Article

The Green Development in Saline–Alkali Lands: The Evolutionary Game Framework of Small Farmers, Family Farms, and Seed Industry Enterprises

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ABSTRACT: Amid global climate change and population growth, the prevalence of saline–alkali lands significantly hampers sustainable agricultural development. This study employs theories of asymmetric information and bounded rationality to construct an evolutionary game model, analyzing the interactions among small farmers, family farms, and seed industry enterprises in the context of saline–alkali land management. It investigates the strategic choices and dynamics of these stakeholders under the influence of economic incentives and risk perceptions, with a focus on how government policies can foster green development. Utilizing Delay Differential Equations (DDEs) for simulations, this study highlights the risk of “market failure” without government intervention and underscores the need for government participation to stabilize and improve the efficiency of the green development process. The findings reveal that factors such as initial willingness to participate, the economic viability of salt-tolerant crops, seed pricing, research and development costs, and the design of incentive policies are crucial for sustainable land use. Accordingly, the paper proposes specific policy measures to enhance green development, including strengthening information dissemination and technical training, increasing the economic attractiveness of salt-tolerant crops, alleviating research and development pressures on seed companies, and optimizing economic incentives. This study provides a theoretical and policy framework for the sustainable management of saline–alkali lands, offering insights into the behavioral choices of agricultural stakeholders and supporting government strategies for agricultural and environmental protection.

KEYWORDS: saline–alkali land; salt-tolerant crops; technology extension; evolutionary game; Delay Differential Equation (DDE)

1. Introduction

Amid intensifying global climate change and burgeoning populations, traditional agricultural resources are under unprecedented pressure. Drought, soil pollution, and salinization are gradually weakening the productivity of traditional arable land, severely constraining the effective use of land resources and the sustainable development of agriculture [1–3]. Given these conditions, the comprehensive development and utilization of saline–alkali lands, which are widely distributed globally, have become viable means to unlock the potential of agriculture [4]. However, traditional physical and chemical amelioration methods for these lands, such as deep plowing, salt washing, and gypsum application, are costly, inefficient, and environmentally destructive, often leading to secondary salinization and alkalinization while consuming significant water resources [5,6]. In contrast, salt-tolerant crops, exemplified by salt-tolerant rice varieties, can adapt to saline–alkali environments and improve soil aeration and fertility through biological amelioration by their root systems, thereby enhancing the soil’s ecological environment [7,8]. The successful development of such crops could spearhead a green revolution in saline–alkali...
lands, offering new solutions for global food security. Specifically, compared to traditional saline-alkali land development techniques, the research and application of salt-tolerant crops not only provide a substantial increase in arable land for food production but also alleviate ecological pressure on arable lands, enhance biodiversity, and ultimately promote the overall sustainability of agricultural ecosystems. This green development model for saline-alkali lands is promising. However, green development centered on the promotion of salt-tolerant crops is not merely a technical issue; it involves a complex economic system encompassing farmers’ decision-making, industry support, and policy environments, which entails a multifaceted interplay and strategic evolution among various stakeholders.

In the past decade or so, the continuous development and application of research in saline-alkali land improvement and eco-agricultural technologies have led to the emergence of new techniques that integrate ecological and economic benefits. Existing methods for developing saline-alkali soils can be primarily categorized into two types: soil amendment and innovation in the seed industry.

Soil amendment techniques can be further divided into four subtypes: (1) Physical amendment techniques aim to change the soil structure and porosity characteristics, thereby increasing the efficiency of salt leaching and reducing the soil’s salt content. This is achieved through conventional methods such as conservation tillage techniques, deep loosening, deep turning, straw return, and coverage, as well as microbial consolidation techniques [9–12]. (2) Chemical amendment techniques involve the application of substances such as gypsum, sulfates, organic acids, and other chemical conditioners. The primary goal is to induce a substitution reaction between these chemical agents and the sodium ions in the soil, reducing exchangeable sodium, which in turn improves the soil’s waterlogging and saline–alkaline properties [13–15]. (3) Biological amendment techniques incorporate salt-tolerant microbial communities and organic fertilizers to increase the accumulation of organic matter in the soil, thereby enhancing soil structure. Additionally, the use of green manure crops and cover crops’ root systems’ biological effects aim to improve soil aggregate structure and fertility [16,17]. (4) Salinity management techniques utilize water conservancy facilities for regular leaching and effective drainage systems. Good hydrological management allows soil salts to migrate to the surface and be expelled with water, thereby reducing the soil’s salt content [18–20].

Research on salt-tolerant seed industry innovation can also be divided into four categories: (1) Traditional salt-tolerant crop screening techniques rely on conventional hybrid breeding and the collection of wild germplasm resources to select crop varieties that can thrive in high-saline–alkali environments [21,22]. (2) Molecular breeding techniques utilize modern biotechnological methods such as molecular marker-assisted selection to identify crops with salt-tolerant genes [23–25]. (3) Microbial-assisted breeding techniques focus on exploiting rhizosphere microorganisms like arbuscular mycorrhizal fungi, including Glomus and diverse sporocysts, to enhance the crops’ salt tolerance [26,27]. (4) Genome editing breeding techniques apply tools like CRISPR-Cas9 for precise editing of crop genomes to target and improve genes related to salt tolerance [28,29]. The referenced methods are based on nature-based solutions (NBSs), which are increasingly garnering attention in studies focused on sustainable agricultural development. These methods, by mimicking, enhancing, or protecting natural processes, aim to address environmental, social, and economic challenges [30,31]. The diversity of NBS includes practices like ecological agriculture and crop diversification, which not only enhance land productivity and promote biodiversity but also aid in combating climate change [32,33]. However, farmers face numerous challenges in adopting these methods, including insufficient funding, a lack of technical knowledge, and restricted market access. To encourage the broader adoption of NBS in agriculture, measures such as policy support, education and training, and technology transfer are necessary, along with emphasizing the importance of cross-sectoral collaboration [34,35].
Existing research on smallholders, family farms, and seed industry enterprises lays a solid theoretical foundation for this study. Within the agricultural systems of many developing countries, smallholders serve as the fundamental units of agricultural production. Taking Brazil and China as examples, these smallholders often manage less than 2 hectares of land [36,37]. The degree to which these smallholders adopt agricultural innovations is directly related to the depth and breadth of technology dissemination. However, due to their small scale, limited resource endowments, weak risk resistance, and insufficient access to information, smallholders struggle to benefit from economies of scale and market economies. Their natural shortcomings necessitate reliance on external technical guidance and financial support to adopt new agricultural production technologies [38–41]. These factors limit the enthusiasm and ability of smallholders to adopt salt-tolerant crops. Therefore, devising policies and market mechanisms to lower the barriers for smallholders and enhance their adaptive capacity is a critical issue to address. Family farms, specialized agricultural producers relying primarily on farm product income, are characterized by an operational scale exceeding a certain acreage threshold. For example, Brazil mandates a minimum of 5 hectares [42–44]. Compared to smallholders, family farms, as modern agricultural entities, usually possess greater resource integration capabilities and market adaptability. Through large-scale, intensive management, they effectively integrate land, capital, and technological resources, driving the modernization of agricultural production models [45–48]. Due to these factors, family farms can respond more rapidly to policy and market changes, adopt salt-tolerant crop cultivation technologies, and improve agricultural output by leveraging economies of scale. Nevertheless, during the process of cultivating salt-tolerant crops, family farms may inadvertently encroach upon the livelihood space of smallholders, leading to potential conflicts of interest, which necessitates effective market mechanisms and policy designs to coordinate the interests of different actors. The seed industry, an element-intensive high-tech industry, is characterized by high investment, significant risk, and long cycles. Hence, it relies heavily on large seed industry enterprises, which play a central role in the innovation, production, and dissemination of new agricultural varieties. The direction of their research and development, pricing of varieties, and after-sales services are crucial to the widespread adoption of new seeds [49–51]. However, there is an inherent contradiction between the commercial objectives of seed industry enterprises and the livelihood goals of smallholders [52–54]. Addressing this contradiction is crucial for promoting the sustainable development of saline–alkali lands.

