CLIMATE-SMART INTEGRATION OF RICE AND LOCAL PALM PRODUCTION: ENHANCING RESILIENCE AND SUSTAINABILITY IN TROPICAL AGROECOSYSTEMS

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ABSTRACT:

Global agricultural systems are facing serious difficulties from climate change, especially in tropical countries where the production of rice and palm is essential for both food security and economic growth. In order to improve resilience and sustainability in tropical agroecosystems, this study investigates the integration of rice and palm production systems as a climate-smart strategy. In addition to changes in temperature, precipitation patterns, and pest dynamics, the study looks into the interplay between climate change and rice and palm product. It assesses the possible benefits and drawbacks of combining agroecological approaches including crop diversification, agroforestry, and water management. In order to establish sustainable land use, lessen environmental effects, and increase the socioeconomic resilience of smallholder farmers, policy frameworks and governance structures that facilitate integrated farming systems are examined. The study additionally investigates at economic factors, evaluating the effects on local populations' livelihoods and the economic viability and market dynamics of integrated rice-palm farming. It is *suggested that knowledge-sharing platforms and capacity-building programs be implemented to help the parties involved in sustainable agricultural development learn from other parties while collaborating together. By providing insights into adaptation strategies, policy interventions, and technological advancements essential for boosting resilience and sustainability in tropical agroecosystems facing climate change challenges, this study anticipates to advance the field of climate-smart agriculture strategies.*

Keywords: Adaptation, Agriculture, Climate Change, Local Palm Trees, Rice Cultivated, Thailand

INTRODUCTION:

The Sustainable Development Goals (SDGs) of the United Nations, especially SDG 2: Zero Hunger, recognize food security as a basic human requirement. Ensuring food security and advancing sustainable agriculture are necessary to achieve this goal. However, historical agricultural practices and climate change pose serious obstacles to the world's food production, particularly in poor nations. In order to improve food security, the sustainability of the environment, and the welfare of farming communities, this study highlights how vulnerable Thai rice cultivation is to climate change and the importance of sustainable agricultural practices. In an effort to increase agricultural production, the Green Revolution brought in chemical inputs and technical innovations. Despite being effective in raising output, these methods have had a negative impact on the environment, degrading soil, contaminating water, and reducing biodiversity. By altering precipitation patterns and raising global temperatures, which in turn affect agricultural productivity, climate change makes these problems worse. The findings of Peng et al. (2004) and Zhao et al. (2017) that rising temperatures have a detrimental effect on rice yields emphasize how urgent it is to address climate change in agriculture.

Thailand, a significant producer of rice, is especially susceptible to these modifications. The Social Ecological Systems (SES) framework, which takes into account elements like resource systems (RS), resource units (RU), and users (U), offers a helpful lens through which to view the obstacles to rice production in Thailand. The resource system has notable issues, including chemical contamination, water scarcity, and deteriorating soil fertility, as highlighted by the Thailand Development Research Institute (2010) and Sirirat Trongwattanawuth et al. (2018). Further exacerbating these problems is the ignorance and lack of technology among farmers, as noted by Wannisa Wangjai et al. (2017) and Thumnong Chidchob (2011). Huai Yang Ton (HYT) Sub-district in Ratchaburi Province serves as a case study for exploring these vulnerabilities. The region's rice farming practices, both chemical and organic, illustrate the contrasting approaches to agriculture and their respective impacts on sustainability. The area's climate, characterized by seasonal rainfall and varying soil types, further complicates rice production. Notably, the use of chemical fertilizers and pesticides in conventional farming practices has led to soil degradation and reduced yields over time. To mitigate the effects of climate change, rice production must adopt a resilience approach. This entails incorporating techniques like organic farming, large-scale rice farming partnerships, potential zoning for fertilizer use, and better seed selection. These tactics not only increase output but also lessen environmental damage and support farmers' sustainable means of subsistence. According to SDG 13: Climate Action, community-based adaptation solutions are crucial, as this study highlights. Farmers in the HYT Sub-district and the province of Nakhon Pathom are adapting their methods to deal with climate fluctuation on a larger scale. This entails changing the timing of plantings, implementing sustainable farming practices, and looking for alternate water sources. Local communities are better equipped to survive climate change and safeguard their food production systems when they cultivate resilience through a variety of biological resources, production techniques, and knowledge systems. In conclusion, investigating how vulnerable Thai rice farming is to climate change emphasizes how important it is to adopt sustainable farming methods that support the SDGs. In the face of persistent climatic challenges, addressing these vulnerabilities through resilience-building measures and community-based adaptation techniques is essential to guaranteeing food security and advancing sustainable development.

