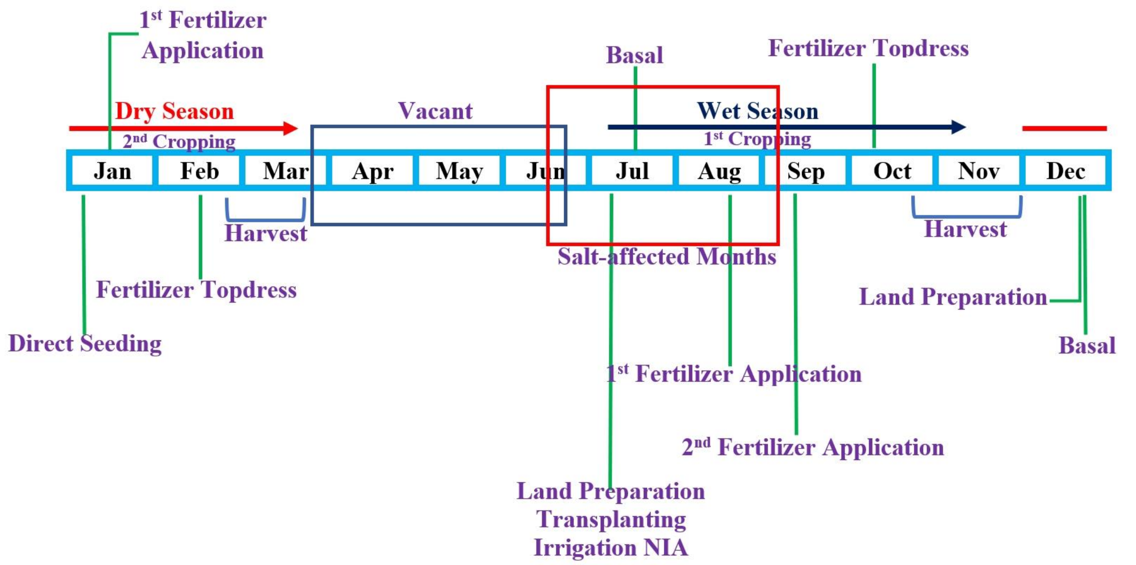
(b)

Figure 4. Problem ranking of (a) rice farmers with saline-sodic lowland rice soils, and (b) MAO, barangay, and farmers' associations officials in Navotas, Balayan, Batangas

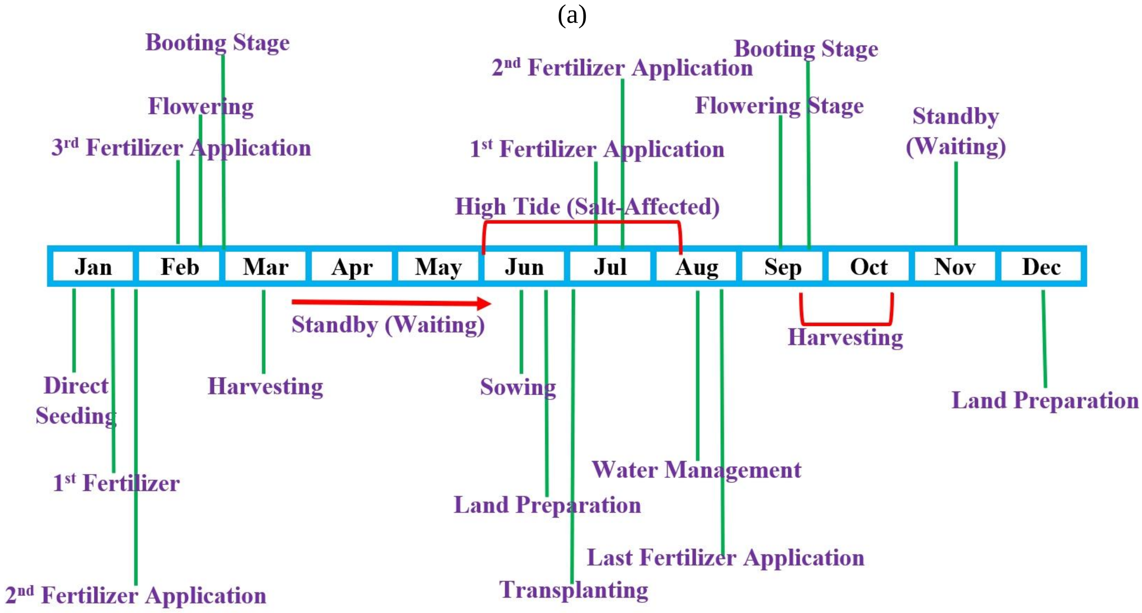
The overall analysis from both the word cloud and the CLD underscores a significant issue: the impacts of saline-sodic soil on rice production are not limited to the biophysical effects on plants but extend to severe economic ramifications for the farmers. They are often caught in a feedback loop where they must increase their spending on agricultural inputs yet see diminishing returns due to the persistent effects of soil degradation. The integration of farmers' perceptions with system modeling in this study provides valuable insights into the complexity of managing saline-sodic rice farmlands (Endale et al., 2023). Addressing these challenges requires not only immediate interventions, such as soil remediation techniques, but also long-term investments in sustainable farming practices that can help farmers adapt to and mitigate the adverse effects of saline-sodic conditions on rice production. The feedback loops modeled in the CLD illustrate the delicate balance that farmers must maintain to achieve profitability in the face of environmental degradation. Understanding these dynamics is critical for policymakers and agricultural extension services, as they develop strategies to support farmers dealing with saline-sodic soils (Islam et al., 2022). Key recommendations include improving access to affordable and effective inputs, such as salt-tolerant rice varieties and amendments, enhancing soil health through strategies like leaching, drainage improvements, and organic amendments, and reducing economic pressures through financial support mechanisms like subsidies, credit access, and insurance schemes to safeguard against failed harvests.

