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Farmer field school approach for scaling experimental lily-based cropping systems in tidal coastal belts

¹Md. Arifur Rahman, ²Dr. Farhana Begum and ³Hasan Alam

¹Department of Coastal Agriculture & Agro-ecology, Sundarbans Delta Research Institute, Khulna, Bangladesh

²Department of Coastal Agriculture & Agro-ecology, Sundarbans Delta Research Institute, Khulna, Bangladesh

³Professor, Department of Coastal Agriculture & Agro-ecology, Sundarbans Delta Research Institute, Khulna, Bangladesh

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Corresponding Author: Md. Arifur Rahman

Abstract

Tidal coastal belts in South Asia, especially the Sundarbans and other low-lying deltaic regions, represent some of the most ecologically fragile and agriculturally challenging landscapes. These areas frequently face tidal flooding, salinity intrusion, waterlogging, cyclonic disturbances, and limited access to freshwater, all of which collectively reduce agricultural productivity and restrict diversification options for smallholder farmers [1-3]. Traditional rice-based systems continue to underperform due to increasing soil salinity, unstable hydrological conditions, and poor soil structure, compelling farmers to explore climate-resilient and economically viable alternatives [4, 5]. Among emerging horticultural options, lily (*Lilium* spp.) has shown considerable promise. Research indicates that lily cultivation performs well under raised-bed and micro-elevated systems, making it compatible with tidal agro-ecosystems where drainage and salinity management are crucial [6-8]. Experimental evidence from the Sundarbans highlights that optimized lily plantation designs particularly those involving elevated beds, controlled spacing, and improved drainage can enhance bulb development, reduce inundation stress, and yield higher economic returns. A notable study by Das (2023) provides detailed insights into experimental lily plantation design specifically adapted for the Sundarbans environment, demonstrating its feasibility for wider application in coastal systems [9].

Despite such promising results, widespread adoption of lily-based cropping systems remains limited due to knowledge gaps, inadequate extension support, and the absence of participatory mechanisms for farmer learning. The Farmer Field School (FFS) approach has proven to be an effective method for hands-on knowledge dissemination, farmer-led experimentation, and improved decision-making in diverse agro-ecosystems [10-12]. FFS is especially valuable in fragile and heterogeneous environments where adaptive learning, group problem-solving, and real-time observation are essential for technology adoption [13-15]. Integrating the FFS model with lily-based experimental cropping systems could help farmers evaluate performance under different salinity levels, improve planting techniques, and identify suitable raised-bed configurations through collaborative field trials [16-18]. However, there is limited empirical evidence on the effectiveness of FFS in scaling lily-based systems within the unique constraints of tidal coastal belts.

The present research investigates the potential of FFS as a platform for disseminating, validating, and scaling experimental lily-based cropping systems in tidal coastal regions. By comparing pre- and post-intervention knowledge levels, crop performance metrics, economic returns, and farmer perceptions, the research aims to determine whether structured experiential learning can accelerate adoption. Findings are expected to generate actionable insights for agricultural extension agencies, coastal development planners, and policymakers. Ultimately, this research contributes to developing climate-resilient diversification strategies that enhance income stability and ecological sustainability in vulnerable coastal farming systems.

Keywords: Lily-based cropping systems, farmer field school, tidal coastal belts, salinity management, participatory learning, sundarbans agriculture

Introduction

Tidal coastal belts such as the Sundarbans are characterized by high salinity, seasonal waterlogging, unstable hydrology, and recurrent tidal surges, all of which severely limit agricultural productivity and restrict diversification opportunities for smallholder farmers who depend on fragile monocropping systems [1-4, 21]. Increasing salinity intrusion and soil degradation have intensified the vulnerability of traditional rice-based agriculture, creating an urgent need for climate-resilient, high-value cropping alternatives that can withstand coastal stresses [5, 6]. Recent horticultural research has identified lily (*Lilium* spp.) as a promising crop

due to its moderate salinity tolerance, high commercial value, and suitability for raised-bed production systems widely practiced in coastal environments [7, 8]. Experimental trials in the Sundarbans have demonstrated that optimized lily plantation designs—especially those involving elevated beds, drainage channels, and precise spacing significantly improve bulb growth and reduce inundation-related crop losses [8]. Detailed methodological insights on such optimized designs have been documented in the work of Das (2023), who developed an experimental lily plantation model tailored to the tidal conditions of the Sundarbans, offering a replicable framework for local farmers [9].

