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An analysis of environmental and economic impacts of the system of rice intensification : A case study in Thai Binh Province, Vietnam

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ABSTRACT

The current research investigates the environmental and economic impacts of the system of rice intensification. Rice, a fundamental staple in our diets, is paradoxically a significant contributor to greenhouse gas emissions, fueling global warming and climate change. A promising solution to this is the System of Rice Intensification (SRI). Embraced in Vietnam's National Determined Contribution (NDC) under the Paris Agreement, SRI aims to boost rice yields while curbing greenhouse gas emissions compared to conventional farming practices. This study focuses on Thai Binh, a key rice-producing province in the Red River Delta. Our objective is to assess the economic, environmental, and broader societal impacts of SRI versus conventional farming. We conducted a comprehensive analysis, utilizing tools such as Cost and Benefit (CBA) evaluations, Marginal Abatement Cost (MAC) calculations, and the Linkert scale to gauge the effects. Data from 175 farmers in Phu Luong commune, Dong Hung district, Thai Binh province, formed the basis of our study. The results highlight the advantages of adopting SRI. Implementing SRI not only leads to a substantial increase of approximately 12 million Vietnamese Dong (VND) in revenue but also showcases a remarkably favorable cost of -2.7 VND for reducing 1 ton of CO2eq/ha during the transition from conventional farming. This highlights the financial and environmental benefits of SRI. Furthermore, our assessment demonstrates that SRI consistently outperforms conventional farming across economic, environmental, and societal dimensions. In essence, our findings strongly advocate for the adoption of SRI over conventional rice cultivation, as it not only mitigates environmental harm but also enhances farmers' profitability and well-being, aligning with sustainable agriculture practices and climate change mitigation efforts.

Contribution/Originality: While there have been individual studies examining the economic and environmental efficiency of the System of Rice Intensification (SRI), there remains a notable gap in research when it comes to assessing the correlation between the costs and benefits associated with reducing greenhouse gas emissions through SRI in Vietnam.

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1. INTRODUCTION

Rice occupies a central position in Vietnam, both economically and culturally. As one of the world's foremost rice producers, Vietnam relies heavily on rice cultivation, a sector that fortifies the nation's food security and sustains over 15 million small farmers (RIKOLTO, 2017). Moreover, rice stands as a cultural pillar in Vietnam, integral to the nation's cuisine and a centerpiece in numerous traditional festivals and ceremonies.

In 2020, rice farming was conducted over an expansive area of about 7.28 million hectares, producing an estimated 43.76 million tons (General Statistics Office of Vietnam (GSO), 2020). Furthermore, Vietnam has established itself as a major player in the global rice export market, channeling a significant stream of foreign income. Vietnamese rice products reach over 100 countries globally, amounting to a turnover of 6.25 million tons and approximately $3.12 billion in 2020 (Tran & Nguyen, 2022).

However, rice cultivation is notably the largest source of greenhouse gas emissions when compared to other crops. These emissions stem from multiple avenues, including the decomposition of organic matter in waterlogged rice paddies and the employment of synthetic fertilizers (Intergovernmental Panel on Climate Change (IPCC), 2006). Consequently, the Vietnamese rice sector was responsible for about 39.36 mtCO2eq[1] of emissions in 2020, nearly accounting for 40% of the total emissions from the country's agricultural sector (Ministry of Agriculture and Rural Development (MARD), 2021).

In recent years, climate change has emerged as a significant challenge, with Vietnam being acutely susceptible to its repercussions (Ministry of Natural Resources and Environment (MONRE), 2016). The country has been consistently identified as one of the most at-risk nations globally (ranked 5th in 2016 and 6th in 2017) (Eckstein, Hutfils, & Winges, 2018). The tangible impact was felt in 2018 when over 250,000 hectares of rice lands were compromised (General Department of Natural Disaster Prevention and Control, 2018). Projected climate change scenarios suggest that by 2050, substantial portions of the agricultural areas in the Red River and Mekong Deltas will be lost, potentially reducing rice production by 10-20% (World Bank (WB), 2010). Without adaptive strategies, 21.4% of rice output could be forfeited by 2100 (Ministry of Natural Resources and Environment (MONRE), 2022).

At the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), Vietnam joined nearly 200 other countries in adopting the Paris Agreement. This pact aims to curb global warming, thus diminishing the adverse impacts of climate change on human societies. The agreement encourages countries to delineate and periodically update nationally determined contributions (NDCs), which stipulate goals for cutting greenhouse gas emissions and enhancing adaptive initiatives.