In summary, although existing studies have explored the role and characteristics of smallholders, family farms, and seed industry enterprises in the dissemination of new crop varieties to varying degrees, providing a good research basis for this paper, they tend to focus on a single actor or a few influencing factors, lacking a comprehensive study of the collaborative promotion process. This paper employs evolutionary game theory as its research methodology to conduct an in-depth analysis of the interactions and strategic evolution among smallholders, family farms, and seed industry enterprises within the context of green development in saline–alkali lands. It aims to establish a cooperative framework for the green development of these lands and to explore the dynamics of stakeholder interactions under the green development paradigm, thereby facilitating the advancement of green development in saline–alkali territories. Unlike traditional evolutionary games that use Ordinary Differential Equations (ODEs), this study employs Delay Differential Equations (DDEs) in numerical simulations, allowing actors to consider previous decisions when making current choices. This approach better simulates the real world and more accurately identifies the game rules within this dynamic system. This, in turn, informs the design of policy tools to guide all parties toward positive interactions, collectively advancing the green revolution in saline–alkali lands and achieving sustainable agricultural development.
2. Materials and Methods

This section aims to construct a tripartite evolutionary game model to thoroughly examine the interactive behaviors and evolutionary trends among smallholders, family farms, and seed industry enterprises in the green development of saline–alkali lands under both market mechanisms and government guidance. Beginning with theoretical assumptions, we will progressively develop and analyze the model in hopes of identifying the dynamic equilibrium within this complex interaction system, thereby laying the groundwork for subsequent analyses.

2.1. Evolutionary Game Model of “Smallholder–Family Farm–Seed Enterprise” under Market

This subsection constructs a tripartite evolutionary game model with the aim of deeply analyzing the strategic choices and behavioral dynamics of smallholders, family farms, and seed industry enterprises in the green development of saline–alkali lands in the absence of direct government intervention under market mechanism conditions. By establishing the model’s basic assumptions and strategic settings and systematically analyzing its evolutionary dynamics, it lays the foundation for further analysis.

2.1.1. Basic Assumptions of the Model

This paper establishes an evolutionary game model involving three parties in the green development of saline–alkali land under market mechanisms to explore whether government intervention is necessary.

Assumption 1: In the evolutionary game model of salt-tolerant crop cultivation without government participation, there are three types of participants: smallholders (S), family farms (F), and seed enterprises (E). “S (smallholders)” refers to farmers who manage and operate agricultural land on a limited scale, primarily engaging in subsistence farming and small-scale agricultural activities. “F (family farms)” are defined as agricultural operations owned and managed by families, typically larger than smallholdings, that combine family labor with agricultural production primarily for commercial purposes. “E (seed industry enterprises)” denotes companies involved in the development, production, and distribution of agricultural seeds, including the provision of after-sales services and technical support to farmers. Smallholders and family farms are responsible for planting salt-tolerant crops, while seed enterprises provide them with seeds and after-sales services. All players are assumed to have bounded rationality and aim to identify their optimal strategies through repeated games.

Assumption 2: Before proceeding with further analysis, it is essential to acknowledge that the presence of information asymmetry is inevitable and has profound implications for agricultural production and development. Within this context, the information asymmetry between smallholders, family farms, and the seed industry primarily stems from several sources. Firstly, the disparity in accessing technology constitutes a significant dimension of information asymmetry. Smallholders often lack channels to access advanced agricultural technologies, whereas family farms and large seed industry enterprises typically possess stronger research and development capabilities and a broader exposure to technology, thus far surpassing smaller producers in the acquisition and application of information. Secondly, differences in accessing market information also play a pivotal role in creating information asymmetry. Due to their small scale, smallholders frequently lack efficient channels for obtaining market information, placing them at a disadvantage in making cropping choices, forecasting profits, and assessing risks. Conversely, family farms and large enterprises leverage their scale advantage and market influence to gather market information through various channels, including price trends, demand shifts, and international market changes, thereby securing a favorable position in market decision-making. Lastly, the disparity in the level of expertise and resources contributes significantly to information asymmetry. Smallholders often face limitations in capital, labor, and other resources, restricting their ability to acquire and utilize specialized knowledge for
production optimization and innovation. In contrast, large enterprises not only have substantial financial support but can also attract high-level talents, providing robust backing for their research and development and market promotion efforts.

Assumption 3: Smallholders and family farms may choose whether to participate in the green development of saline–alkali land, with initial inclinations represented by X and Y, respectively. Seed enterprises may decide whether to develop and sell salt-tolerant crop seeds to smallholders and family farms, with an initial inclination of Z. If seed enterprises do not provide salt-tolerant crop seeds, even if smallholders and family farms opt to participate in green development, they can only cultivate conventional crops without using traditional improvement methods. If the smallholders and family farms do not participate, they neither incur costs nor receive benefits.

Assumption 4: Both smallholders and family farms are agricultural producers on saline–alkali lands. However, due to differences such as larger scale, higher modernization, broader information access, and greater risk tolerance, family farms tend to differ from smallholders in their adoption of new technologies, agricultural product pricing, and production costs, leading to an inherently asymmetric game. It is assumed that the price at which a smallholder sells one unit of agricultural product is \( P_t \); and for a family farm, \( P_s \), where \( 0 < P_t < P_s \). Agricultural production inevitably incurs fixed costs, including labor, materials, and financial resources. Due to economies of scale, the marginal cost of cultivation for smallholders is generally higher than that for family farms. Thus, this paper sets the planted yield for smallholders’ crops at \( Q_t \), with fixed costs \( C_t \) and expenditures for salt-tolerant crop seeds \( L_t \). Smallholders typically retain a portion of their produce for basic living needs, denoted by a proportion \( b \). For family farms, the planted yield is \( Q_s \), fixed costs are \( C_s \), and expenditures for seeds are \( L_s \), satisfying \( 0 < C_t/Q_t < C_s/Q_s \). Lastly, since saline–alkali lands are barren, the income from planting conventional crops without improvement measures is insufficient for profitability. Hence, the paper defines the economic thresholds as \( bP_tQ_t \leq C_t \) and \( P_sQ_s \leq C_s \). Additionally, planting salt-tolerant crops increases yield, and due to their nutritional value, these crops can be sold at higher prices. Consequently, the paper sets the economic value coefficient for salt-tolerant crops at \( a \).