OBJECTIVE OF THE STUDY:

1. To assess the impacts of climate change on rice production in Huai Yang Ton (HYT)
2. To evaluate the effectiveness of resilience strategies
3. To investigate the socio-economic and environmental resilience of communities in Thailand.

METHODOLOGY:

Secondary Study: Carry out an exhaustive analysis of the literature, research papers, and reports that are currently available about the effects of climate change on Thai agriculture, with a particular emphasis on rice production and the function of local Thai knowledge. The response of palm trees to climate change.

Qualitative Approaches: Interviews with key informants in the area, such as farmers, regional specialists, extension agents for agriculture, and local leaders.

Case Study Location: Ban Lat District in Phetchaburi Province and Huai Yang Ton Sub-district in Pak Tho District in Ratchaburi Province

Data Analysis: Using content analysis, investigate how the community's adaptive tactics and rice agriculture are affected by climate change.

Exploring Climate Change Vulnerability in Thai Rice Farming

Food is a human need. Zero hunger is part of the Sustainable Development Goals (SDGs) by the United Nations. More importantly, food security and production safety should be aware of the implementation for better production, environment, and life. The world's food production in several countries, especially developing countries, is facing insecurity due to the Green Revolution and climate change. Though the green revolution used technology and chemical substances to overcome a challenge, the yield was unsafe and had environmental impacts. Climate change affects the precipitation (e.g., freshwater, rain, and snow). The world temperature is rising greenhouse gases, which consist of Carbon dioxide (CO_2), Methane (CH_4), and Nitrous oxide (N_2O). Peng, Huang, Sheehy, Laza, Visperas, Zhong, Centeno, Khush, and Cassman (2004) said that the rice yield decline when the world temperature is increased, consistent with Zhao, Liu, Piao, Wang, Lobell, Huang, Huang, Yao, Bassu, Ciais, Durand, Elliott, Ewert, Janssens, Li, Lin, Liu, Martre, Müller, Peng, Peñuelas, Ruane, Wallach, Wang, Wu, Liu, Zhu, Zhu, and Asseng (2017) who reported that climate change, as well as temperature and precipitation changing, influences on productivity.

Barriers to rice production can be explained using the Social Ecological Systems framework, which includes the resource system (RS), resource unit (RU), and user (U). RS is caused by chemical contamination in cultivation areas and occurs during transportation (Sirirat Trongwattanawuth, Piyawan Siriprasertsin, & Chaiwat Baimai, 2018). Climate change is causing a scarcity of previously unavailable production inputs, such as water and natural resources (Sirirat Trongwattanawuth et al., 2018; Thailand Development Research Institute, 2010). RU has not changed the land used, but inputs (seeds and fertilizers) have increased. Furthermore, soil fertility in rice production areas is declining because the substance must be balanced when used and maintained. Previously, fertilizer ratios were utilized to analyze soil textural qualities, which were different and unrelated to soil potential. U consists of Lack of knowledge, is confirmed by Thumnong Chidchob (2011); Wannisa Wangjai, Benchamas Yooprasert, and Ponsaran Saranrom (2017) found the pre-harvesting phase is characterized by a lack of understanding about rice cultivation (for example, water management, weed management, fertilizer use, plant diseases, and harvesting methods). The post-harvest phase includes rice processing and storage. Sirirat Trongwattanawuth et al. (2018) stated that information flow is non - connecting data for personalized retail plans that alter rather than forecast demand. Lack of technology - agricultural machines were discovered during the pre - harvesting and distribution phases. The Thailand Development Research Institute (2010) supported the Lack of Labor report, which identified the problem of upstream production.

Rice Production in Huai Yang Ton (HYT) Sub – district, Ratchaburi Province

Ratchaburi Province is located in the Western Region, divided into eleven districts. There were approximately 1.50 million rai (Land Development Department, 2023). Ratchaburi province's annual rainfall ranged from 8.70 to 29.08 millimeters ($\bar{X}$ = 14.39), with the rainy season occurring from March to October (Data Innovation and Governance Institute, 2022). Soil groups were 1, 6, 18, 36, 48, 49, 56, 60, and 62, respectively, with low soil fertility and organic matter, fine - loamy soil, and slightly acid (pH ≈ 5.5 – 6.5) (Land Development Department, 2024). The agricultural area consists of Excellent (Yellow Zones), High (Pink Zones), and Low (Orange Zones) Potential Cultivation. The Excellent Potential Cultivation to grow rice is mostly in Photharam District, which covers approximately 0.12 million rai. Meanwhile, The High Potential Cultivation is mostly located in Pak Tho District as shown in Figure 1.