To address these challenges, the Vietnamese government has embarked on both adaptive and mitigative strategies for climate change. By 2030, the country's agricultural sector seeks to cut total greenhouse gas emissions by 12.4 million tons of CO2eq using domestic resources and 50.9 million tons of CO2eq with international assistance (Ministry of Natural Resources and Environment (MONRE), 2016). SRI offers a potential approach for achieving Vietnam's NDC objectives. This eco-friendly and efficient farming approach not only boosts yield but also cuts greenhouse gas emissions, primarily through reduced fertilizer and pesticide usage (Norman, Koma, Phrek, Klaus, & Humayun, 2000). First introduced in Vietnam in 2003, it was widely applied under Decision "No. 3062/QD-BNN-KHCN", [2]benefiting nearly 450,000 hectares and about 1.8 million farmers nationwide by 2015 (Hoang, Nguyen, & Nguyen, 2015).

This study aspires to amass information on the implementation of SRI techniques in the face of climate change, intending to propose methods to foster environmentally sustainable economic development. Given the scant previous research evaluating the economic and environmental efficacy of SRI in the Red River Delta, this study seeks to fill the gap by analyzing the costs associated with emission reductions when transitioning from conventional farming to SRI. Policymakers are likely to find the insights garnered from this study invaluable in evaluating SRI against other rice cultivation methods and fulfilling the stipulations outlined in the NDCs. Furthermore, this research aims to perform a comprehensive assessment of the impact of SRI, taking into account farmers' viewpoints across economic, environmental, and social facets.

2. LITERATURE REVIEW

The System of Rice Intensification (SRI)presents a promising methodology that optimizes the utilization of input resources such as plants, water, and nutrients to augment rice yields (Arsil et al., 2022; Shah, Tasawwar, Bhat, & Otterpohl, 2021). Currently, more than 20 million farmers in over 60 countries globally are employing SRI practices (Uphoff & Thakur, 2019). A multitude of studies have testified to the efficacy of SRI, highlighting benefits such as enhanced nutrient absorption, improved disease resistance, resilience to climate pressures, and increased rice yields (Doni, Mispan, Suhaimi, Ishak, & Uphoff, 2019; Nugroho et al., 2018; Thakur, Mandal, Verma, & Mohanty, 2023).Moreover, this approach allows for the reduction in the quantities and costs associated with inputs such as seeds, water, fertilizers, and laborcosts (Arif et al., 2022; Meesala & Rasala, 2022).

[1] CO_{2eq}: $CO_{2equivalent}$

[2] Decision "No. 3062/QD-BNN-KHCN" issued by the Ministry of Agriculture and Rural Development on October 15, 2007: recognized "Application of integrated intensive farming in rice production in some Northern provinces" as Technical Progress.

Table 1. Economic and environmental efficiency when applying SRI compared to conventional cultivation in some regions.

Country/Region	Amount (%)	Status	Sources
Seed/ Seed cost			
Nepal: Eastern	90	↓	Surdeep (2010)
Mali	85-90	↓	Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA) (2014)
Vietnam: Tra Vinh	70	↓	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2013)
Vietnam: Binh Dinh	21.3	↓	Vu et al. (2018)
Water usage			
China: Sichuan	70	↓	Lu, Dong, Yuan, and Hilario (2013)
Indo-gangetic plains	36	↓	Jain et al. (2013)
Mali	10	↓	Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA) (2014)
Labor/Service cost			
Nepal: Eastern	17	↓	Surdeep (2010)
Mali	15-25	↑	Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA) (2014)
Vietnam: Tra Vinh	10-29	↑	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2013)
Vietnam: Binh Dinh	9.7	↓	Vu et al. (2018)
Fertilizer / Fertilizer cost			
Nepal: Eastern	46-49	↓	Surdeep (2010)
China: Sichuan	10-15	↓	Lu et al. (2013)
Mali	30	↓	Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA) (2014)
Vietnam: Tra Vinh	35	↓	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2013)
Pesticide			
Nepal : Eastern	99	↓	Surdeep (2010)
Vietnam: Tra Vinh	87	↓	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2013)
Vietnam: Binh Dinh	34.8	↓	Vu et al. (2018)
Yield			
Nepal: Eastern	118	↑	Surdeep (2010)
China: Sichuan	19.8 - 59.8	↑	Lu et al. (2013)
Mali	34	↑	Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA) (2014)
Vietnam: Quang Binh	19.6-23.6	↑	Duong (2017)
Vietnam: Tra Vinh	20	↑	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2013)
Vietnam: Binh Dinh	10.6	↑	Vu et al. (2018)
Greenhouse gas emissions			
Indo-gangetic plains	28-30	↓	Jain et al. (2013)
Vietnam: Quang Binh	11.9-18.5	↓	Duong (2017)
Vietnam: Binh Dinh	47-69	↓	Vu et al. (2018)

SRI applications have shown promising potential for reducing emissions and fostering sustainable development when compared to traditional farming techniques (Hoang et al., 2015; Nirmala et al., 2021). Table 1 shows various benefits of adopting SRI over conventional farming methods. Applying SRI helped to reduce 21.3% (Vu et al., 2018), 70% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2013), 85-90% (Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA), 2014) and 90% (Surdeep, 2010) Seed/ seed cost; reduced water use 10% (Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA), 2014), 36% (Jain et al., 2013) and 70%