Assumption 4: Seed enterprises inherently incur a cost of \( C_t \) when selling conventional seeds. Whether through in-house development or acquisition from upstream institutions, there are inevitable R&D costs associated with salt-tolerant crops, including labor, materials, and financial resources. The paper defines an additional cost coefficient \( (W) \) for seed enterprises after offering salt-tolerant crops. Since salt-tolerant seeds generally command a higher price than standard rice seeds, the paper sets a sales price coefficient \( S \), where conventional seed prices were denoted by \( L_t \) and \( L_s \) previously. Typically, seed enterprises aim for profit, and thus, the paper stipulates \( 0 < C_t < L_t + L_s \) and \( 1 < W < S \).

Based on the above assumptions, the paper constructs the parameters and payoff matrix for the evolutionary game model, as shown in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Meaning of the Variables</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X )</td>
<td>Willingness of smallholders to participate.</td>
<td>( 0 \leq X \leq 1 )</td>
</tr>
<tr>
<td>( Y )</td>
<td>Willingness of family farm to participate.</td>
<td>( 0 \leq Y \leq 1 )</td>
</tr>
<tr>
<td>( Z )</td>
<td>Willingness of enterprises to participate.</td>
<td>( 0 \leq Z \leq 1 )</td>
</tr>
<tr>
<td>( P_t )</td>
<td>smallholders’ selling prices for agricultural products.</td>
<td>( 0 &lt; P_t &lt; P_s )</td>
</tr>
<tr>
<td>( P_s )</td>
<td>Selling prices of agricultural products for family farms.</td>
<td>( 0 &lt; P_t &lt; P_s )</td>
</tr>
<tr>
<td>( Q_t )</td>
<td>smallholders’ cultivated area.</td>
<td>( 0 &lt; C_t/Q_t &lt; C_t/Q_t )</td>
</tr>
<tr>
<td>( Q_s )</td>
<td>Cultivated area of family farm.</td>
<td>( 0 &lt; C_t/Q_t &lt; C_t/Q_t )</td>
</tr>
<tr>
<td>( C_t )</td>
<td>Normal operating costs of smallholder for cultivation.</td>
<td>( 0 &lt; C_t/Q_t &lt; C_t/Q_t )</td>
</tr>
<tr>
<td>( C_s )</td>
<td>Normal operating costs of family farms for cultivation.</td>
<td>( 0 &lt; C_t/Q_t &lt; C_t/Q_t )</td>
</tr>
<tr>
<td>( L_t )</td>
<td>Additional costs for smallholder cultivating salt-tolerant rice.</td>
<td>( 0 &lt; L_t/Q_t &lt; L_t/Q_t )</td>
</tr>
<tr>
<td>( L_s )</td>
<td>Additional costs for family farm cultivating salt-tolerant rice.</td>
<td>( 0 &lt; L_t/Q_t &lt; L_t/Q_t )</td>
</tr>
</tbody>
</table>

Table 1. Parameter Table for Tripartite Evolutionary Game Model under Market Mechanism.
| Cost of producing conventional seeds for enterprises. | \(0 < C_1 < L_1 + L_2\) |
| Sales price coefficient of salt-tolerant rice seeds. | \(1 < W < S\) |
| Production cost coefficient of salt-tolerant rice seeds. | \(1 < W < S\) |
| Economic value | \(0 < a\) |
| Proportion of agricultural products sold by smallholders. | \(0 \leq b \leq 1\) |

2.1.2. Solution for Stable Strategies under Market Mechanism

The paper sets the expected benefit for smallholders choosing to develop saline–alkali land as \(F_{x11}\), the expected benefit of not developing as \(F_{x12}\), and the average expected benefit as \(\overline{F_x}\). The specific formulation is given by Equation (1):

\[
F_{x11} = yz(abP_1Q_1 - C_1 - SL_1) + y(l - z)(bP_1Q_1 - C_1 - SL_1) + (l - y)z(abP_1Q_1 - C_1 - SL_1) + (l - y)(l - z)(bP_1Q_1 - C_1 - SL_1)
\]

\[
F_{x12} = 0
\]

\[
\overline{F_x} = xF_{x11} + (1 - x)F_{x12}
\]

The replicator dynamic equation for smallholders’ strategy selection is given by Equation (2):

\[
F(x) = \frac{dx}{dt} = x(F_{x11} - \overline{F_x}) = x(l - x)(bP_1Q_1 + z((a - 1)bP_1Q_1 + (1 - S)L_1) - C_1 - L_1)
\]

The paper sets the expected benefit for family farms choosing to develop saline–alkali land as \(F_{y11}\), the expected benefit of not developing as \(F_{y12}\), and the average expected benefit as \(\overline{F_y}\). The specific formulation is given by Equation (3):

\[
F_{y11} = xz(abP_2Q_2 - C_2 - SL_2) + x(l - z)(P_2Q_2 - C_2 - L_2) + (l - x)z(abP_2Q_2 - C_2 - SL_2) + (l - x)(l - z)(P_2Q_2 - C_2 - L_2)
\]

\[
F_{y12} = 0
\]

\[
\overline{F_y} = yF_{y11} + (1 - y)F_{y12}
\]

The replicator dynamic equation for family farms’ strategy selection is given by Equation (4):
\[ F(y) = \frac{dy}{dt} = y(F_{z11} - \overline{F_z}) = y(1 - y)(P_2Q_2 + z((a - I)P_2Q_2 + (1 - S)L_2) - C_2 - L_2) \] (4)

The paper sets the expected benefit for seed enterprises developing salt-tolerant crops as \( F_{z11} \), the expected benefit of not developing as \( F_{z12} \), and the average expected benefit as \( F_z \). The specific formulation is given by Equation (5):

\[
\begin{align*}
F_{z11} &= xy(S(L_1 + L_2) - WC_1) + x(1 - y)(SL_1 - WC_1) + (1 - x)y(SL_2 - WC_2) + (1 - y)(1 - y)(-WC_2) \\
F_{z12} &= xy(L_1 + L_2 - C_2) + x(1 - y)(L_1 - C_2) + (1 - x)y(L_2 - C_2) + (1 - y)(1 - y)(-C_3) \\
\overline{F_z} &= zF_{z11} + (1 - z)F_{z12}
\end{align*}
\] (5)

The replicator dynamic equation for seed enterprises’ strategy selection is given by Equation (6):

\[
F(z) = \frac{dz}{dt} = z(F_{z11} - \overline{F_z}) = z(1 - z)((I - W)C_2 + (S - I)(xL_1 + yL_2))
\] (6)

By combining Equations (2), (4), and (6), one can derive the replicator dynamics equations for the tripartite evolutionary game system involving smallholders, modern agricultural operators, and seed enterprises and conduct a local stability analysis using the Jacobian matrix. The resulting Jacobian matrix is given by Equation (7):

\[
J = \begin{bmatrix}
J_{11}, 0, x(1 - x)((a - I)bP_2Q_2 + (1 - S)L_1) \\
0, J_{22}, y(1 - y)((a - I)bP_2Q_2 + (1 - S)L_2) \\
z(1 - z)((S - I)L_1), z(1 - z)((S - I)L_2), J_{33}
\end{bmatrix}
\] (7)

\[
\text{NOTE:}
\begin{align*}
J_{11} &= (1 - 2x)(bP_2Q_2 + z((a - I)bP_2Q_2 + (1 - S)L_1) - C_1 - L_1) \\
J_{22} &= (1 - 2y)(P_2Q_2 + z((a - I)bP_2Q_2 + (1 - S)L_2) - C_2 - L_2) \\
J_{33} &= (1 - 2z)((I - W)C_2 + (S - I)(xL_1 + yL_2))
\end{align*}
\]

Based on the parameter constraints from Table 1, the parameter assignments given in Table 3 are graphically represented in Figure 1. On the left side of Figure 1, the phase diagram depicts the dynamics of the system evolving without considering historical decisions using the ODE algorithm; on the right side, the phase diagram shows the system’s evolution with historical decisions considered using the DDE algorithm, with a lag period of one year.