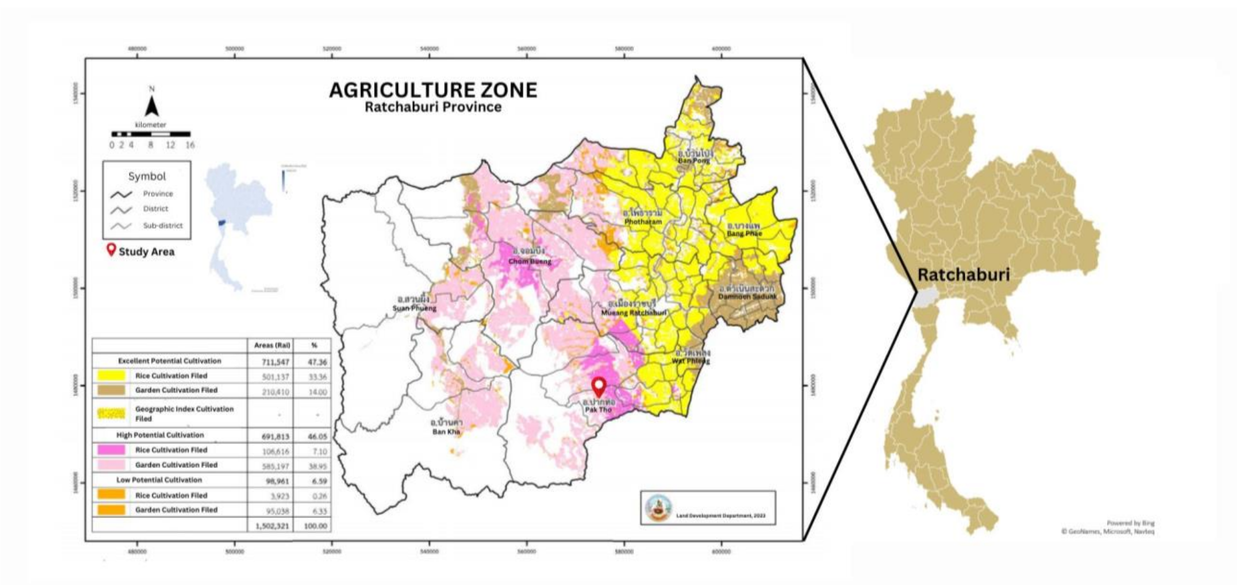

Figure 1 Agriculture zone, Ratchaburi province

Source: Land Development Department, 2023

Huai Yang Ton (HYT) Sub - district is part of Pak Tho District. There was approximately 0.04 million rai (National Science and Technology Development Agency, 2024). The majority of the land is utilized for rice cultivation (Yellow Zones), which is approximately 9,481 rai (Fig.2). This area has two rice production approaches: chemical and organic as seen in Table 1.