3.1.3 Perceived time of occurrence of saline-sodic lowland rice soils (Theme 3)

The perception of time refers to the month, year, crop stage, and cropping season when the farmers see the effects of saline-sodic soil. In Figure 5, July is the most prevalent word, indicating that it is the most saline-sodic month. The months of June and August are also shown in the word cloud. In the cropping calendar of rice farmers with saline-sodic lowland rice soils (Subgraph (a) of Figure 5), the months of June, July, and August were identified as the saline-sodic affected months. Similarly, officials also identified the months of June, July, and August as saline-sodic affected months (Subgraph (b) of Figure 5). The result fits with the Coronas climate classification under cluster 4, where Batangas is classified, showing that the identified months, especially July, are the peak of rainfall in a year (Corporal-Lodangco & Leslie, 2017). Similar to the KII, the president of the association stated that the beginning of the wet season for the first cropping starts in the month of May until July, which corresponds to the increase in rainfall.



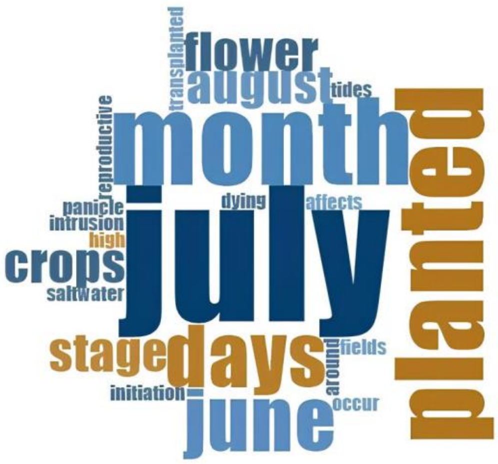
(a)



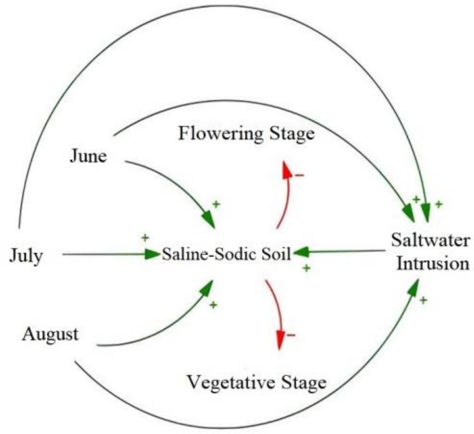
(b)