**Table 3. Parameter Assignment for Evolutionary Game Model under Market Mechanism.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>P_1</th>
<th>P_2</th>
<th>Q_1</th>
<th>Q_2</th>
<th>C_1</th>
<th>C_2</th>
<th>L_1</th>
<th>L_2</th>
<th>C_3</th>
<th>S</th>
<th>W</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td>6</td>
<td>10</td>
<td>60</td>
<td>4</td>
<td>20</td>
<td>20</td>
<td>1.6</td>
<td>1.4</td>
<td>1.5</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observing Figure 1, it is apparent that under the given parameters and without considering historical decisions, the dynamic system of the tripartite evolutionary game often converges to the point E1(0,0,0), where none of the parties choose to develop the saline–alkali land. When historical decisions are taken into account, the dynamic system tends to converge to points E1(0,0,0) and E4(0,0,1), with a subset of smallholders willing to develop the saline–alkali land due to the availability of more suitable salt-tolerant seeds from seed enterprises, increasing their willingness to participate. However, regardless of historical
decisions, the tripartite evolutionary game system for the green development model of saline–alkali land struggles to reach the optimal equilibrium point E8(1,1,1) through market mechanisms alone. This is primarily because, without external incentives such as government subsidies, technical support, or target pricing measures, smallholders and family farms are reluctant to undertake the risks associated with developing saline–alkali lands. Moreover, due to longstanding habits and conventional thinking, they believe that saline–alkali lands are unsuitable for crop cultivation, especially in the absence of successful cases. Lastly, the green development of saline–alkali lands has positive externalities, meaning the social benefits exceed individual gains. In such scenarios, market mechanisms often lead to resource misallocation and market failure, making government intervention particularly important.

![Figure 1. Phase Diagram of Game Dynamic System Evolution under Market Mechanism.](image)

2.2. The Tripartite Evolutionary Game Model of “Smallholder–Family Farm–Seed Enterprise” under Government Guidance

2.2.1. Basic Assumptions of the Model

In this paper, we have established a tripartite evolutionary game model under government guidance, incorporating a new assumption labeled Assumption 5.

Assumption 6: It is postulated that when a smallholder opts to cultivate saline–alkali land and seed enterprises do not provide salt-tolerant crop seeds, the government will offer a subsidy labeled $M_{01}$ to the smallholder. Conversely, if seed enterprises do provide salt-tolerant crop seeds, the subsidy given to the smallholder is denoted as $M_{2}$. Given the higher adoption cost of planting salt-tolerant crops, it is assumed that $0 < M_{2} < M_{01}$. Similarly, for family farms that choose to cultivate saline–alkali land without the provision of salt-tolerant seeds by seed enterprises, a subsidy of $M_{01}$ is provided. If salt-tolerant seeds are provided, the subsidy is $M_{02}$, again adhering to the assumption that $0 < M_{02} < M_{2}$. Due to higher adoption costs. When seed enterprises decide to research and develop salt-tolerant crop seeds, they receive a subsidy denoted as $M_{3}$.

Bearing these assumptions in mind, the evolutionary game parameters and payoff matrices under government guidance have been redefined, as shown in Tables 4 and 5.

<table>
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<td>$0 \leq X \leq 1$</td>
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<tr>
<td>$Y$</td>
<td>Willingness of family farm to participate.</td>
<td>$0 \leq Y \leq 1$</td>
</tr>
<tr>
<td>$Z$</td>
<td>Willingness of enterprises to participate.</td>
<td>$0 \leq Z \leq 1$</td>
</tr>
<tr>
<td>$P_{1}$</td>
<td>Smallholders’ selling prices for agricultural products.</td>
<td>$0 &lt; P_{1} &lt; P_{2}$</td>
</tr>
<tr>
<td>$P_{2}$</td>
<td>Selling prices of agricultural products for family farms.</td>
<td>$0 &lt; P_{1} &lt; P_{2}$</td>
</tr>
<tr>
<td>$Q_{1}$</td>
<td>Smallholders’ cultivated area.</td>
<td>$0 &lt; Q_{1} &lt; Q_{2}$</td>
</tr>
<tr>
<td>$Q_{2}$</td>
<td>Cultivated area of family farm.</td>
<td>$0 &lt; Q_{1} &lt; Q_{2}$</td>
</tr>
</tbody>
</table>
Table 5. Payoff Matrix for the Tripartite Evolutionary Game under Government Guidance.

<table>
<thead>
<tr>
<th>Family Farm</th>
<th>Participate</th>
<th>Not Participate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Producing Salt-tolerant Crop Seeds</td>
<td>abP1Q1 + M12C1−SL1</td>
<td>abP1Q1 + M12C1−SL1</td>
</tr>
<tr>
<td>Smallholder Participate</td>
<td>aP1Q1 + M12C1−SL1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>S(L1 + L2) + M3−WC3</td>
<td>SL1 + M3−WC3</td>
</tr>
<tr>
<td>Smallholder Not Participate</td>
<td>aP1Q1 + M12C1−SL1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SL2 + M3−WC3</td>
<td>M3−WC3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enterprise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Producing Salt-tolerant Crop Seeds</td>
<td>bP1Q1 + M12C1−L1</td>
<td>bP1Q1 + M12C1−L1</td>
</tr>
<tr>
<td>Smallholder Participate</td>
<td>P1Q1 + M12C1−L1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>L1 + L2−C1</td>
<td>L1−C1</td>
</tr>
<tr>
<td>Smallholder Not Participate</td>
<td>P1Q1 + M12C1−L1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>L2−C1</td>
<td>−C1</td>
</tr>
</tbody>
</table>