(Lu et al., 2013); fertilizer quantity/fertilizer cost reduced 10-15% (Lu et al., 2013), 35% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2013), 30% (Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA), 2014), 46-49% (Surdeep, 2010); reduced pesticides 34.8% (Vu et al., 2018), 87% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2013), 99% (Surdeep, 2010); reduced greenhouse gas emissions 47-69% (Vu et al., 2018), 11.9-18.5%(Duong, 2017), 28-30% (Jain et al., 2013); Reduced labor/ service costs 9.7% (Vu et al., 2018) and 17% (Surdeep, 2010) but in Tra Vinh province of Vietnam and Mali, labor costs when applying SRI was higher than conventional cultivation, 10-29% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2013) and 15-25%(Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA), 2014) respectively. Yields when applying SRI also gave overall results that were higher than conventional farming (10.6% (Vu et al., 2018), 20% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2013), 19.6-23.6 (Duong, 2017), 34% (Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA), 2014), 19.8-59.8% (Lu et al., 2013), 118% (Surdeep, 2010). In sum, different studies have found that the performance of SRI can vary depending on factors such as geographical location, soil type, or the specific rice variety grown.

Despite the promising findings, it is clear that further research is necessary to fully delineate the potential of SRI and to tailor its application optimally to diverse regions and farming contexts. To formulate strategies for the effective implementation of the Nationally Determined Contributions (NDC), detailed assessments are required to analyze the cost-benefit efficiency, environmental impact, and emissions reduction costs—establishing a coherent relationship between economic and environmental dimensions. The objective of this study is to devise optimal solutions that guarantee economic viability for farmers while safeguarding environmental benefits. This will be achieved through the conceptualization of hypothetical calculation scenarios, which will serve as a foundation for policymakers in evaluating various prioritized mitigation strategies in rice cultivation, thereby facilitating Vietnam's commitment to reducing emissions.

3. MATERIAL AND METHODOLOGY

3.1. Study Area Selection

This study was conducted in Phu Luong commune, Dong Hung district, Thai Binh province, Vietnam. Nestled in the northern part of both the Dong Hung district and the Thai Binh province, Phu Luong is a mere 3 km away from Dong Hung town and borders National Highway 10. It spans a natural land expanse of 476.78 hectares.

Predominantly, the inhabitants of Phu Luong Commune sustain themselves through agricultural endeavors. As per the data from the Phu Luong Commune People's Committee (2021), a significant portion of the land, encompassing 371.73 hectares, or 77.98% of the total area, is earmarked for agricultural production. Out of this, a substantial part, aggregating to 297.86 hectares, or just over 80%, is utilized for cultivating rice.

3.2. Data Collection Methods

Primary data was gathered from 175 farmers who engaged in both SRI and conventional cultivation methods. The data collection process involved direct interviews facilitated through a detailed questionnaire, administered in October 2022. This questionnaire was segmented into three primary sections: particulars pertaining to rice farming households, insights into the economic indicators of rice farming, and evaluations of the economic, environmental, and social repercussions of both conventional and SRI rice farming approaches.

The data compilation spanned two critical agricultural sessions: the spring season, which extended from November 2021 to May 2022, and the subsequent summer season, from June to October 2022.To ascertain the optimal sample size for this study, the renowned Yamane (1967) was employed:

$$n = \frac{N}{1 + N * e^2}$$

Where, n is the sample size.

N is the size of rice cultivation household.

e is the allowable error of 10 percent.

Table 2 presents a comparison of household details between those practicing SRI and conventional cultivation methods. Generally, the demographic of respondents involved in rice farming skews older, boasting an average age of 59.4 years. Additionally, the educational background among this group is relatively limited, with the majority, accounting for over 80%, having completed their education at the secondary school level.

When it comes to labor division, just over half of the family's working members are engaged in rice cultivation. It was noted that 54% of the respondents were male. A notable fraction of the interviewees possess a substantial history in rice cultivation, including a duration of over three decades. However, the rice cultivation plots in the study area tend to be small and dispersed, averaging 0.175 hectares per household.

To complement the primary data, secondary information was amassed from various sources, including books, newspapers, websites, legal documents, and publications and statistical yearbooks from organizations such as the General Statistics Office (GSO), the Ministry of Agriculture and Rural Development (MARD), and the Department of Agriculture and Rural Development (DARD). Furthermore, this study leveraged previously published projects, studies, and documents as references and foundational data sources.

Table 2. Description of household background information between SRI and Conventional cultivation.