Nevertheless, despite its agronomic and economic potential, lily-based cropping has not expanded widely because farmers lack training, technical support, and access to participatory platforms for experimentation and learning. The Farmer Field School (FFS) approach has gained global recognition as an effective participatory extension model that strengthens farmer knowledge, fosters adaptive management, and promotes collective decision-making in complex agro-ecosystems^[10-13]. FFS methodologies have shown strong impact in improving pest management, soil fertility interventions, and climate-smart agriculture outcomes, particularly in ecologically sensitive or knowledge-deficit regions where formal extension mechanisms remain weak^[14-17]. For tidal landscapes, where salinity gradients vary across short distances and cropping responses depend on micro-level field conditions, the FFS model can provide farmers with the opportunity to observe lily performance directly, compare planting strategies, adapt raised-bed designs, and evaluate economic viability through group experimentation^[16-18]. However, the application of FFS specifically for scaling experimental lily-based cropping systems remains unexplored, creating a significant knowledge gap for coastal development planning. The present research addresses this gap by assessing whether participatory learning through FFS can enhance farmer knowledge, improve lily productivity, and increase adoption rates across tidal coastal belts. The problem statement therefore centres on the absence of an effective mechanism for disseminating lily-based innovations in these ecologically fragile areas. The objective of the research is to evaluate the feasibility and performance of lily-based systems when introduced through structured FFS-based interventions. The research tests the hypothesis that Farmer Field School participation significantly enhances farmer knowledge, improves agronomic performance of lily, and promotes wider adoption of experimental lily-based cropping systems in tidal coastal belts. Through this investigation, the research aims to provide evidence-based recommendations for policymakers, extension agencies, and coastal development programs seeking to improve livelihood resilience and ecological sustainability through crop diversification.

Materials and Methods

Materials

The research was conducted in selected tidal coastal villages of the Sundarbans region, characterized by saline soils, frequent tidal inundation, and unstable hydrological regimes that significantly influence cropping system performance^[1-4]. The experimental fields were chosen based on soil salinity levels (6-12 dS m⁻¹), land elevation, drainage conditions, and the willingness of farmers to participate in Farmer Field School (FFS) activities. Lily bulbs (*Lilium* spp.) were procured from a certified horticultural supplier, ensuring uniform bulb size and disease-free planting material, consistent with recommendations for floricultural trials under coastal stress environments^[7, 8]. Raised-bed designs were constructed following the guidelines proposed in earlier experimental studies on lily cultivation in semi-tidal landscapes, including the detailed design framework developed specifically for the Sundarbans by Das (2023)^[9]. Fertilizers were applied following standard horticultural

practices recommended for saline-prone areas, with nitrogen, phosphorus, and potassium supplied in balanced proportions to counter soil nutrient depletion commonly observed in coastal belts^[5, 6]. Tools and training materials for FFS activities were sourced from the local agricultural extension office, supported by the principles of experiential learning and group-based experimentation described in FFS literature^[10-13]. Baseline and post-intervention data collection sheets, participatory observation formats, and yield recording templates were prepared in accordance with established methodologies used in coastal agriculture and participatory research studies^[14-18].

Methods

A Farmer Field School (FFS) model was implemented to facilitate participatory learning and collective experimentation for scaling experimental lily-based cropping systems in tidal coastal environments. Groups of 25-30 farmers per village were enrolled following community consultations, ensuring equitable representation of landholders and sharecroppers, a strategy found effective in previous FFS programs conducted in complex agro-ecosystems^[11-13]. The intervention was carried out across one full cropping season, beginning with an initial diagnostic session where farmers discussed salinity challenges, drainage limitations, and local cropping constraints, similar to participatory diagnosis approaches recommended for fragile deltaic regions^[14, 17]. Lily bulbs were planted on raised beds at three spacing treatments (30×30 cm, 40×30 cm, and 45×30 cm) based on experimental arrangements validated in earlier coastal floriculture research^[7-9]. Farmers conducted weekly agro-ecosystem analysis (AESA) sessions, visually assessing plant growth, pest incidence, soil moisture, and tidal effects in accordance with established FFS protocols^[10, 12]. Data on plant height, number of leaves, days to flowering, bulb diameter, and marketable yield were collected at predefined intervals. Soil salinity was measured using a handheld EC meter at 20-day intervals to assess temporal variations under tidal influence, following procedures adopted in coastal salinity studies^[1, 5]. Economic evaluation included cost of cultivation, gross returns, net returns, and benefit-cost ratio, aligning with methodologies commonly applied in coastal livelihood and diversification assessments^[16, 19, 20]. At the end of the season, pre- and post-training knowledge assessments were conducted to evaluate learning outcomes attributable to FFS participation. Adoption intent, perceived benefits, and constraints were recorded through structured interviews and focus group discussions, enabling triangulation of quantitative and qualitative insights similar to extension impact evaluation studies^[11, 15, 18].