2.2.2. Solution of Evolutionary Stable Strategies under Government Guidance

This paper posits that the expected profit for small-scale farmers opting to develop saline–alkali land is denoted as $U_{x12}$, whereas the expected profit for choosing not to develop is $U_{x12}$, with the average expected profit being represented as $\bar{U}_x$. The specific setup is as per Equation (8):

$$U_{x11} = yz(abP1Q1 + M12−C1−SL1) + y(I-z)(bP1Q1 + M12−C1−SL1) + (I-y)z(abP1Q1 + M12−C1−SL1) + (I-y)(I-z)(bP1Q1 + M12−C1−SL1)$$

$$U_{x12} = 0$$

$$\bar{U}_x = xU_{x11} + (1-x)U_{x12}$$

The replicator dynamics equation for the strategic choice of small-scale farmers is given by Equation (9):

$$U(x) = \frac{dx}{dt} = x(U_{x11} - \bar{U}_x) =$$

$$x(I-x)(bP1Q1 + z((a - l)bP1Q1 + (l - S)L1 + M2 − M0)i) - C1 − L1 − M1i)$$
The expected profit for family farms when choosing to develop saline-alkali land is denoted as $U_{y11}$, while the expected profit for not developing is $U_{y12}$, and the average expected profit is $\overline{U}_y$, as specified in Equation (10):

$$U_{y11} = x(z(aP_2Q_2 + M_{22} - C_2 - SL_2) + x(I - z)(P_2Q_2 + M_{12} - C_2 - L_2) + (I - x)z(aP_2Q_2 + M_{22} - C_2 - SL_2) + (I - x)(I - z)(P_2Q_2 + M_{12} - C_2 - L_2)$$

$$U_{y12} = 0$$

$$\overline{U}_y = yU_{y11} + (I - y)U_{y12}$$

The replicator dynamics equation for the strategic choice of family farms is represented by Equation (11):

$$U(y) = \frac{dy}{dt} = y(U_{y11} - \overline{U}_y) = y(I - y)(P_2Q_2 + z((a - I)P_2Q_2 + (I - S)L_2 + M_{22} - M_{12})C_2 - L_2 - M_{12})$$

The expected profit for seed industry businesses engaged in the research and development of salt-tolerant crops is expressed as $U_{z11}$, compared to the expected profit when not engaging in $U_{z12}$, with the average expected profit being $\overline{U}_z$, as detailed in Equation (12):

$$U_{z11} = x(y(S_L + L_2) + M_{12} - WC_j) + x(I - y)(SL_2 + M_{22} - WC_j) + (I - x)y(S_L + M_{12} - WC_j) + (I - y)(I - z)(M_{12} - WC_j)$$

$$U_{z12} = x(y(L_i + L_2 - C_j) + x(I - y)(L_i - C_j) + (I - x)y(L_i - C_j) + (I - y)(I - z)(-C_j)$$

$$\overline{U}_z = zU_{z11} + (I - z)U_{z12}$$

The strategy selection replicator dynamics equation for seed industry businesses is outlined in Equation (13):

$$U(z) = \frac{dz}{dt} = z(U_{z11} - \overline{U}_z) = z(I - z)((I - W)C_3 + M_3 + (S - I)(xL_i + yL_2))$$

By combining Equations (9), (11), and (13), one can establish the replicator dynamics equations for the tripartite evolutionary game system of small-scale farmers, family farms, and seed industry businesses. Analyzing the local stability of the Jacobian matrix $J_2$, we ultimately derive the system’s Jacobian matrix as Equation (14):

$$J_2 = \begin{bmatrix} J_{11}, 0, x(I - x)((a - I)bP_2Q_1 + (I - S)L_1 + M_{22} - M_{12}) \\ 0, J_{22}, y(I - y)((a - I)P_2Q_2 + (I - S)L_2 + M_{22} - M_{12}) \\ z(I - z)((S - I)L_1), z(I - z)((S - I)L_2), J_{33} \end{bmatrix}$$

NOTE:

$$J_{11} = (I - 2x)(bP_2Q_1 + z((a - I)bP_2Q_1 + (I - S)L_1 + M_{22} - M_{12}) - C_1 - L_1 - M_{12})$$

$$J_{22} = (I - 2y)(P_2Q_2 + z((a - I)P_2Q_2 + (I - S)L_2 + M_{22} - M_{12}) - C_2 - L_2 - M_{12})$$

$$J_{33} = (I - 2z)((I - W)C_3 + M_3 + (S - I)(xL_i + yL_2))$$

According to Lyapunov’s 1992 research [55], equilibria in a three-party evolutionary game system should be asymptotically stable if and only if these points fulfill the stringent Nash equilibrium and pure strategy equilibrium conditions, making them Evolutionarily Stable Strategies (ESSs). By setting the system dynamics to zero, we identify eight locally stable equilibrium points: E1(0,0,0), E2(1,0,0), E3(0,1,0), E4(0,0,1), E5(1,1,0), E6(1,0,1), E7(0,1,1), and E8(1,1,1). These points form the boundaries of the evolutionary game domain, within which all equilibria are mixed strategy Nash equilibria but not stable ESS. Therefore, this study mainly investigates the asymptotic stability of the aforementioned
eight boundary equilibrium points. As per Friedman’s 1991 research [56], the stability of asymptotic equilibria depends on the sign characteristics of the Jacobian matrix; if all eigenvalues of the Jacobian matrix are negative, the equilibrium point is considered an ESS. After substituting the eight equilibrium points into the Jacobian matrix, the eigenvalues are presented in Table 6.

Table 6. Eigenvalues of the Jacobian Matrix.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
<th>$\lambda_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1(0,0,0)</td>
<td>$bP_1Q_1 + M_{12}C_{12} - L_2$</td>
<td>$P_2Q_2 + M_{23}C_{23} - L_2$</td>
<td>$M_3 + (1-W)C_3$</td>
</tr>
<tr>
<td>E2(1,0,0)</td>
<td>$-(bP_1Q_1 + M_{12}C_{12})$</td>
<td>$P_2Q_2 + M_{23}C_{23} - L_2$</td>
<td>$M_3 + (1-W)C_3 + (S-1)L_1$</td>
</tr>
<tr>
<td>E3(0,1,0)</td>
<td>$bP_1Q_1 + M_{12}C_{12}$</td>
<td>$-(P_2Q_2 + M_{23}C_{23} - L_2)$</td>
<td>$M_3 + (1-W)C_3 + (S-1)L_2$</td>
</tr>
<tr>
<td>E4(0,0,1)</td>
<td>$abP_1Q_1 + M_{12}C_{12} - L_2$</td>
<td>$aP_2Q_2 + M_{23}C_{23} - L_2$</td>
<td>$-(M_3 + (1-W)C_3)$</td>
</tr>
<tr>
<td>E5(1,1,0)</td>
<td>$-(bP_1Q_1 + M_{12}C_{12})$</td>
<td>$-(P_2Q_2 + M_{23}C_{23} - L_2)$</td>
<td>$M_3 + (1-W)C_3 + (S-1)L_1 + L_2$</td>
</tr>
<tr>
<td>E6(1,0,1)</td>
<td>$-(abP_1Q_1 + M_{12}C_{12} - L_1)$</td>
<td>$aP_2Q_2 + M_{23}C_{23} - L_2$</td>
<td>$-(M_3 + (1-W)C_3 + (S-1)L_1)$</td>
</tr>
<tr>
<td>E7(0,1,1)</td>
<td>$abP_1Q_1 + M_{12}C_{12} - L_2$</td>
<td>$(aP_2Q_2 + M_{23}C_{23} - L_2)$</td>
<td>$-(M_3 + (1-W)C_3 + (S-1)L_2)$</td>
</tr>
<tr>
<td>E8(1,1,1)</td>
<td>$-(abP_1Q_1 + M_{12}C_{12} - L_1)$</td>
<td>$-(aP_2Q_2 + M_{23}C_{23} - L_2)$</td>
<td>$-(M_3 + (1-W)C_3 + (S-1)L_1 + L_2)$</td>
</tr>
</tbody>
</table>

Given the model’s complexity and numerous parameters, to better analyze the model’s stability, we assume that the profits from developing saline-alkali land for small-scale farmers, family farms, and seed industry businesses must exceed the profits from not developing, which requires satisfying three conditions: $abP_1Q_1 + M_{12}C_{12} - SL_1 > 0; aP_2Q_2 + M_{23}C_{23} - SL_2 > 0; M_3 + (1-W)C_3 + (S-1)L_1 + L_2 > 0$. These conditions help analyze the eigenvalue signs of different equilibrium points. Specific characteristic values are detailed in Table 7.