Information	SRI		Conventional cultivation		All respondents	
	Mean	SD[3]	Mean	SD	Mean	SD
Age of respondents	58.667	6.972	60.176	7.322	59.400	7.163
Primaryschool(%)	10.000		3.529		6.857	
Secondary school (%)	72.222		92.941		82.286	
High school (%)	8.889		1.176		5.143	
University/college (%)	8.889		2.353		5.714	
Number of family members (Person)	4.244	1.283	4.211	1.092	4.229	1.191
Number of family members in working age (Person)	2.944	0.964	3.011	0.837	2.977	0.903
Number of family members join rice production (Person)	1.822	0.384	1.776	0.419	1.800	0.401
Male respondents (%)	47.778		61.176		54.285	
Head of households (%)	55.556		65.882		60.571	
Year of experience	32.09	7.9	30.4	5.9	31.2	7.05
Rice farming area (ha)[4]	0.173	0.073	0.179	0.127	0.175	0.102
Total Agriculture areas (ha)	0.188	0.083	0.186	0.136	0.187	0.112

3.3. Data Analysis Method

A Cost-Benefit Analysis (CBA) was conducted to assess the economic efficiency of implementing the System of Rice Intensification (SRI) in comparison to conventional cultivation practices. The economic data was gathered through direct interviews at the research site, utilizing the information gleaned from the questionnaire.

To ascertain the costs associated with reducing emissions when transitioning from conventional cultivation to the SRI approach, the Marginal Abatement Cost (MAC) was calculated. The emission data was drawn from the research conducted by Dao Minh Trang and colleagues in 2019 in the specific study area of Phu Luong commune, Dong Hung district, and Thai Binh province.

The marginal abatement cost (MAC) formula is based on cost-effectiveness and total mitigation potential:

$$MAC = \frac{NPV_B - NPV_{SRI}}{NGT}$$

Where

SRI: SRI measure.

B: Conventional cultivation measure.

NPV: Net present value is calculated using the formula:

$$NPV = \sum \left(\frac{P}{(1+i)^t}\right) - C$$

Where:

P: Cash inflow.

i : Discount rate = 10%.

t: Time.

C: Initial cost.

NGT: Net total greenhouse gas emission is calculated using the formula:

$$NGT = \sum (E_{SRI} - E_B) * t$$

Where:

E: Emission.

t: Time.

The impact assessment of SRI was collected using a Likert scale from 1-5. It collected people's evaluations of the economy, society and environment.

4. RESULTS AND DISCUSSION

Table 3 illustrates the difference in the cost structure between SRI and conventional cultivation methods per hectare per year. Initially, farmers utilizing the SRI methods incur lesser expenses compared to traditional farming, approximately 1.74 million Vietnamese Dong (VND).Notably, the largest cost reduction is witnessed in seeding and plouinglabor, amounting to around 1.39 million VND. Furthermore, the expenditures for seeds and pesticides are roughly 0.90 million VND and 0.55 million VND, respectively. Conversely, fertilizer costs under the SRI approach are about 1.10 million VND higher than those for conventional farming.

[3]SD: Standard deviation.
[4]1ha = 10000 m^2

Table 3. Description of the cost structure of rice production between SRI and conventional cultivation for 1 ha area/year.

Items	SRI	Conventional cultivation	Difference
	Mean	Mean	
Input cost	8.813.330	9.164.622	-351.292
Seeds	1.000.080	1.900.152	-900.072
Fertilizer	4.924.130	3.819.750	1.104.380
Herbicide	583.380	583.380	0
Pesticides	1.944.600	2.500.200	-555.600
Irrigation expenses (Paid to the cooperative)	361.140	361.140	0
Labor and machine cost	21.104.300	22.493.300	-1.389.000
Soil making	3.889.200	3.889.200	0
Seeding. Plowing	5.556.000	6.945.000	-1.389.000
Caring. Fertilizing. Spray pesticides.Weeding. etc.	5.547.500	5.547.500	0
Harvest cost	4.167.000	4.167.000	0
Transporting. Drying. Cleaning	1.944.600	1.944.600	0
Other costs	2.027.940	2.027.940	0
Total	31.945.570	33.685.862	-1.740.292

Certain expenses remain similar between SRI and traditional cultivation due to fixed costs established by the cooperativebased on the land area owned by individuals. For instance, in the studied locale, irrigation costs are fixed, unrelated to the volume of water used. The trend extends to labor and machinery costs, which remain relatively unchanged in the area and are arranged by the cooperative to simplify management. Other costs, encompassing weeding, pruning, rat poison purchase, and contributions to the collective fund, are equivalent between the two methods. Fertilizer costs for SRI farmers are 28.91% higher compared to conventional farming. The observed disparity, in comparison to previous research results, can attributed to the lack of established protocols governing the use of fertilizers in the specific geographic region under investigation. Generally, SRI adoption leads to a reduction in NPK fertilizer usage, while the use of urea and potassium chloride fertilizers increases to enhance plant water and nutrient absorption. In contrast, conventional farming rarely involves the application of potassium fertilizer.

Table 4 highlights the economic efficacy of adopting SRI over conventional farming. Generally, the SRI model yields a higher rice output (6.8 tons/ha compared to 6.2 tons/ha), resulting in an augmented income of about 8.52 million VND/ha, and reduced input costs of approximately 3.48 million VND/ha. Consequently, the overall profit derived from SRI surpasses that of conventional farming, amounting to roughly 12 million VND/ha. Moreover, the benefit-cost ratio of SRI stands at 1.43, exceeding the 1.24 ratio of traditional cultivation.