Figure 5. Cropping calendar based on the (a) rice farmers with saline-sodic lowland rice soils, and (b) MAO, barangay, and farmers' association officials in Navotas, Balayan, Batangas

Subgraph (a) of Figure 6, the word cloud prominently displays terms such as "planted," "flower," "panicle," and "reproductive," indicating the stages of rice most vulnerable to saline-sodic soil. These stages were identified by the farmers as critical points in the growth cycle when the negative effects of saline-sodic soil were most apparent. The farmers described that they perceived the effects of saline-sodic soil at these two stages of their rice crop. Farmers specifically noted that the vegetative and reproductive stages, including flowering and panicle initiation, are most prone to the damaging effects of saline-sodic soils. This is aligned with the findings of Islam et al. (2020), which indicated that the vegetative and flowering stages of rice are highly sensitive to salinity. During these stages, the uptake of water and nutrients is crucial for the development of the plants. However, the presence of saline-sodic conditions impedes this process, leading to stunted growth of the plant and reduced yields.



(a)



(b)

Figure 6. Word cloud of perceived time of occurrence of saline-sodic soil: a) interviewed rice farmers, b) CLD of time of occurrence of saline-sodic lowland rice soils

Note: The "+" sign at the end of the arrows indicates (x ↑→ y ↑); and the "-" sign at the end of the arrows indicates (x ↑→ y ↓).

Subgraph (b) of Figure 6 shows the temporal dynamics and intricate interactions between saline-sodic soils, saltwater intrusion, and the growth stages of rice crops during the critical months. The CLD illustrates how reinforcing and balancing feedback loops shape the system's response to environmental and agricultural factors, emphasizing the cyclical and systemic nature of the challenges faced by rice farmers. Saltwater intrusion, which contributes to the increase in saline-sodic soil, has a direct positive relationship with the deterioration of soil quality during these sensitive stages of rice growth. This dynamic is most pronounced during the critical months of June, July, and August, with July experiencing the peak of saltwater intrusion and salinity stress. The increase in saline-sodic soil negatively affects the vegetative and flowering stages of rice. It indicates that as saline-sodic soil increases, the vegetative and flowering stages are negatively affected (as indicated by the negative arrows). The vegetative stage is essential for early crop development, while the flowering stage is critical for yield formation. High salinity during either stage impedes water and nutrient uptake, resulting in stunted growth and reduced harvests.

The timing of saltwater intrusion plays a significant role in this cycle. As saltwater intrusion intensifies, it contributes to the build-up of saline-sodic conditions, particularly during the months when rice plants are transitioning from vegetative growth to flowering (Tivianton et al., 2021; Subekti et al., 2020). This timing correlates with the farmers' observations of the most severe effects occurring around July and August, as indicated in the word cloud (Subgraph (a) of Figure 6). The negative impacts during these months create a feedback loop where saline-sodic soils increase the difficulty of successful crop cultivation, further compounding the challenges for the farmers. Synthesizing the timing with causes and effects reveals that addressing saline-sodic conditions requires season-specific interventions. These include prioritizing water management and soil remediation during peak rainfall periods to reduce salinity impacts during vulnerable crop stages. This temporal insight advances the understanding of dynamic interactions between environmental stressors and crop development, contributing to precision agriculture approaches that optimize interventions based on seasonal variations.

3.1.4 Farmers' strategies for saline-sodic lowland rice soils (Theme 4)

Figure 7 depicts the strategies employed by rice farmers to combat saline-sodic conditions in their fields. The word cloud (Subgraph (a) of Figure 7) clearly highlights the predominant strategy—freshwater use—which is interconnected with other key practices such as washing, irrigating, and flushing. All the farmers consistently reported utilizing freshwater as the primary method for mitigating the effects of saline-sodic soils. This is demonstrated by one farmer's comment, "Pinapasukan ng tubig tabang para manumbalik ang sigla ng palay," which can be translated to "Irrigate with freshwater to revive the vigor of the rice plants."