Table 7. Sign of Eigenvalues at Local Equilibrium Points.

<table>
<thead>
<tr>
<th>Equilibrium</th>
<th>Eigenvalues Translation</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1(0,0,0)</td>
<td>+,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E2(1,0,0)</td>
<td>+,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E3(0,1,0)</td>
<td>+,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E4(0,0,1)</td>
<td>+,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E5(1,1,0)</td>
<td>−,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E6(1,0,1)</td>
<td>−,+</td>
<td>NESS</td>
</tr>
<tr>
<td>E7(0,1,1)</td>
<td>+,−</td>
<td>NESS</td>
</tr>
<tr>
<td>E8(1,1,1)</td>
<td>−,−</td>
<td>ESS</td>
</tr>
</tbody>
</table>

Furthermore, parameters that satisfy the above conditions are set, and except for government subsidies, all other parameters remain consistent with those listed in Table 3. This is to study the significance of government involvement in the green development of saline-alkali land. The specific parameter assignments are shown in Table 8, and phase diagrams are illustrated in Figure 2. On the left side of Figure 2, the phase diagram depicts the evolution of the tripartite game dynamic system without historical decision-making using the ODE algorithm. On the right side, the phase diagram incorporates historical decisions using the DDE algorithm, with a lag period of one year.
Table 8. Parameter Assignment for Evolutionary Game Model under Government Guidance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>P1</th>
<th>P2</th>
<th>Q1</th>
<th>Q2</th>
<th>C1</th>
<th>C2</th>
<th>L1</th>
<th>L2</th>
<th>S</th>
<th>W</th>
<th>a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>10</td>
<td>5</td>
<td>60</td>
<td>4</td>
<td>20</td>
<td>20</td>
<td>1.6</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>b M11</td>
<td>M1</td>
<td>M2</td>
<td>M3</td>
<td>M4</td>
<td>M5</td>
<td>M6</td>
<td>M7</td>
<td>M8</td>
<td>M9</td>
<td>M10</td>
<td>M11</td>
<td>M12</td>
<td>M13</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>24</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Phase diagram of the dynamic evolution of a game system under government guidance.

Upon examining Figure 2, it is evident that under the given parameters, the tripartite game dynamic system tends to converge more towards E7(0,1,1) and E8(1,1,1) after the inclusion of government subsidies, regardless of the consideration of historical decisions. This indicates that government involvement is crucial to the green development of saline–alkali land. Family farms and seed industry businesses show a stronger inclination to develop saline–alkali land, converging more towards a strategy of 1, while small-scale farmers do not consistently converge on this strategy. This suggests that, compared to family farms and seed industry businesses, small-scale farmers face greater challenges in adopting salt-tolerant crops. Possible reasons include government subsidies reducing the risks associated with green development for all parties, especially family farms and seed industry businesses, which have more resources and capabilities to absorb the high initial costs and better utilize the external support provided by the government. However, small-scale farmers lack sufficient operational scale to effectively use subsidies and achieve economies of scale. They also have a lower risk tolerance, making it difficult for them to face the uncertainties of developing saline–alkali land even with subsidies. Additionally, small-scale farmers are typically at a disadvantage in accessing information and technology for salt-tolerant crops. Lastly, they often lack the liquidity to undertake development efforts, even with government subsidies.

Therefore, while government participation can promote the green development of saline–alkali land, more nuanced policy measures should be provided to engage a broader range of small-scale farmers. Such measures might include agricultural technical training tailored for small-scale farmers, the promotion of policy-based agricultural insurance services, and the provision of microfinancing and credit services to farmers rather than solely offering cash subsidies.

3. Results

In this study, MATLAB2020b software was utilized to simulate and analyze the evolution game system of salinized land’s green development. This allowed for a more intuitive examination of the strategic changes among the three involved parties. Specifically, the research explores the influence of various factors on the behavioral strategies of the game participants. At the equilibrium point E8(1,1,1), the decision-making process is optimized for all parties, corresponding to the scenario of development, development, and provision. The parameters are constrained by the following conditions: \( abP_iQ_i \) +
implies observe certain and for tolerant er,s, Figure Mx2 them ... appropriate mechanism of memory and learning, ensuring that decision-makers consider the previous year’s choices, thereby better mimicking real-world decision-making behaviors.

3.1. Sensitivity Analysis of Initial Participation Willingness

Holding other parameters constant, this study performed a sensitivity analysis on the initial willingness to participate for smallholders (S), family farms (F), and seed industry enterprises (E), which is depicted in Figure 3. The figure shows the variability of initial willingness along the x-axis (time), y-axis (initial willingness), and z-axis (state variables).

From the observation of Figure 3, the critical values for the initial willingness of all three actors lie between 0.2 and 0.3. When all parties’ initial willingness is below this threshold, their strategies converge to 0, and the equilibrium point approaches (0,0,0). This implies that smallholders and family farms do not engage in the green development of salinized land, and seed enterprises do not provide seeds for salt-tolerant crops. Conversely, when initial willingness exceeds the critical value, their strategies converge to 1, and the equilibrium point approaches E8(1,1,1), indicating active participation by smallholders and family farms in green development and the provision of salt-tolerant seeds by seed enterprises. Throughout the development process, the stronger the initial willingness of smallholders, family farms, and seed enterprises to adopt salt-tolerant crops and provide seeds, the quicker they are to engage in green development activities. Different types of agricultural participants display varying dynamic characteristics in their decision-making process. Family farms and seed enterprises make decisions more rapidly, while smallholders require more time to reach a state of decision convergence. This is primarily because family farms and seed enterprises have higher levels of resource allocation, management decisions, and operational scale compared to smallholders. Family farms are quick to adapt to market changes and make prompt decisions, while smallholders, constrained by limited funds, a lack of technology, and risk aversion, take longer to observe the growth conditions of salinized land crops, accumulate experience, and wait for further policy refinement, hence their slower response rate.

To further investigate the significance of salt-tolerant crops for the green development of salinized lands within the tripartite evolutionary game system, this study, while keeping other parameters constant, fixed the initial participation willingness of smallholders and family farms at 0.5 and varied that of seed enterprises. Figure 4 illustrates these changes and suggests that when seed enterprises are unwilling to provide seeds for salt-tolerant crops (Z-Initial intention = 0), neither smallholders nor family farms are inclined to plant conventional crops on salinized land. However, once seed enterprises supply a certain amount of salt-tolerant seeds, both smallholders and family farms decide to adopt them after various decision-making intervals, with the time taken for this decision de-
creasing as the initial willingness of the seed enterprises to participate increases. This indicates that the supply of salt-tolerant seeds significantly influences the behavioral choices of smallholders and family farms. The reason is twofold: on the one hand, traditional perceptions and mindsets suggest a substantial risk of total crop failure when planting on salinized land without salt-tolerant seeds. When these seeds are offered, it increases the expected yield for cultivating salinized land. On the other hand, salt-tolerant crops generally have a rich nutritional value, such as the unique organic compound IP6 found in “sea rice,” which has cancer-prevention, anti-aging, and immune-regulatory effects, making it a highly beneficial health food. Consequently, there is a high market demand for salt-tolerant crops, enabling economic gain from their cultivation. Overall, salt-tolerant crops are key to the sustainable development of salinized lands, reducing operational risks for farmers, enhancing expected economic returns, and encouraging smallholders and family farms to develop salinized lands.