Table 4. Economic efficiency between SRI and conventional cultivation for 1 ha area/year.

Farming measure	SRI	Conventional cultivation	Difference
Average yield (ton/ha)	6.8	6.2	0.6
Total cost (mVND)	67.78	71.26	-3.48
Income (mVND)	96.64	88.12	8.52
Benefit cost ratio (%)	1.43	1.24	-0.19

Figure 1 illustrates the potential reduction in greenhouse gas emissions from utilizing SRI as opposed to conventional methods over a one-hectare area. This estimation leverages the findings from a 2019 carbon footprint study of rice production in Phu Luong Commune, Dong Hung District, Thai Binh Province, conductedby Dao, Huong, and Van Trinh (2019). The study indicates that SRI cultivation releases 32,144.35 kgCO2eq/ha, considerably less than the 35,144.18 kgCO2eq/ha, emitted through conventional rice cultivation (Dao et al., 2019). Employing the SRI method over a hectare can potentially curtail 3.03 tons of CO2eq emissions per hectare. Additionally, the marginal abatement cost equates to -2.7 million VND per ton of CO2eq when transitioning from traditional to SRI cultivation methods.

According to the developmental blueprint of Thai Binh province, outlined in the rice construction and development project for 2023-2025 with a vision towards 2030, Figure 2 depicts the prospective greenhouse gas emission reduction in the region. The scenario unfolds in three phases: Initially, the Business As Usual (BAU) scenario maintains a 76,600 ha rice cultivation area in 2022, with SRI practices encompassing about 60% and conventional farming covering the remaining 40%. Subsequently, by 2025, the cultivation area is expected to shrink to 74,000 ha, with SRI practices covering approximately 85% and conventional methods accounting for 15%. Ultimately, by 2030, the rice cultivation area in Thai Binh province is projected to contract further to 70,000 ha, fully adopting the SRI technique. This transition is forecast to curtail 1.56 million tons of CO2 equivalent emissions, with a marginal abatement cost of -479.73thousand VND per ton of CO2 equivalent.

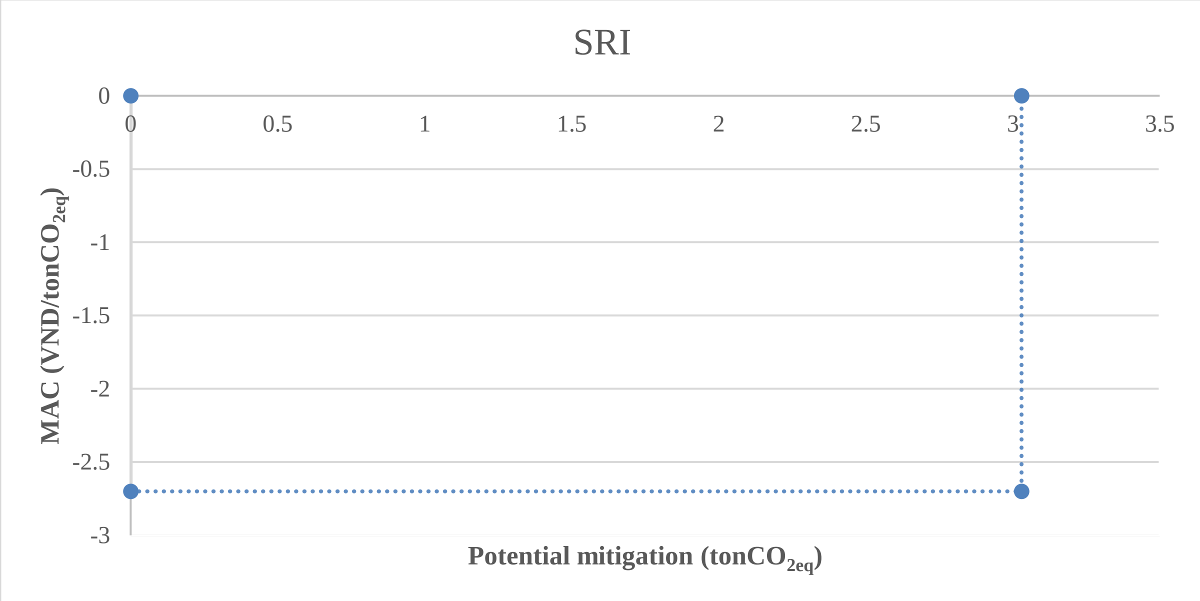

Figure 1. Environment efficiency when applying SRI compared to conventional cultivation in 1 ha area/year.