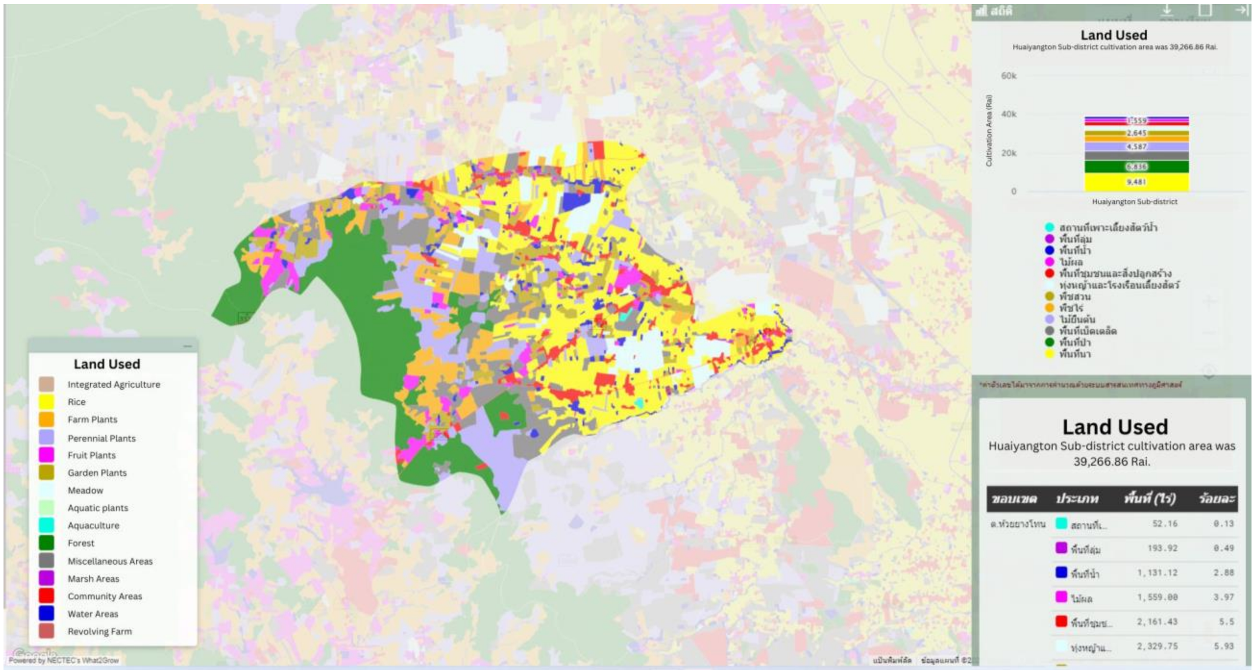

Figure 2 Land used in Huai Yang Ton sub - district, Pak Tho district, Ratchaburi province

Source: National Science and Technology Development Agency, 2024

Table 1 Rice production in HYT

	Rice Production	
	Chemical	**Organic**
Size (hectare)	1. 0.8 – 1.6 2. 1.6 – 7.2 3. > 7.2	
Crop period	1^{st} (May - November)	
Rainwater	Rainfed	
Post – harvesting Management	Combustion is used to eliminate rice straw after harvesting.	Ploughing and rice residue fermentation are used to manage rice straw to maintain and boost soil organic matter.
Soil Preparation	1. The machines are typically used to plow soil to help it ventilate, weed, and eventually grow rice.	Soil preparation involves using organic fertilizer, manure, or plant fertilizer (*Crotalaria juncea*), or bio - fermentation.

	2. Chemical fertilizers containing nitrogen, phosphate, and potassium are applied twice a year during the rainy season, in May and June, as well as in August.	
Planting	Pesticides and herbicides are also used to protect crops, particularly during planting.	Microbial pesticides (*Trichoderma harzianum*) are also used to protect crops, particularly during planting.
Harvesting	Harvesting rice takes approximately four to five months, depending on the climate.	

Resilience Approach in Rice Production

Previously, HYT's farmer - determined fertilizer ratios by evaluating soil textural features rather than soil potential. Also, HYT's chemical rice production areas have not changed land use, but inputs (seeds and fertilizers) have increased. Furthermore, soil fertility in rice production areas has decreased since soil fertilizers must be balanced, used, and maintained. Hence, the resilience approach in rice production is appropriate for this case as seen in Table 2.

Table 2 Resilience Approach in HYT's Rice Production

Approach	Description	Reference
Rice Production by Potential Zoning	Rice cultivation yield increases as fertilizer is applied based on soil potential.	Rice Department, 2013
Organic Rice Production	1. Organic jasmine rice production reduces resource use, has a lower environmental impact, and increases product value. 2. Organic jasmine rice cultivation yields were significantly higher than chemical jasmine rice production.	Jirapornvaree, I., Suppadit, T. and Kumar, V., 2021
Large - scale Rice Farming	Farmers in the region collaborate to produce rice. This decreases expenses while increasing production efficiency.	Assavarak, P., Seeprasert, P., and Jirapornvaree, I., 2024
Seed Selection	Seed selection is a critical factor in rice production. RD95 rice seeds are eligible for selection for cultivation in this area. The result of this study found RD95 can produce the yield, approximately 0.8 to 1.0 tonnes/rai/crop. Compared to RD105, the yield can be around 0.5 tonnes/rai/crop.	
Form of Participation in Rice Supply Chain Management	1. Three perspectives on connecting stakeholders in Rice Supply Chain include information flow, product quality, and production costs.	Thumnong Chidchob, 2011

	2. Farmer should focus on production quality rather than quantity. 3. Rice processor and distributor operated by fair price mechanism. 4. Consumer sent the feedback information to the both for continuous improvement.	

Table 2. explained that despite the climate change issue, farmers must improve their ability to cope with change through integrated production management. Additionally, HYT's farmers must plan their produce and calculate the cost, especially in rain-fed agricultural areas, to reduce the risk of loss and future debt.