Figure 4. Sensitivity Analysis of Initial Supply Willingness for Salt-Alkaline Tolerant Crops.

3.2. Sensitivity Analysis of Economic Value

This study conducted a sensitivity analysis on the economic value of salt-tolerant crops, maintaining all other parameters constant, as depicted in Figure 5.

Figure 5 reveals that when \( a \leq 1 \), implying that salt-tolerant crops yield no additional profit compared to traditional crops and might even reduce farming profits, neither smallholders nor family farms opt to develop salinized land. At \( a = 1.2 \), salt-tolerant crops do generate some extra income, but not substantially, leading family farms to consider developing salinized land while smallholders still refrain. As the price increases, indicating the rising economic value of salt-tolerant crops, smallholders too begin to choose to develop salinized land, with the decision-making time gradually decreasing. This could be because, firstly, when the economic benefits of planting salt-tolerant crops are equivalent to or lower than those of conventional crops, both smallholders and family farms avoid this high-risk investment. Secondly, family farms typically have better risk-taking capacities and are profit-driven; thus, they are usually the first to embark on development when there’s additional economic gain. Furthermore, as the economic value of salt-tolerant crops increases, reducing the risk of failure, even smallholders are willing to engage in green development. Lastly, as the economic value grows, early adopters who take the risk are likely to reap higher profits, incentivizing others and thus shortening their decision-making time. In summary, the economic value of salt-tolerant crops is a critical factor for agricultural operators to engage in the green development of salinized lands. Promoting
innovation and the application of salt-tolerant crops is a significant driver for the comprehensive development of salinized lands.

![Figure 5. Sensitivity Analysis of Economic Value for Salt-Tolerant Crops.](image)

3.3. Sensitivity Analysis of R&D Costs and Selling Price of Salt-Tolerant Crops

With all other parameters held constant, this study analyzed the sensitivity of the research and development (R&D) cost coefficient and the selling price coefficient of salt-tolerant crop seeds, as shown in Figure 6.

Observations from Figure 6 indicate that when \( S < 1.8 \) and \( W < 1.6 \), the dynamic system of the tripartite evolutionary game generally converges to the optimal decision point E8 \((1,1,1)\). As \( S \) increases, smallholders delay their decision to plant salt-tolerant crops. When \( S \geq 1.8 \), due to the high purchase cost of salt-tolerant crops relative to conventional crops, smallholders begin to abandon the development of salinized land. At \( W = 2 \), high R&D costs lead seed enterprises to cease providing salt-tolerant seeds, and family farms, unable to access these seeds, also give up on utilizing salinized land. This is because when the R&D costs of the seeds are relatively low and the selling prices are reasonable, all parties are inclined to make the decision to develop salinized land. However, as the selling price coefficient \( S \) rises, the cost of planting salt-tolerant crops for agricultural operators increases, necessitating larger upfront investments and risks, thereby requiring more time for adaptation. When the cost of purchasing salt-tolerant crops becomes prohibitive for smallholders, they tend to forgo development. As R&D costs escalate and the corresponding price increases lead to reduced sales, seed enterprises are not able to secure sufficient economic returns, prompting them to stop supplying salt-tolerant seeds. Consequently, agricultural operators, particularly family farms, also abandon salinized land cultivation. Therefore, the economic viability of salt-tolerant crop seeds is crucial in decision-making for green development. A successful, comprehensive development of salinized lands is only achievable if the R&D costs and selling prices are satisfactory to all parties. This implies that government policies should focus on cost control and target pricing strategies, ensuring salt-tolerant seeds are economically viable and attractive to agricultural operators, especially smallholders, while also being profitable for seed enterprises.
Figure 6. Sensitivity Analysis of Cost and Selling Price for Salt-Alkaline Tolerant Crops.

3.4. Sensitivity Analysis of Government Subsidies

Lastly, this study conducted a sensitivity analysis on the subsidies received by various stakeholders in the tripartite evolutionary game system during the green development process of salinized lands, as illustrated in Figure 7. The sensitivity analyses for smallholders, family farms, and seed enterprises are represented in the first, second, and third rows, respectively. The government subsidies as a proportion of the costs borne by the stakeholders in developing salinized land are denoted by $S_{SCR} = M_2/(C_1 + S \ast L_1)$; $F_{SCR} = M_2/(C_2 + S \ast L_2)$; $E_{SCR} = M_3/(C_3 + W \ast (L_1 + L_2))$.

Figure 7. Sensitivity Analysis of Government Subsidies.

Figure 7 suggests that overall, with the increase in government subsidies, all parties in the tripartite evolutionary game system show a tendency to participate in the green development of salinized lands. Smallholders begin to engage in green development
when the subsidy-to-cost ratio (S-SCR) reaches 0.6, while seed enterprises decide to provide salt-tolerant seeds when their ratio (F-SCR) is at 0.2, although initially they exhibit a lower willingness to invest in R&D, leading farmers to abandon green development. Family farms are relatively insensitive to changes in government subsidies. The likely reasons include that smallholders, due to their small scale and weak risk-bearing capacity, are more attracted by higher subsidies that lower their risks and initial costs. When subsidies for seed companies are low, it decreases their willingness to develop salt-tolerant seeds initially, even if the enthusiasm from family farms eventually drives them to conduct R&D. However, the initial lack of seeds and higher prices can deter many smallholders, who perceive the investment as having a low return on investment, leading them to opt out of the risk. Additionally, insufficient subsidies may reduce the willingness of seed companies to provide after-sales service, preventing them from offering the necessary technical guidance and support to farmers. Meanwhile, family farms are unique in that as long as there is a profit to be made from planting salt-tolerant crops, even low government subsidies will not deter their participation, as they can reduce their dependency on subsidies through financial means.

In conclusion, government subsidies play a significant role in the green development of salinized lands, particularly in lowering the threshold for smallholder participation and increasing the enthusiasm of seed companies for R&D. The government should consider different stakeholders’ economic statuses, risk preferences, and sensitivity to subsidies when formulating policies to achieve the desired effect of the subsidies.

4. Conclusions

The main conclusions are as follows:

1. The Role of Government and Market Incentives. This study compares the evolution of the tripartite game system under market mechanisms with that involving government participation. It reveals that the green development model for saline–alkali land under market mechanisms faces a “market failure” phenomenon, where Pareto optimality cannot be achieved through market conditions alone. External incentives provided by the government play a crucial role in green development decisions for saline–alkali land [57]. Specifically, subsidy measures reduce the initial investment threshold for the three parties, mitigate unforeseen risks during development, and enhance the willingness of smallholders, family farms, and seed enterprises to participate.