Subgraph (b) of Figure 7 further illustrates the dynamics of this practice. The use of freshwater creates a balancing loop. This loop addresses the salinity issue by directly diluting salt concentrations in the soil. It demonstrates the critical role of freshwater availability in mitigating salinity stress, particularly during sensitive growth stages of rice. An increase in the level of saline-sodic soil requires an additional increase in the use of freshwater to wash the salts. However, the CLD also reflects the delays in this process, as freshwater availability fluctuates with seasonal changes and water supply limitations. The KII with the local stakeholders revealed that farmers often adjust their planting schedules based on the availability of water, sourcing it from national irrigation systems, rainwater, and shallow tube wells. Similarly, Ahmmed et al. (2020), Haldar & Debnath (2014), and

Rabbani et al. (2013) also reported that farmers waited either for rainfall or a sufficient supply of water to wash the saline-sodic soil.

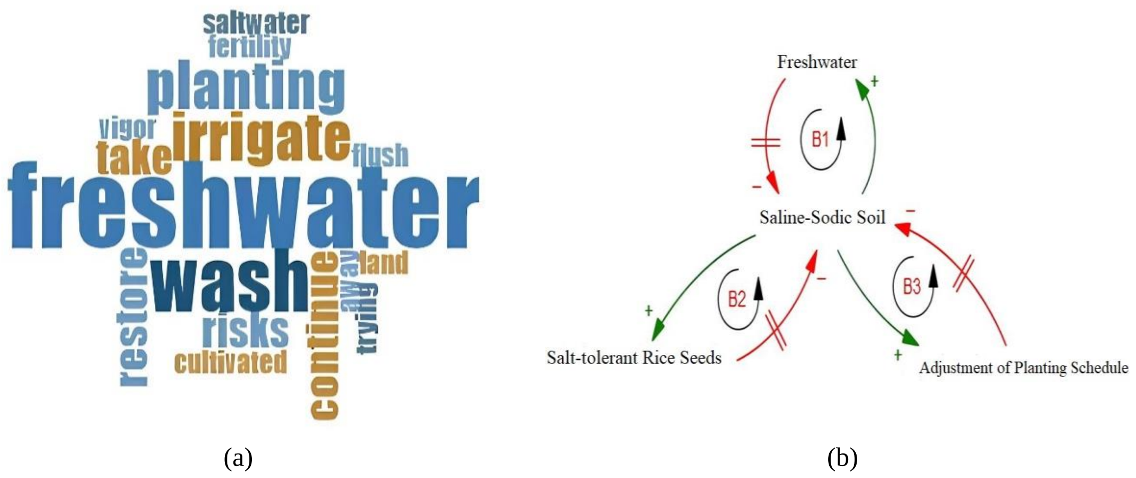


Figure 7. Word cloud of strategies practiced to address saline-sodic lowland rice soils: a) interviewed rice farmers, b) CLD of the strategies practiced to address saline-sodic lowland rice soils

Note: B means balancing; the "+" sign at the end of the arrows indicates (x ↑→ y ↑); and the "-" sign at the end of the arrows indicates (x ↑→ y ↓).

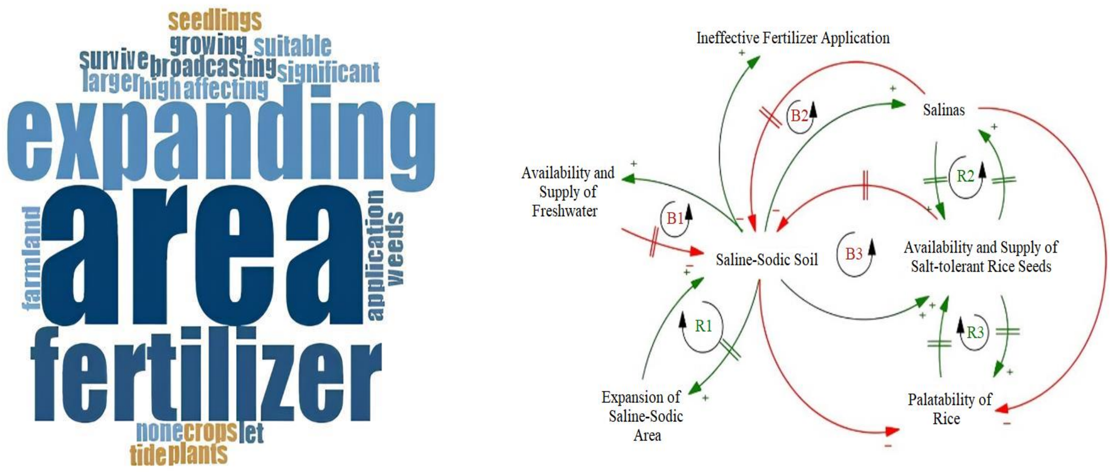
Salt-tolerant rice seeds and adjustment of the planting schedule are also shown in the CLD (Subgraph (b) of Figure 7). The use of salt-tolerant rice varieties such as the Salinas variety, creates another balancing loop (B2), where an increase in saline-sodic conditions prompts the farmers to adopt these rice varieties, ultimately reducing the adverse effects of salinity on their crops (Gregorio et al., 2014). This loop highlights an adaptive biological strategy where the focus shifts from altering soil conditions to improving the inherent tolerance of crops to salinity. This aligns with the previous findings of Kabir et al. (2017) and Rabbani et al. (2013), who documented similar strategies among farmers in other countries. The CLD also demonstrates how planting schedule adjustments create a third balancing loop (B3), whereby farmers alter planting times to mitigate the impact of saline-sodic soil. This highlights the importance of temporal management in mitigating salinity impacts. By aligning planting schedules with periods of lower salinity, farmers can optimize the growth conditions for their crops, reducing the need for external interventions. As with the other strategies, a delay is introduced due to the timing and availability of water resources. While these strategies help the farmers cope with saline-sodic soils, their effectiveness is constrained by external factors such as water availability and seed supply.