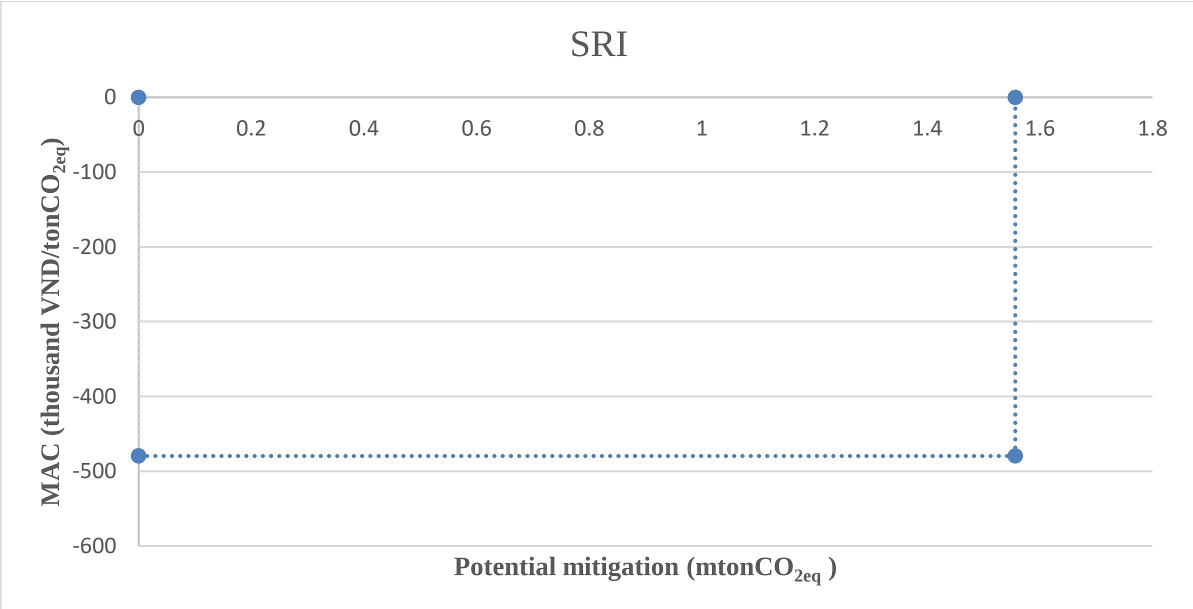

Figure 2. Environmental efficiency scenario of Thai Binh province in the period of 2023-2025, with orientation to 2030.

Table 5 assesses the contrast between SRI and conventional cultivation, based on questionnaires administered directly to farmers in the survey area. According to respondents, SRI demonstrates a markedly positive impact compared to conventional farming, with significant differences in most assessment outcomes. Profits from SRI methods are estimated to be approximately 12 million VND/ha higher than those from traditional farming. The reduction in investment costs also augments farmers' opportunity costs, enabling them to allocate capital towards other economic activities, such as banking savings or investing in alternate ventures. Furthermore, increased financial resources mitigate the risk of accruing debt from credit reliance.

Environmentally, SRI adoption facilitates a decrease in air pollution while enhancing water and soil quality. This is achieved by minimizing chemical fertilizer and pesticide applications directly to fields, consequently reducing greenhouse gas emissions. Meanwhile, this methodology reduces the negative impacts on advantageous insects and microorganisms that reside inside the agricultural fields, thereby decreasing the reliance on additional natural resources for the manufacturing of chemical fertilizers and pesticides.From a social perspective, rice production aids in securing and generating employment for a substantial segment of the local populace.Given that nearly half the individuals engaged in rice farming are women, the introduction of SRI fosters opportunities to advance women's empowerment, fostering gender equality in the production process. Additionally, workshops and experience-sharing sessions to familiarize farmers with SRI serve as a platform to forge connections among farmers, fostering awareness and understanding of the significant role people play in agriculture.

Table 5. Impact assessment between SRI and conventional cultivation.

Component	Indicators	SRI		Conventional cultivation	
		Mean	SD	Mean	SD
Economic	Contributing to increased productivity by saving capital and costs, reducing dependence on production inputs such as seeds, fertilizers, and pesticides, etc.	4.590	0.580	1.258	0,440
	Contribute to changes such as technological changes and changes in manufacturing activities.	3.647	0.827	1.023	0.152
	Contribute to creating business opportunities and investment activities such as: Selling rice straw…	2.272	0.670	1.047	0.213
Environment	Contribute to reducing pollution and improving air quality	4.386	0.730	1.105	0.309
	Contribute to reducing pollution and improving soil quality.	4.443	0.706	1.035	0.185
	Contribute to reducing pollution and improving water quality.	4.352	0.692	1.023	0.152
	Contribute to the sustainable use of natural resources and promote the development of ecosystem services.	1.863	0.873	1.011	0.108
	Contribute to biodiversity conservation.	3.784	0.843	1.023	0.152
Social	Contribute to increasing employment opportunities and income.	4.625	0.650	2.976	0.407
	Contribute to improving health.	4.193	0.837	3.117	1.199
	Contributing to raising community awareness in response to climate change and sustainable development.	4.681	0.653	1.247	0.433
	Contributing to poverty alleviation, food security and quality of life.	4.670	0.521	4.211	0.874
	Contributing to ensure social justice, especially for vulnerable groups, children, and women.	2.988	0.673	1.517	0.795
	Contributing to the improvement of farmers' qualifications and skills.	4.022	0.639	1.788	0.465