The concerning pattern of rice productivity declines due to environmental changes linked to climate change is consistent with research on climate change adaptation among growers of major cash crops in the Nakhon Pathom province, Thailand. This research emphasizes the main problems farmers face: temperature variations, disease and pest outbreaks, and flooding. Farmers are responding to these challenges by implementing a variety of measures, such as revising planting schedules, transitioning to sustainable agriculture, seeking alternate sources of water during dry spells, and changing the types of crops grown (Jirattinart Thungngern et al., 2023).

The sustainable development concepts provide the foundation for community-based climate change adaptation using several frameworks. Communities employ a variety of biological resources, production techniques, knowledge types, and revenue sources to manage climatic fluctuations and extremes. This method of relying on diversity improves the ecological, social, and economic resilience of local communities by expanding the range of adaptation options available across various spatial and temporal dimensions.

Climate Resilience of Local Palm Trees in Thailand

Although palm trees have long been associated with the tropics, they are currently facing new difficulties due to climate change. Notwithstanding these challenges, palm trees are demonstrating incredible resilience and flourishing in new habitats. They are adapting significantly, one of which is by being able to withstand a wider variety of temperatures. Numerous palm species are expanding their geographic ranges in response to global warming. Furthermore, as a result of rising temperatures and atmospheric carbon dioxide concentrations, palm trees are expanding more quickly. Their rapid growth enables them to outcompete other species for resources and establish themselves in new settings quickly.

There are around 161 native palm species in Thailand, which are categorized into 33 genera. Two infraspecific taxa and sixteen species are native to the nation. Thailand's climate, which spans 511,731 km^2, is distinguished by a latitudinal gradient of temperature and precipitation as well as a longitudinal gradient of precipitation. Peninsular Thailand, which is bounded to the east by the Andaman Sea (Indian Ocean), to the west by the Gulf of Thailand, and to the east by a portion of the South China Sea, is home to 80 percent of all Thai palm species. The majority of species in the north can be found in the montane forests that border Burma, Laos, and Cambodia. In Thailand, palm trees are used for many different things. They are a major source of food and shelter for rural inhabitants. This study addresses the native wisdom palm tree found in Thailand, emphasizing their adaptability and resilience to the environmental and socioeconomic difficulties posed by climate change.

Challenges of the Palmyra palm (*Borassus flabellifer*)

The palmyra palm (*Borassus flabellifer*), which grows all over Thailand, is essential to the regional economy. It lives a very long time and starts reproducing at the age of 12 to 15. Because it is a dioecious plant, the male and female specimens are different. The palmyra palm is crucial to the Ban Lat District of Phetchaburi province's efforts to adapt to climate change. The district's primary assets include its physical layout, historical significance, and tradition of using palmyra palm products. Culturally significant is the palm sugar production heritage in Phetchaburi Province, commonly referred to as the 'Muang Phet, City of Palmyra Palm.' A 2007 survey found that there were 300,355 palmyra palm trees in Phetchaburi Province, with 73,858 of those trees—or 24.59 percent of the total—located in Ban Lat District. The knowledge of palm sugar production is crucial for career development in this field, turning it into an economically viable crop that provides income for the local community. Palm local wisdom, which varies by locality, includes unique characteristics, methods, and practices, all of which hold important cultural and commercial value. Understanding the production of palm sugar is essential for advancing one's career in this field and making palm sugar a sustainable crop that boosts the local economy.

It was noted that farmers are boosting their rice cultivation while decreasing their production of Palmyra palm sugar as a means of responding to economic, technological, and social demands. Traditionally, farmers would rotate between producing palm sugar and rice once a year. Farmers no longer have time to make palm sugar because rice is now farmed twice a year. As a result, many people have given up on this habit. Moreover, the twice-yearly farming results in water retention throughout the year, which causes sugar palm trees planted beside rice fields to eventually die off. Additionally, they are altering their production processes by substituting less expensive melt sugar with more costly real Palmyra palm sugar. Regarding the efforts to maintain the production of Palmyra palm sugar, the data indicates that the conventional method—which uses palm material from trees planted in rice fields—is deteriorating and may disappear in the next thirty years (Angkavanich & Nitjaran, 2013).

Not only is there a risk of losing biodiversity due to changing planting patterns, but socio-economic factors also pose a threat. The expertise and cultural heritage associated with palm sugar production are at risk due to a generational gap, as most individuals skilled in this craft are over 50 years old (Kamnuansin, 2019). The number of people engaged in palm sugar-making has decreased, causing the wisdom associated with palm trees to fade away. This emphasizes the need for sustainable development and resilience within the community. Government agencies and community leaders are aware of these problems and are working to find sustainable solutions to preserve and develop the palm sugar occupation (Nokkaew, 2021). In Ban Lat District, Phetchaburi Province, which consists of 115 villages in 18 sub-districts, only 291 people are currently engaged in palm sugar production.