These strategies reflect an adaptive, yet resource-dependent, approach to managing saline-sodic rice soils. The observed delays in the CLD depict the importance of enhancing water infrastructure and ensuring the availability of salt-tolerant rice seeds to support farmers' resilience against salinity stress. Through a balanced integration of freshwater usage, seed selection, and planting schedule adjustments, farmers can mitigate some of the negative impacts of saline-sodic soils, though ongoing challenges remain (Biswas & Biswas, 2014; Moustafa et al., 2021; Singh et al., 2016).

The synthesis of coping strategies with timing, causes, and effects underscores the resilience of farmers in adapting to adverse conditions, albeit with significant resource dependencies. While strategies like freshwater use and salt-tolerant crops offer immediate relief, their success is constrained by systemic barriers, such as seasonal water shortages and limited access to high-quality seeds. The findings suggest a novel insight: fostering community-driven water resource management and promoting decentralized seed distribution systems could significantly enhance the scalability and sustainability of these coping mechanisms. These strategies also align with global calls for climate-resilient agricultural practices.

3.1.5 Perceived challenges of saline-sodic lowland rice soils (Theme 5)

Figure 8 provides valuable insights into the challenges rice farmers faced in dealing with saline-sodic lowland rice soils in the area. Subgraph (a) of Figure 8 highlights the most prominent challenges perceived by the farmers, including the expansion of affected areas and ineffective fertilizer application. The terms "area," "expanding," and "fertilizer" prominently reflect the farmers' concerns about the growing extent of saline-sodic soils and the ineffectiveness of fertilizers in such conditions. One farmer remarked, "lumalawak ang nahuhulaban ng alat," which can be translated to "the salt-affected area is expanding." This sentiment was echoed by the president of the farmers' association, who estimated that approximately 3.45 hectares of farmland are currently impacted by saline-sodic conditions.



(a) (b)

Figure 8. Word cloud of perceived challenges of having saline-sodic lowland rice soils: a) interviewed rice farmers, b) CLD of the challenges of having saline-sodic lowland rice soils

Note: R means reinforcing; B indicates balancing; a "+" sign at the end of arrows indicates (x ↑→ y ↑); and a "-" sign at the end of arrows indicates (x ↑→ y ↓).

Subgraph (b) of Figure 8 shows a reinforcing loop (R1) that depicts the continual expansion of saline-sodic soil. This indicates that an increase in the level of saline-sodic soil can also result in further expansion of the affected area. However, a delay is noted in this loop, reflecting the gradual nature of this expansion. As saline-sodic soil expands, it reduces the availability and quality of freshwater resources (linked by a negative arrow). This reduction in freshwater further accelerates the expansion of saline-sodic areas. This is a vicious cycle where the spread of salinity depletes critical resources, creating more saline-sodic soil and worsening the situation for farmers.