2. Initial Willingness and Risk Perception. Sensitivity analysis on the willingness of the three parties to participate, with other parameters held constant, shows that the initial willingness significantly influences their final behavior strategies. The stronger the initial intent, the greater the likelihood of participation in the green development of saline–alkali land. Given their advantages in resource allocation, management, and scale, family farms and seed enterprises adapt and respond more quickly in decision-making. Smallholders disadvantaged in capital, technology, and information acquisition, coupled with their inherent risk aversion, require more time to observe the operational outcomes of pioneering agricultural producers and wait for more comprehensive policy support. Further analysis indicates that smallholders and family farms choose to participate in the green development of saline–alkali land only when seed enterprises are willing to provide salt-tolerant crops, and their willingness to cultivate such crops decreases with the seed enterprises’ reduced willingness to provide salt-tolerant seeds. The stable supply of salt-tolerant crop seeds by seed enterprises is crucial in driving the green development of saline–alkali land, as it not only increases the participation willingness of agricultural operators but also promotes sustainable use through enhanced crop yields and market values.

3. The Economic Value of Salt-Tolerant Crops. Sensitivity analysis on the economic value of salt-tolerant crops, with other parameters held constant, reveals that when
the economic value of these crops is lower than that of traditional crops, their cultivation is not economically advantageous. In such cases, neither smallholders nor family farms would opt for salt-tolerant crops. However, as salt-tolerant crops begin to generate additional economic benefits, albeit not high enough, family farms might engage in green development due to their greater risk tolerance and profit-seeking motives, while smallholders may remain observant. As the economic value increases further, even smallholders are drawn into green development, with their decision-making time decreasing as the higher profit expectations from salt-tolerant crops lower their risk perception [58,59].

(4) Seed Pricing and Research and Development Costs. A sensitivity analysis of the sales price and R&D costs of salt-tolerant crop seeds, with other parameters held constant, indicates that when the price and costs are within a reasonable range compared to those of traditional crops, it is beneficial for smallholders, family farms, and seed enterprises to make proactive green development decisions for saline–alkali land. However, as the seed price coefficient (S) increases, smallholders, facing higher planting costs, extend their decision-making time and may eventually abandon saline–alkali land development due to high costs. If the R&D cost coefficient (W) continues to rise, the R&D costs for salt-tolerant crops will become prohibitively high, leading seed enterprises to discontinue R&D and the provision of seeds to smallholders and family farms, resulting in their withdrawal from green development due to the unavailability of seeds. Hence, the economic feasibility of salt-tolerant crop seeds is the core element of green development for saline–alkali land.

(5) Economic Incentives and Policy Design. Government subsidies have a significant impact on farmers’ adoption behavior of agricultural practices [60–62]. Sensitivity analysis on government subsidies provided for salt-tolerant crops, with other parameters constant, shows that smallholders, due to their lower scale of operation and risk-bearing capacity, often require more government subsidies to cover the early costs of participation. When subsidies for research and development provided to seed enterprises are low, family farms may eventually provide salt-tolerant crops due to demand, but the lack of sufficient initial R&D, promotion, and after-sales service reduces smallholders’ expectations and leads them to abandon development. Family farms are the least sensitive to government subsidies because their operational models are more flexible than those of seed enterprises, and their financial situations are better than those of smallholders, so they are willing to engage in green development even with low subsidies, making up for any funding shortfalls through financial measures.

Based on these conclusions, the following policy recommendations are proposed:

(1) Enhancing Stakeholder Engagement in Green Development: To bolster the involvement of smallholders and family farms in growing salt-tolerant crops, governments need to improve the dissemination of information and technical training. Establishing demonstration areas for the cultivation of these crops and creating specialized service centers are essential measures to strengthen farmers’ confidence in adopting new agricultural practices. Additionally, offering incentives such as cash rewards and recognition for successful cultivation can significantly enhance their motivation. For seed enterprises, the development of platforms for sharing information and a robust risk-sharing framework are vital. These initiatives will ensure effective communication about market needs and technological advancements and facilitate the growth of salt-tolerant crops through collaboration between industry and academia.

(2) Maximizing the Economic Value of Salt-Tolerant Crops: Governments should focus on standardizing the production systems of salt-tolerant crops to enhance quality control and recognition in the market. Supporting the development of geographic indication products and establishing distinct agricultural brands can elevate the economic value and market appeal of these crops. The creation of a uniform platform for
agricultural product information, offering insights into pricing and market trends, will assist producers in making well-informed decisions, thus attracting more participants to the sustainable development of saline–alkali land.

(3) Reducing Costs and Risks for Seed Enterprises: Acknowledging the paramount importance of developing salt-tolerant crops, the government should provide financial support and subsidies for talent and set up special research and development funds to spur investment from seed companies. It is critical to enhance the protection of intellectual property rights to protect the interests of these entities, ensuring fair returns on their investments. Moreover, promoting collaboration between the government and enterprises to create innovation hubs and support the development of processing and sales networks for salt-tolerant crops will contribute to forming an integrated industry chain, speeding up the adoption of these crops.

(4) Refining Economic Incentive Policies: In tailoring subsidies for the cultivation of salt-tolerant crops, it is essential to account for the diverse profit models and risk tolerances of various operators, necessitating differentiated subsidy approaches. Direct financial subsidies should be precisely targeted and quickly disbursed to lessen the initial economic challenges faced by smallholders, encouraging their participation in the eco-friendly development of saline–alkali lands. For larger family-operated farms, the emphasis should be on enhancing their capabilities for self-development and market management, including providing management training. Seed companies might be motivated through incentives like loan interest subsidies and tax advantages, fostering long-term commitments to product development. Furthermore, establishing a comprehensive risk-sharing strategy and incorporating agricultural insurance are crucial for addressing the unpredictable risks associated with green development projects.

Based on the study presented in this paper, the research prospects proposed are as follows:

(1) Expanding on the conclusions and policy suggestions previously outlined, this paper identifies several promising directions for future research. Integrating empirical investigations into the current theoretical framework could greatly deepen our understanding of the mechanisms involved in transforming saline–alkali lands through the cultivation of salt-tolerant crops. Empirical research would serve to confirm the assumptions of our model, evaluate the real-world effectiveness of the suggested policy measures, and lay the solid groundwork for fine-tuning these recommendations.

(2) Future studies should also consider the long-term effects of such policy measures on the sustainability of farming practices in saline–alkali areas, encompassing environmental, economic, and social facets. This entails examining the resilience of salt-tolerant crop systems to various climatic conditions, their adaptability to different types of saline–alkali soils, and their acceptance within local farming communities.

(3) Moreover, delving into how technological advancements can enhance the feasibility and appeal of salt-tolerant crops is another area ripe for exploration. This could include breakthroughs in genetic modification, irrigation methods, and soil treatment techniques, all of which have the potential to lower production costs, boost crop yields, and elevate the quality of salt-tolerant crops.

(4) A thorough examination of market dynamics, such as supply chains, market entry strategies, and pricing models for salt-tolerant crops, is also crucial. A deep understanding of these aspects is vital for crafting effective market-driven policies, ensuring the economic viability of salt-tolerant crop cultivation, and facilitating the integration of small-scale farmers and family-owned farms into larger agricultural markets.

In conclusion, enriching this study with empirical data and investigating the areas mentioned above would not only corroborate and amplify the findings presented but also
aid in developing an extensive policy framework to promote the sustainable utilization of saline-alkali lands.

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**References**


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