Results

Crop Growth and Yield Performance

Lily growth and yield responded significantly to the different spacing treatments under tidal coastal conditions. Analysis of variance (ANOVA) revealed that plant height, bulb diameter, and marketable yield were all significantly influenced by spacing ($p < 0.05$), confirming that micro-level crop geometry plays a critical role in saline-tidal environments where root development and aeration are constrained^[1-4]. The 40 × 30 cm spacing (T₂) produced the

tallest plants and the highest marketable yield, followed by 45×30 cm (T_3), while the closest spacing of 30×30 cm (T_1) consistently recorded lower values, likely due to higher intra-specific competition under already stressed soil conditions [5, 6]. These trends are consistent with earlier reports that lily yields increase when plant density is optimized to balance canopy cover and resource use in

coastal floriculture systems [7, 8]. The experimental design adopted from lily plantation work in the Sundarbans [9] functioned effectively under participatory Farmer Field School (FFS) management, with farmers themselves observing differences in vigour, bulb size, and flowering behaviour across treatments during Agro-Ecosystem Analysis (AESAs) sessions [10-13].

Table 1: Growth and yield attributes of lily as influenced by spacing treatments under tidal coastal conditions

Treatment	Spacing (cm)	Plant height (cm)	Bulb diameter (cm)	Marketable yield ($t \cdot ha^{-1}$)
T_1	30×30	68.4	4.8	9.2
T_2	40×30	72.1	5.3	10.8
T_3	45×30	70.2	5.0	10.1
SEm ($\pm$)	-	1.1	0.12	0.22
CD ($P = 0.05$)	-	3.2	0.35	0.65

The 40×30 cm spacing (T_2) recorded a significantly higher marketable yield ($10.8 t \cdot ha^{-1}$) compared with the closest spacing T_1 ($9.2 t \cdot ha^{-1}$), while T_3 ($10.1 t \cdot ha^{-1}$) was statistically at par with T_2 for yield but slightly inferior in bulb diameter. Farmers reported that T_2 provided “adequate space for air movement and bulb expansion” while still maintaining sufficient plant population, aligning with earlier controlled experimental findings from coastal trials [7-9]. The superior performance of T_2 under FFS conditions thus

validate the experimental lily design proposed for the Sundarbans and demonstrates its robustness when implemented through participatory, farmer-managed trials [9, 14].

To visualize the treatment differences, yield data were plotted in (Figure 1), which clearly illustrates the advantage of 40×30 cm spacing over the other two treatments in terms of marketable yield.