Beyond these challenges, the CLD highlights several other issues that exacerbate the difficulties the farmers faced. The availability and supply of freshwater, salt-tolerant rice varieties (Salinas), and the palatability of rice were all identified as additional concerns (Subgraph (b) of Figure 8). For instance, the use of freshwater to mitigate saline-sodic conditions is limited by seasonal availability. The farmers reported relying on irrigation from the National Irrigation Administration (NIA) or waiting for rain to wash away the salts. However, water availability is inconsistent, and rainfall patterns in Batangas fluctuate throughout the year, peaking between May and July before declining in August (Corporal-Lodangco & Leslie, 2017). This inconsistency introduces a delay in the balancing loop (B4), as freshwater is not always available when needed, delaying mitigation efforts. The KIIs confirmed that planting schedules are adjusted based on water supply, further delaying the start of the cropping season. The sources of water cited in the interviews include rainwater, national irrigation, and shallow tube wells.

Similarly, the availability of salt-tolerant rice seeds poses a challenge for farmers. Although salt-tolerant varieties, such as Salinas, have been employed to counteract saline-sodic conditions, issues with seed supply persist (R2). The farmers noted that procuring sufficient quantities of Salinas seeds each season is difficult, leading to delays in implementation. Moreover, the results from field trials have been mixed. One farmer reported that the Salinas variety exhibited stunted growth despite its salt tolerance. Others mentioned that while Salinas rice was fluffy, its taste was less appealing, with some even describing it as salty. This contradicts the findings from Gregorio et al. (2014), which highlighted Salinas as having good eating quality. The CLD shows a reinforcing loop (R3) between the availability of Salinas seeds and the palatability of rice, suggesting that the perceived palatability influences future adoption and availability of the seeds. However, this loop is balanced by the constraints imposed by the growing level of saline-sodic soils (B3), where delays in seed procurement further hinder effective adaptation.

Another significant challenge for farmers is the inefficacy of fertilizer application in saline-sodic soils. Farmers stated that fertilizer has no effect when the soil is saline-sodic. One farmer stated "Hindi na epekto ang sabog ng abono sa palay," which can be translated to "broadcasted fertilizer has no effect on rice plants." According to Machado & Serralheiro (2017), the high level of salts in the root zone causes osmotic stress and disrupts cell-ion homeostasis by inhibiting nutrient uptake.

The challenges of expanding saline-sodic areas, ineffective fertilizer application, and limited access to crucial resources such as freshwater and salt-tolerant seeds represent significant barriers to rice production in the area. While farmers have adapted through various strategies, their effectiveness is hampered by external factors, particularly the availability of resources and the delayed responses inherent in addressing saline-sodic soil. These findings are consistent with studies by Kashenge-Killenga et al. (2014) and Omar et al. (2022), who observed similar challenges in salt-affected rice farmlands.

To mitigate the impacts of saline-sodic soils, reinforcing loops like R1 (salinity expansion) must be disrupted by addressing root causes such as water scarcity and inefficient irrigation. Strengthening balancing loops (B1 and B3) is crucial for long-term sustainability, with investments in technologies and policies to enhance freshwater management and ensure steady access to salt-tolerant seeds. A combination of short-term interventions (like fertilizers tailored for saline conditions) and long-term adaptive strategies (like sufficient and timely supply of freshwater and salt-tolerant seeds) can help counteract the challenges experienced by the affected rice farmers.

The challenges reveal structural vulnerabilities in resource management and input accessibility, directly linking to the previously identified themes of causes, effects, timing, and strategies. For example, the expansion of saline-sodic soils exacerbates the effects on yield and increases dependency on freshwater irrigation, creating a reinforcing cycle of resource scarcity. An insight from this study is the critical role of balancing long-term interventions, such as enhancing irrigation infrastructure and developing saline-specific fertilizers, with short-term adaptive practices to disrupt the self-reinforcing feedback loops identified in the CLD. This insight contributes to the broader discourse on integrating short- and long-term interventions in climate-smart agriculture.