"*...It takes time for one Palmyra tree to regrow fully and produce quality products. Typically, it requires a minimum period of 15 years before it begins yielding high-quality output….*" said the headman of Rai Krang village.

In an interview, the local headman stated that the production of palm sugar is currently the principal profession of approximately 11 households in Rai Krang local. Furthermore, about ten workers are engaged in climbing and harvesting duties. Participants in these activities range in age from a minimum of around 22 years old to a maximum of about 80 years old.

Because of the vast traditional knowledge of Palmyra palm products—which are now essential to community livelihoods—there are several economic options. The community's ability to respond to shifting environmental conditions and economic challenges is strengthened by this economic diversification. Renowned for its adaptability, the Palmyra palm is an essential source of income for many underprivileged people. Different sections of the palm are used to make different goods. A representative from Rai Krang Village stated that female Palmyra palm trees yielded approximately 4,500 THB (equivalent to 125 USD) per tree per harvest, while those working in climbing and harvesting tasks are paid about 50 THB (1.5 USD) per tree, with a maximum capacity of about 8 trees per day. Value-added goods, such as palm sugar, can support economic viability. In addition to their nutritional and therapeutic benefits, these items are important sources of employment and income, especially for underprivileged groups involved in their cultivation and sale (Srivastava et al., 2017).

In conclusion, the traditional practice of palm sugar production is declining due to changing agricultural practices, economic pressures, and a generational gap in knowledge. The decreasing number of individuals engaged in this craft, particularly in Ban Lat District, underscores the need for sustainable development and community resilience. Government agencies and community leaders are actively seeking solutions to preserve and develop palm sugar production. The palmyra palm's adaptability and economic potential, including its role in providing income for underprivileged groups, highlight its importance. Sustaining this tradition is crucial for maintaining biodiversity, cultural heritage, and economic stability in the region.

In Thailand, the Palmyra palm (*Borassus flabellifer*) is an important ecological component because of its remarkable tolerance to drought, ability to prevent landslides, ability to sequester carbon, and ability to maintain biodiversity. Palmyra palms are well-known for growing well in arid climates. Their large root systems help to prevent soil erosion and promote water retention. The numerous environmental advantages of the palmyra palm highlight how crucial it is for fostering resilience and sustainability in regional ecosystems.

According to Ali-Dinar et al. (2023), the Palmyra palm (Borassus flabellifer) thrives in arid settings, making it essential for areas experiencing drought issues that affect agricultural sustainability. Due to their deep root systems, these palms help retain water and reduce soil erosion, making them ideal for regions with variable rainfall patterns. Research conducted in Odisha, India (Behera et al., 2021), shows that alluvial soils with optimal pH, high amounts of organic carbon and moisture, and moderate temperatures are ideal for Palmyra palm growth and yield. Palmyra palms are the predominant perennial component in Nalgonda, Andhra Pradesh, India (Osman et al., 2000). Their adaptability in providing a variety of products in addition to sugary juice supports lucrative agriculture in drylands.

As mentioned earlier, in addition to drought resistance, the robust root systems of Palmyra palms are pivotal in stabilizing soil and reducing the risk of landslides, especially in hilly or sloped terrain. These palms act as natural barriers, effectively preventing soil erosion and enhancing overall environmental stability. Aroonsrimorakot et al. (2021) highlight that the extensive root system of sugar palm trees, reaching depths of up to 15 meters, offers a practical approach to mitigating landslides and erosion along riverbanks when strategically planted along roadsides and canals in Thailand. This approach provides an eco-friendly alternative to traditional concrete barriers funded by substantial government allocations for erosion control. However, the successful implementation of such strategies requires meticulous planning, continuous maintenance, and community support, underscoring the need for policymakers and management teams to collaborate effectively to establish sustainable defenses against natural disasters.

Because they absorb and store carbon dioxide, palmyra palms are essential for carbon sequestration, which reduces greenhouse gas emissions and fights climate change. Studies carried out in diverse locations have evaluated the capacity of Palmyra land use to sequester carbon across a range of soil types. The results have indicated differing concentrations of soil organic carbon and biomass carbon stocks, with the highest concentrations being found in the uppermost soil layers. Research conducted in the province of Phetchaburi revealed that palm plantations and natural regions had noteworthy capacity to store carbon, with mean carbon levels of 30.84±2.59 kilograms and 37.08±2.28 kilograms, respectively (Gnanavelrajah et al., 2023; Pattamaporn Yodsanti et al., 2020). These results highlight the role that Palmyra palms play in environmental conservation initiatives by efficiently capturing and storing carbon.