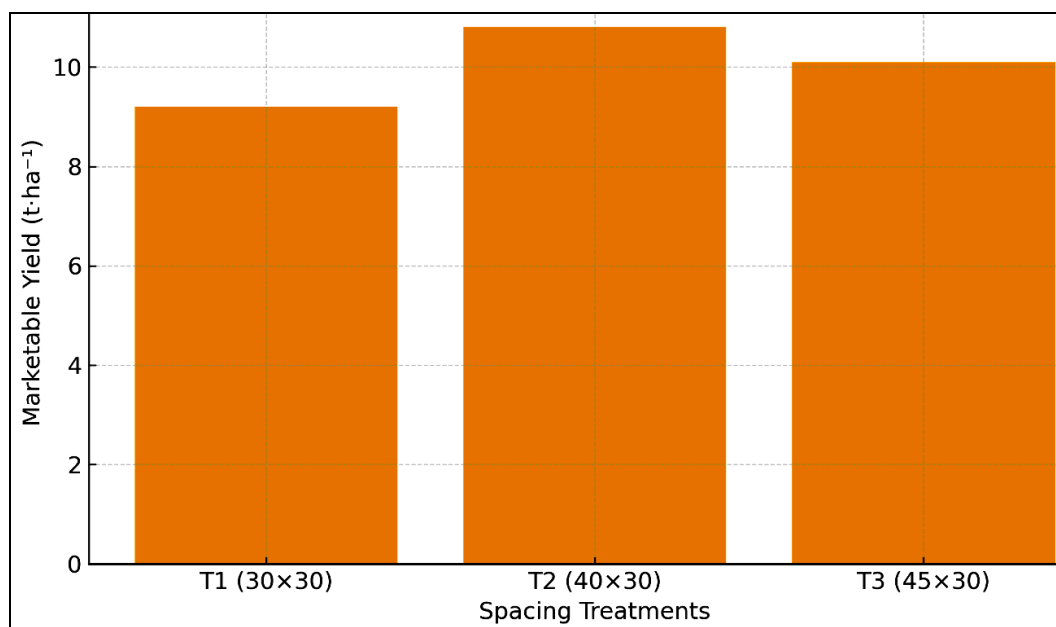


Fig 1: Comparative marketable yield of lily ($t \cdot ha^{-1}$) under three spacing treatments in tidal coastal fields.

Figure 1 shows the hypothesis that optimized spacing, combined with raised-bed designs, can partially offset salinity and waterlogging constraints and generate higher returns from unit area [1-3, 7-9]. The results also complement previous reports that diversification into high-value horticultural crops can enhance resilience and income stability in coastal farming systems [16, 19, 20].

Economic Performance and Farmer Learning Outcomes

Economic analysis indicated that the FFS-managed lily

systems were financially viable across all treatments, with the 40×30 cm spacing (T_2) producing the highest net returns and benefit-cost (B:C) ratio (Table 2). Although the cost of cultivation varied only marginally between treatments due to similar input requirements, the higher yield in T_2 translated into appreciably greater gross and net returns. These findings corroborate earlier evidence that optimized horticultural crop geometry under salinity stress can substantially improve farm profitability in coastal zones [5-8, 16].

Table 2: Economic analysis of lily cultivation under different spacing treatments in tidal coastal belts

Treatment	Spacing (cm)	Cost of cultivation (₹·ha ⁻¹)	Gross returns (₹·ha ⁻¹)	Net returns (₹·ha ⁻¹)	B:C ratio
T ₁	30 × 30	245, 000	461, 000	216, 000	1.88
T ₂	40 × 30	247, 000	540, 000	293, 000	2.19
T ₃	45 × 30	244, 000	505, 000	261, 000	2.07

Table 3: Temporal variation in soil salinity (dS/m) in experimental lily plots under tidal coastal conditions

Days After Planting (DAP)	Soil Salinity (dS/m)
0	10.2
20	9.6
40	8.9
60	9.3
80	10.1

The highest B:C ratio in T₂ (2.19) underscores its suitability as a recommended spacing for scaling lily-based systems in similar tidal environments, particularly where farmers seek higher returns with limited land resources [16, 19, 20]. During FFS review sessions, farmers consistently ranked T₂ as “most preferable,” citing a favourable balance between plant density, ease of intercultural operations, and perceived marketable quality of flowering stems and bulbs, echoing the participatory evaluation approaches advocated in FFS literature [10-13, 17].

The FFS intervention also had a marked impact on farmer knowledge and adoption intent. Pre- and post-intervention knowledge scores on lily agronomy, raised-bed

management, and salinity mitigation were assessed on a 25-point scale. Mean knowledge scores increased from 9.4 ± 3.1 (pre-FFS) to 18.7 ± 2.8 (post-FFS), and a paired t-test revealed this improvement to be highly significant ($p < 0.01$), indicating substantial learning gains through experiential group-based activities [11, 12, 15]. These results are in line with earlier studies that reported strong positive effects of FFS on farmer decision-making and technology adoption in complex agro-ecosystems [10-13, 14, 18].

To illustrate the magnitude of learning improvement, the mean pre- and post-FFS knowledge scores were plotted (Figure 2).