5. CONCLUSIONS

The research findings indicate that utilizing the SRI method for rice cultivation decreases input costs by 1.7 million VND while increasing the yield by 0.6 tons/ha. This results in a profit surge of approximately 12 million VND. Moreover, the adoption of SRI significantly curtails greenhouse gas emissions by 3.03 tons of CO_2 equivalent per hectare compared to traditional rice farming methods, with the marginal abatement cost (MAC) standing at -2.7 millionVND per ton of CO_2 equivalent per hectare. Additionally, the implementation of SRI yields positive impacts in economic, environmental, and social dimensions for farmers.

In contrast to earlier studies, the cooperative has fixed some costs, such as labour and water, through contracts, so there is no difference between the two methods in these areas. However, it is noteworthy that the expenditure on fertilizers is higher when employing the SRI method compared to conventional farming practices.

Regarding the initiatives by the Thai Binh authorities, it is imperative to persistently advocate for the proliferation of the SRI model, aligning with the province's strategic plan. This should coincide with the promotion of land-consolidation initiatives to facilitate large-scale production. It is vital to standardize techniques in accordance with local conditions to streamline the measurement of agricultural inputs effectively and consequently elevate the productivity and income levels of rice farmers. Concurrently, there is a need to further research and enhance the training quality for technicians specializing in SRI, equipping them to adeptly guide farmers in the region.

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Institutional Review Board Statement: The Ethical Committee of the Tohoku University, Japan has granted approval for this study.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Arif, C., Saptomo, S. K., Setiawan, B. I., Taufik, M., Suwarno, W. B., & Mizoguchi, M. (2022). A model of evapotranspirative irrigation to manage the various water levels in the system of rice intensification (SRI) and its effect on crop and water productivities. *Water, 14*(2), 1-18. https://doi.org/10.3390/w14020170

Arsil, P., Tey, Y. S., Brindal, M., Ardiansyah, Sumarni, E., & Masrukhi. (2022). Perceived attributes driving the adoption of system of rice intensification: The Indonesian farmers' view. *Open Agriculture, 7*(1), 217-225. https://doi.org/10.1515/opag-2022-0080

Dao, T. M., Huong, H. T. L., & Van Trinh, M. (2019). Calculating the carbon footprint of rice production in Vietnam and formulating a proposal for mitigation options. *Vietnam Journal of Science, Technology and Engineering, 61*(2), 85-89. https://doi.org/10.31276/vjste.61(2).84-89

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (2013). *Promoting the system of rice intensification, lesson learned from Tra Vinh province, Viet Nam.* Retrieved from https://wocatpedia.net/images/f/f2/Giz2013-0503en-rice-lessons-learned-vietnam.pdf

Doni, F., Mispan, M. S., Suhaimi, N. S. M., Ishak, N., & Uphoff, N. (2019). Roles of microbes in supporting sustainable rice production using the system of rice intensification. *Applied Microbiology and Biotechnology, 103*(13), 5131-5142. https://doi.org/10.1007/s00253-019-09879-9

Duong, T. N. (2017). *Research on some technical measures towards improved rice intensification (SRI) in quality rice production in Quang Binh province.* PhD Thesis in the University of Agriculture and Forestry, Hue University, Viet Nam.

Eckstein, D., Hutfils, M.-L., & Winges, M. (2018). *Global climate risk index 2019. Germanwatch e.V.* Retrieved from https://www.germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202019_2.pdf

General Department of Natural Disaster Prevention and Control. (2018). *Statistics table of damage caused by natural disasters in 2018.* Retrieved from https://phongchongthientai.mard.gov.vn/FileUpload/2019-08/046vFTG-cEmSb-iw2018-00.%20THIET%20HAI%20NAM%202018_CT%2031-12-2018.pdf

General Statistics Office of Vietnam (GSO). (2020). *Database.* Retrieved from https://www.gso.gov.vn/nong-lam-nghiep-va-thuy-san/

Hoang, V. P., Nguyen, N. Q., & Nguyen, T. H. (2015). *Improved rice farming system (SRI): Scientific basis and approach to ecological agriculture.* Retrieved from http://sri.ciifad.cornell.edu/countries/vietnam/vn_HVPhu_SRI_scientific_bases_and_ecoagriculture_approach0916.pdf

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC guidelines for national greenhouse gas inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).* Japan: IGES.

Jain, N., Dubey, R., Dubey, D. S., Singh, J., Khanna, M., Pathak, H., & Bhatia, A. (2013). *Mitigation of greenhouse gas emission with system of rice intensification in the indo-gangetic plains.* Japan: Paddy and Water Environment, Springer.