According to one of the informants, "*…I will use a palm sugar knife to thinly slice the tips of the male palm flowers, allowing fresh sugar to flow out, and I will use hanging containers to catch this fresh sugar….*" This practice ensures that male flowers of sugar palm trees are deliberately removed before blooming to benefit sugar tappers, as flowering palms attract crucial pollinating insects that are scarce in heavily taped areas.

Because palmyra palms are essential habitats and resource sources for a variety of species, they promote ecological balance and greatly enhance local biodiversity. Adhering to traditional knowledge in sustainable harvesting practices is essential for biodiversity conservation as it prevents overexploitation from depleting the resource. According to a study, there are 50 insect pollinators that thrive among sugar palms in natural forest environments. This highlights the importance of protecting these habitats in order to promote pollination activities and preserve the health of the ecosystem as a whole (Susanti Withaningsih and Haifa Nurislamidini, 2021).

Other than cultivating sugar palms in Phetchaburi province, various areas across Thailand feature indigenous palm species, such as the Sago palm (*Metroxylon sagu Rottb.*), native to Southeast Asia and Oceania. These palms are culturally and economically important in Thailand, especially in southern provinces like Nakhon Si Thammarat and Phatthalung, where they exhibit potential for climate adaptation. They play crucial roles in both local agriculture and ecological systems. Nearly all parts of the sago palm find use: its sucker and young leaves are edible, the bark serves as flooring or fuel, seeds are decorative, and the pith is used in animal feed or food processing. Despite its versatility, Thailand lags behind neighboring countries like Malaysia and Indonesia in sago palm cultivation and utilization. Economic studies highlight significant benefits from utilizing sago palms, particularly in Nakhon Si Thammarat, where leaves are the most economically valuable part, contributing annually to substantial incomes. Age and utilization type significantly influence economic productivity, with older trees being more profitable, primarily through starch production and as a food source for sago grubs. However, challenges persist, especially in managing younger trees to sustain sago palm forests (Wattananarong Markphan et al., 2016, Wichit Charungsutjaritkul et al., 2017). The study conducted in Yala, Pattani, and Narathiwat aimed to assess the current status and distribution of sago palm (*Metroxylon sagu Rottb.*) forests using observational methods, interviews, and focus groups across 199 sub-districts. Findings indicated that sago palms thrive in swampy, waterlogged, and occasionally rocky environments, often growing alongside other trees. Narathiwat showed significant sago palm coverage with over 1 million square meters and a majority of trees. Most sago palm forests in these provinces were privately owned, and a substantial portion was deemed to be in good condition. The study underscores the importance of sustainable conservation efforts by local communities and stakeholders to ensure the preservation of sago palm forests for future generations (Wilaiwan Kaewtathip et al., 2018).

The research conducted in Nakhon Si Thammarat province on sago palm forests explored their utilization, aquatic biodiversity, and water quality. Sago palm leaves are commonly used for roofing, while the trunk serves as feed for animals and sago worms, contributing economically. The fish community in these ecosystems showed high diversity with 74 species across 9 orders and 24 families. Phytoplankton diversity varied between dry and wet seasons, reflecting 21-32 genera and 22-28 genera respectively. Water quality assessments indicated a mesotrophic to meso-eutrophic status suitable for aquatic life despite varying trophic levels (Suriya Chankaew et al., 2014). Another study on algae diversity in the same area highlighted significant variation with 100 genera and 210 species identified across five divisions (Manthaka Weeraphong et al., 2016).

This study emphasizes the potential of integrating two palm tree species and indigenous knowledge in Thailand to combat climate change through ecological, economic, and cultural strategies, serving as a model for sustainable development in comparable regions. The Palmyra palm (*Borassus flabellifer*) is crucial to Thailand's economy, particularly in Phetchaburi province's Ban Lat District, renowned for its palm sugar production heritage. Despite challenges such as declining traditional practices and economic pressures favoring rice cultivation over palm sugar, efforts are underway to sustain and develop palm sugar production. Meanwhile, the Sago palm (*Metroxylon sagu Rottb.),* found in southern Thailand, holds cultural and economic significance, despite lagging cultivation compared to neighboring countries. Studies underscore its versatile uses and economic benefits, urging sustainable conservation to ensure its ecological and economic contributions endure for future generations, providing a model for sustainable development in similar areas.