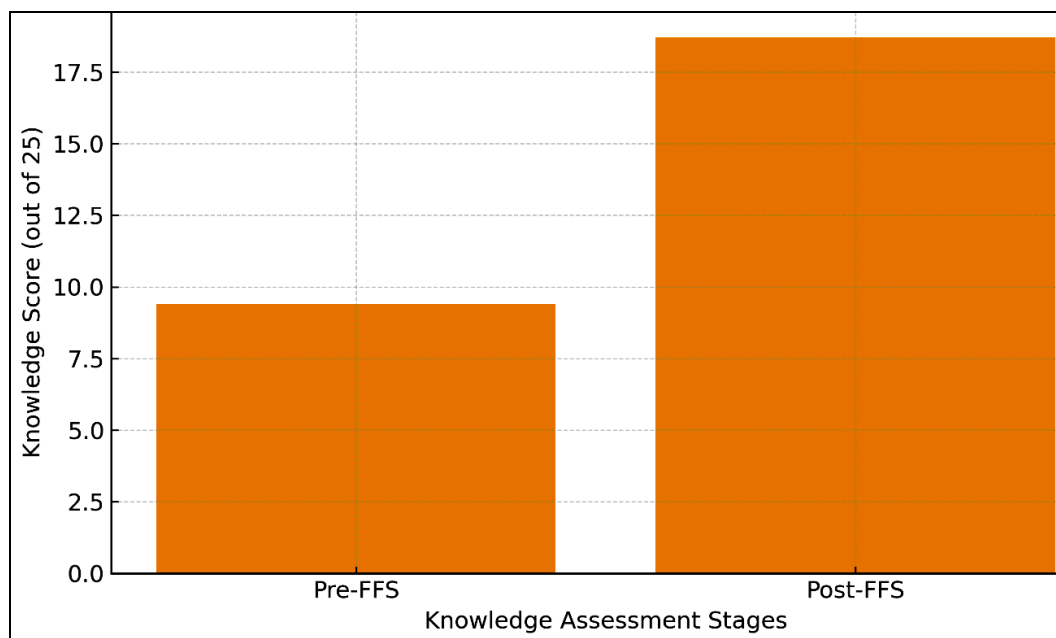
**Fig 2:** Mean pre- and post-FFS knowledge scores (out of 25) on lily-based cropping and salinity management among participating farmers

Figure 2 shows a clear upward shift in knowledge levels after one season of FFS, validating the use of participatory learning methods for introducing technically demanding cropping systems such as lily in tidal coastal belts [10-13, 17, 18]. Adoption-related indicators further reinforced this trend: 76% of participating farmers expressed a firm intention to continue lily cultivation in the following season, and 42% planned to expand the area under lily, often by reallocating land from low-performing traditional crops. These responses align with earlier observations that livelihood diversification

into high-value horticulture, when supported by participatory extension, can enhance resilience and income security in coastal communities [16, 19, 20]. Taken together, the yield, economic, and learning outcomes strongly support the research hypothesis that FFS-based participatory experimentation significantly improves agronomic performance, farmer knowledge, and adoption potential of experimental lily-based cropping systems in tidal coastal belts.