Lu, S. H., Dong, Y. J., Yuan, J., & Hilario, P. (2013). High-yielding, water-saving innovation combining SRI with plastic cover on no-till raised beds in Sichuan, China. *Taiwan Water Conservancy, 61*(4), 94-109.

Meesala, K., & Rasala, S. (2022). Potential of system of rice intensification (SRI) to contribute to the policy objectives: Paradigm of three-tier approach in Southern Telangana—a case study of Narayanpet. *Agricultural Sciences, 13*(4), 542-554. https://doi.org/10.4236/as.2022.134036

Ministry of Agriculture and Rural Development (MARD). (2021). Summary report on the national determination contribution (NDC) implementation plan for crop production for 2021-2030. [Unpublished Manuscript].

Ministry of Natural Resources and Environment (MONRE). (2016). *Climate change and sea level rise scenarios for Vietnam.* Retrieved from http://www.imh.ac.vn/files/doc/2017/CCS%20final.compressed.pdf

Ministry of Natural Resources and Environment (MONRE). (2022). *National determined contribution (NDC) updated in 2022.* Retrieved from https://unfccc.int/sites/default/files/NDC/2022-11/Viet%20Nam_NDC_2022_Eng.pdf

Nirmala, B., Tuti, M., Mahender Kumar, R., Waris, A., Muthuraman, P., Parmar, B., & Vidhan Singh, T. (2021). Integrated assessment of system of rice intensification vs. conventional method of transplanting for economic benefit, energy efficiency and lower global warming potential in India. *Agroecology and Sustainable Food Systems, 45*(5), 745-766. https://doi.org/10.1080/21683565.2020.1868648

Norman, U., Koma, S. Y., Phrek, G., Klaus, P., & Humayun, K. (2000). *The system of rice intensification (SRI) and its relevance for food security and natural resource management in Southeast Asia.* Paper presented at the The International Symposium on Sustaining Food Security and Managing Natural Resources in Southeast Asia: Challenges for the 21st century, Chiang Mai, Thailand, January 8 - 11.

Nugroho, B. D. A., Toriyama, K., Kobayashi, K., Arif, C., Yokoyama, S., & Mizoguchi, M. (2018). Effect of intermittent irrigation following the system of rice intensification (SRI) on rice yield in a farmer's paddy fields in Indonesia. *Paddy and Water Environment, 16*(4), 715-723. https://doi.org/10.1007/s10333-018-0663-x

Oakland Institute and Alliance for Food Sovereignty in Africa (AFSA). (2014). *System of rice intensification (SRI) in Mali.* Retrieved from https://afsafrica.org/wp-content/uploads/2019/04/sri_mali.pdf

Phu Luong Commune People's Committee. (2021). Report on socio-economic situation of Phu Luong commune 2021, goals and main tasks and solutions in 2022 [Unpublished Manuscript].

RIKOLTO, i. V. (2017). *Annual report 2017 – What will we eat tomorrow?* Retrieved from https://assets.rikolto.org/paragraph/attachments/annual_report_2017_-_rikolto_in_vietnam_0.pdf

Shah, T. M., Tasawwar, S., Bhat, M. A., & Otterpohl, R. (2021). Intercropping in rice farming under the system of rice intensification—An agroecological strategy for weed control, better yield, increased returns, and social–ecological sustainability. *Agronomy, 11*(5), 1010. https://doi.org/10.3390/agronomy11051010

Surdeep, K. (2010). *System of rice intensification: An analysis of adoption and potential environmental benefits.*MSc Thesis in International Environmental Studies, Norwegian University of Life Sciences.

Thakur, A. K., Mandal, K. G., Verma, O. P., & Mohanty, R. K. (2023). Do system of rice intensification practices produce rice plants phenotypically and physiologically superior to conventional practice? *Agronomy, 13*(4), 1098. https://doi.org/10.3390/agronomy13041098

Tran, T. H. H., & Nguyen, T. T. N. (2022). Sustainable development for Vietnam's rice export. *Industry and Trade Magazine, 9*, 67-71.

Uphoff, N., & Thakur, A. K. (2019). *An agroecological strategy for adapting to climate change: The system of rice intensification (SRI). In: Sarkar, A., Sensarma, S., vanLoon, G. (eds) sustainable solutions for food security.* Cham: Springer.

Vu, D. Q., Mai, V. T., Bui, T. P. L., Chan, T. A., Bui, V. M., Nguyen, H. S., . . . Nguyen, T. O. (2018). *Evaluation of the economic, environmental and resilience to adverse weather conditions of the system of rice intensification (SRI) compared with traditional rice farming in Binh Dinh.* Vietnam Journal of Agricultural Science and Technology - No. 6(91)/2018.

World Bank (WB). (2010). *Economics of adaptation to climate change in Viet Nam.* Washington, DC: The World Bank Group.

Yamane, T. (1967). *Statistics an introductory analysis* (2nd ed.). New York: Harper and Row.