3.2 Representation, Limitations and Insights

While the study involved a smaller sample size, the sample selection was based on purposive sampling, targeting individuals with extensive and direct experience in managing saline-sodic soils. This approach ensures detailed insights into the issue, though the small sample size limits generalizability. The findings are representative of localized perceptions in the study area and should be interpreted as indicative rather than exhaustive. Future studies should expand sample sizes and incorporate diverse demographic and geographic contexts to validate these insights. These limitations highlight the need for further research to contextualize these findings in broader agricultural systems.

This study advances understanding by synthesizing the interconnected dynamics between causes, effects, timing, strategies, and challenges associated with saline-sodic soils. It emphasizes the importance of integrating farmers' perceptions with system modeling to develop targeted, context-sensitive interventions. The findings contribute novel insights into how reinforcing feedback loops perpetuate salinity issues and highlight actionable entry points for breaking these cycles through integrated soil, water, and agricultural management practices.

4. Conclusion and Recommendations

The study was conducted in barangay Navotas, Balayan, Batangas, aiming to provide a comprehensive assessment of the farmers' perceptions of saline-sodic rice farmlands in their community. The assessment was made possible using KIIs and FGDs with the help of PRA tools. Using thematic analysis and CLD to determine the causal positive and negative relationship of different factors, one major theme and five subthemes were identified. The perceptions of rice farmers with saline-sodic lowland rice soils resulted in an understanding of the causes, effects, time, strategies, and challenges of having saline-sodic soil.

Saltwater intrusion emerged as the primary cause of saline-sodic soils, attributed to high tides, river narrowing, and contributing factors such as urbanization, climate change, erosion, and improper waste disposal. These soils cause impeded plant growth and decreased harvests, leading to increased production costs and reduced incomes. Farmers highlighted July as the most critical month for saltwater intrusion, coinciding with high sea levels during the vegetative and flowering stages of rice, which are particularly vulnerable.

In response, farmers primarily use freshwater irrigation to mitigate salt levels, though they also consider salt-tolerant rice varieties and adjusted planting schedules. However, these strategies face limitations, including delays in freshwater availability and seed supply. The challenges of expanding saline-affected areas and ineffective fertilizer applications further exacerbate the issue.

This study revealed a complex interplay of environmental and socio-economic factors driving soil salinization in the area. It shows the necessity for proactive interventions to safeguard farmers' livelihoods. The findings contribute novel insights into the temporal patterns of saline-sodic soil occurrence and the adaptive strategies employed by small-scale rice farmers, enhancing the understanding of localized agricultural challenges.

To address the issues identified in the study, several policy and practical recommendations were proposed. Firstly, investing in sustainable freshwater supply systems and flood control infrastructure is crucial to preventing saltwater intrusion and ensuring reliable water sources for irrigation. Secondly, improving access to salt-tolerant rice varieties through government-subsidized seed programs and enhanced distribution channels can significantly aid farmers in managing saline-sodic soils. Additionally, capacity-building initiatives are essential; these should include farmer training programs focused on effective soil management practices and optimizing fertilizer applications to combat salinity. Research and promotion of province-specific planting schedules can further mitigate the adverse effects of saline-sodic soils on critical crop stages, ensuring better alignment with seasonal challenges. Lastly, the establishment of localized monitoring and early warning systems can enable timely predictions and interventions to mitigate the impacts of high tides and saltwater intrusion, providing farmers with critical information to adapt effectively. These measures collectively aim to enhance agricultural resilience and productivity in areas affected by saline-sodic soils.

While this study is specific to Navotas, Balayan, the findings offer valuable implications for other regions facing similar challenges of soil salinization. The seasonal trends, strategies, and challenges identified may serve as a framework for understanding and addressing saline-sodic soil issues in coastal agricultural areas globally. However, further research is required to adapt these insights to regions with differing climatic, geographical, and socio-economic conditions.

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Informed Consent Statement

The study had undergone ethics certification from the University of the Philippines Los Baños (UPLB) Research Ethics Board (Study protocol code UPLB REB 2023-0038). Informed consent was sought from the participants before the activities were conducted in barangay Navotas, Balayan, Batangas. Information sheets were provided to all the participants regarding the context and process of the study. Participation was voluntary. The participants had the right to refuse or stop partaking before, during, or after the activity. Photo documentation and audio recording was also requested for consent, and the participants were given the right to refuse to be photographed or audio recorded.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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