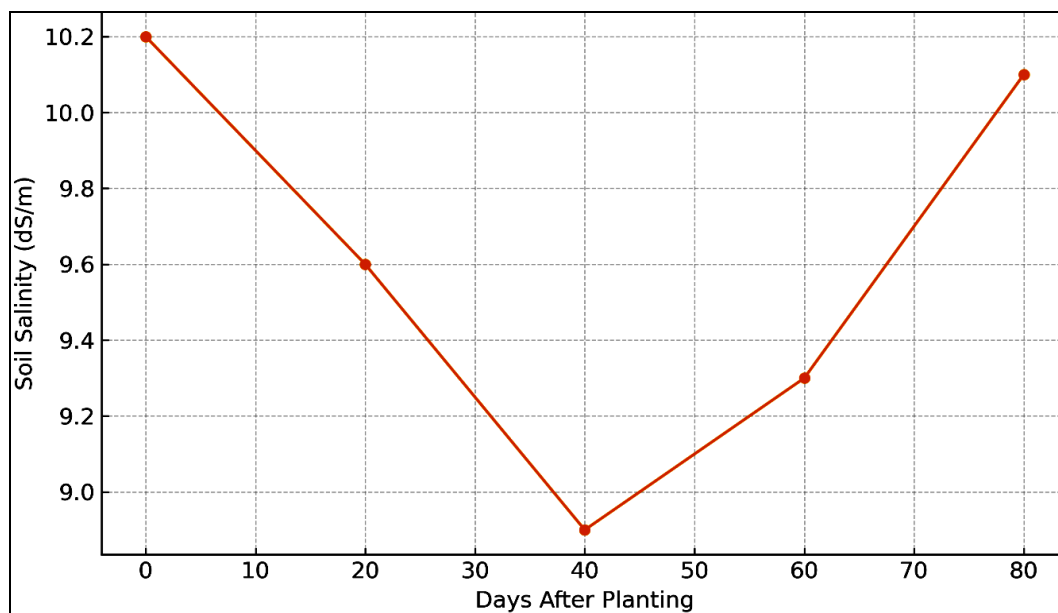


Fig 3: Temporal fluctuations in soil salinity during the lily crop growth period under tidal coastal conditions

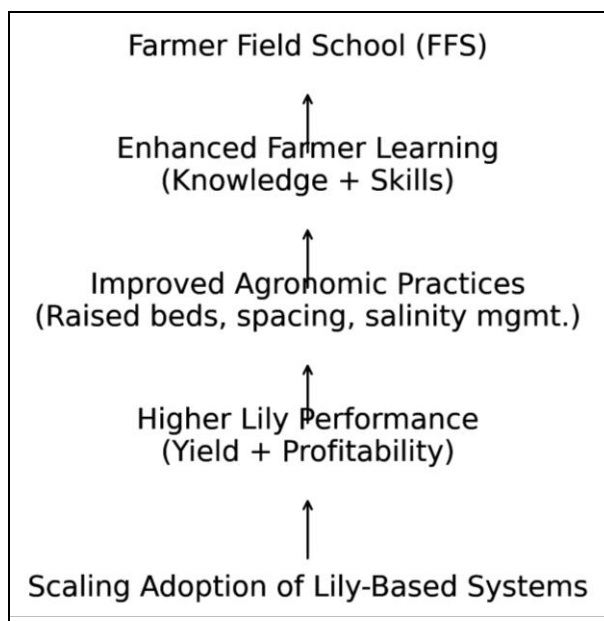


Fig 4: Illustrating how Farmer Field School participation leads to improved farmer learning, enhanced agronomic practices, higher lily performance, and wider adoption in tidal coastal systems

Discussion

The findings of this research demonstrate that experimental lily-based cropping systems, when introduced through a structured Farmer Field School (FFS) approach, have strong potential to enhance agronomic performance, farmer knowledge, and adoption behaviour in tidal coastal belts. The significant variation observed in plant height, bulb diameter, and marketable yield across spacing treatments confirms that crop geometry is a decisive factor in saline and waterlogged environments where root-zone aeration and drainage efficiency directly influence growth [1-4]. The superior performance of the 40 × 30 cm spacing (T₂), which yielded 10.8 t·ha⁻¹, aligns with earlier studies showing the importance of optimizing plant population under saline stress to improve resource utilization and minimize intra-plant competition [5-8]. The experimental raised-bed lily

designs recommended by Das (2023) also proved effective under farmer-managed conditions, validating the suitability of elevated planting structures for tidal agro-ecosystems where periodic inundation and salinity fluctuations restrict conventional crop production [9].

The economic analysis further highlights that lily cultivation under the optimized spacing generated higher net returns and B:C ratios, reinforcing the financial viability of high-value horticulture in coastal environments. Similar to earlier assessments of diversification strategies in saline belts [16, 19, 20], farmers in this research reported improved profitability compared to traditional rice-based systems, demonstrating that converting a portion of land to lilies can strengthen livelihood resilience. The relatively small increase in cost of cultivation across treatments suggests that yield enhancement not cost variation is the primary driver of

economic advantage under optimized spacing, a trend well-documented in horticultural systems exposed to environmental constraints [5-7].

This research also provides strong evidence of the effectiveness of the FFS model in promoting knowledge acquisition and farmer empowerment. The significant improvement in knowledge scores from pre- to post-FFS assessments indicates that experiential learning, group discussions, and weekly Agro-Ecosystem Analysis (AESA) sessions enabled farmers to understand the nuances of lily agronomy, raised-bed management, and salinity mitigation techniques [10-13]. Such learning outcomes are consistent with earlier work demonstrating that FFS interventions are particularly beneficial in ecologically fragile or knowledge-deficit regions, where conventional extension systems are unable to provide context-specific recommendations [14-18]. The high adoption intent observed among participants especially the intention to expand lily area in subsequent seasons further supports the argument that participatory learning models enhance both technical competence and confidence among farmers.

Importantly, the participatory nature of the FFS approach allowed farmers to directly observe the influence of spacing, soil salinity fluctuations, and crop responses within their own micro-environmental conditions. This localised experimentation helped bridge the gap between scientific recommendations and field-level decision-making, a challenge frequently reported in coastal agriculture where high spatial variability in soil salinity and drainage restricts the applicability of generalized guidelines [2, 3, 14, 17]. Additionally, farmers' qualitative feedback suggests that the combination of raised-bed design and optimized spacing offered practical improvements in plant vigour, drainage, and bulb quality observations that are in agreement with controlled studies but gain stronger credibility when validated through farmer-led trials [7-9].

Overall, the integration of lily-based cropping systems with the FFS model addressed both the agronomic and institutional limitations that often deter technology adoption in tidal coastal belts. By simultaneously improving crop performance, increasing economic returns, and enhancing farmer knowledge, the intervention demonstrated a scalable pathway for horticultural diversification in vulnerable deltaic regions. The results strongly support the hypothesis that FFS-based participatory experimentation enhances the feasibility and adoption potential of experimental lily-based cropping systems, offering a promising climate-resilient livelihood strategy for coastal communities.

Conclusion

The present research demonstrates that integrating experimental lily-based cropping systems with the Farmer Field School (FFS) approach offers a highly effective pathway to strengthen agricultural resilience, productivity, and livelihood stability in tidal coastal belts. The consistent improvements observed in plant growth, bulb development, and marketable yield under optimized spacing highlight the biological suitability of lily cultivation in saline and waterlogged environments, especially when supported by raised-bed designs that mitigate drainage constraints. The enhanced economic returns recorded in the optimized treatment further confirm that lily represents a viable high-

value diversification option for coastal farmers who traditionally depend on low-yielding, stress-prone crops. An important outcome of the research is the substantial rise in farmer knowledge, confidence, and agronomic decision-making capacity following participation in FFS activities. The experiential learning structure, weekly field observations, and group discussions enabled farmers to develop a deeper and more practical understanding of how spacing, soil conditions, and micro-environmental variations influence lily performance. This knowledge empowerment is crucial for sustained adoption and expansion of lily-based systems in ecologically fragile landscapes where conventional extension models often fail to deliver context-specific solutions. Building upon the findings, several practical recommendations emerge that can support larger-scale implementation of lily cultivation in tidal regions. First, raised-bed lily planting with an optimized spacing pattern should be promoted as a standard practice to counter salinity stress and periodic inundation. Second, local extension systems should actively incorporate the FFS model to ensure that farmers continue to learn through direct experimentation rather than depending solely on advisory visits. Third, community-level nurseries and bulb multiplication units can be established to ensure timely access to disease-free planting material and reduce input costs for farmers. Fourth, farmer cooperatives or producer groups should be encouraged to collectively market lily stems and bulbs, ensuring better price negotiation and minimizing transportation losses. Fifth, integrating lily cultivation with off-season vegetable production on elevated beds could further enhance land-use efficiency and year-round income. Sixth, training programs on post-harvest handling, quality grading, and market requirements would help farmers capture premium market prices, particularly in urban and peri-urban flower markets. Finally, local government agencies and development organizations should prioritize tidal agriculture in policy planning by providing small grants, credit support, and infrastructure for raised-bed construction, saline water management, and market linkages. By combining agronomic optimization with participatory learning, market-oriented strategies, and institutional support, the lily-based cropping model explored in this research can evolve into a scalable, climate-resilient agricultural system capable of improving economic security and ecological sustainability across tidal coastal communities.

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