DISCUSSION:

The vulnerability of rice farming in Thailand to climate change is a significant concern, particularly in the context of sustainable development goals (SDGs). The United Nations' SDG 2, which aims to end hunger, achieve food security, and promote sustainable agriculture, underscores the importance of addressing these vulnerabilities. This research highlights several critical aspects that need to be considered to enhance the resilience and sustainability of rice farming in the Huai Yang Ton (HYT) sub-district of Ratchaburi Province.

Climate Change and Rice Production

Climate change poses a profound threat to rice production, as evidenced by the impacts on precipitation patterns and temperature increases. The findings of Peng et al. (2004) and Zhao et al. (2017) align with this study, indicating that rising temperatures and altered precipitation patterns negatively affect rice yields. In HYT, farmers face challenges such as water scarcity, reduced soil fertility, and increased input costs, which are exacerbated by climate change. The reduction in yield not only threatens food security but also the economic stability of farming communities reliant on rice production.

Social Ecological Systems Framework

The application of the Social Ecological Systems (SES) framework provides a comprehensive understanding of the barriers to rice production in HYT. Chemical contamination and the overuse of fertilizers have degraded the resource system (RS), leading to long-term environmental damage. The resource unit (RU) has also been affected, as the continuous use of chemical inputs without considering soil potential has led to decreased soil fertility. The user (U) aspect highlights the lack of knowledge and technology among farmers, which hampers their ability to adapt to changing conditions and optimize production practices.

Resilience and Adaptation Strategies

Resilience approaches in rice production, as demonstrated in HYT, offer potential pathways to mitigate the impacts of climate change. Implementing practices such as potential zoning for rice cultivation, organic farming, and large-scale farming can enhance productivity and environmental sustainability. The success of organic jasmine rice production, which reduces resource use and increases product value (Jirapornvaree et al., 2021), suggests that similar strategies could be effective in HYT. Additionally, collaborative farming efforts can reduce costs and improve efficiency, providing a model for scaling up these practices. Resilience strategies in palm production are essential to mitigate the impacts of climate change and ensure long-term sustainability. Agroecological practices, such as intercropping, cover cropping, and maintaining biodiversity, can improve soil health and reduce pest outbreaks. These practices not only enhance the resilience of local palm plantations but also contribute to the broader ecological health of the region (Garrett et al., 2017).

Community-Based Adaptation

Community-based adaptation (CBA) strategies, rooted in sustainable development principles, are crucial for enhancing the resilience of local communities. By leveraging local knowledge and diversifying agricultural practices, communities can better manage climatic variability and extremes. The study on climate change adaptation among farmers in Nakhon Pathom province (Thungngern et al., 2023) illustrates the importance of adjusting planting calendars, seeking alternative water sources, and modifying crop types to cope with changing environmental conditions. Similar CBA approaches could be applied in HYT to strengthen local resilience.

THE POLICY RECOMMENDATIONS:

1. Promotion of Organic Farming: Encourage and support farmers in HYT to adopt organic farming practices similar to the successful model of organic jasmine rice production. Organic farming can improve soil fertility, reduce dependency on chemical inputs, and enhance product value, contributing to both environmental sustainability and economic stability.
2. Implementation of Climate-Resilient Agricultural Practices: Introduce potential zoning for rice cultivation based on climate suitability assessments. This approach helps farmers optimize planting decisions and reduce the risk of crop failure due to climate variability. Additionally, promoting large-scale farming and cooperative efforts can help consolidate resources and increase efficiency in water and input use.
3. Community-Based Adaptation (CBA) Strategies: Facilitate community-led initiatives that leverage local knowledge and diversify agricultural practices. Encourage HYT farmers to adjust planting calendars, explore alternative water sources, and diversify crop types to enhance resilience against changing climate conditions. Providing support for these adaptive measures through local institutions and partnerships can amplify their effectiveness.
4. Community Engagement and Benefits Sharing: Ensure that local communities benefit from local palm production through equitable employment opportunities, revenue-sharing schemes, and

community development projects. Implement policies that require palm production companies to engage with local communities, respect indigenous land rights, and contribute to local infrastructure and social programs.

5. Research and Development Investment: Allocate resources towards research and development aimed at developing climate-resilient palm varieties. This includes breeding programs focused on drought resistance, disease tolerance, and improved nutrient uptake. Support collaborative research efforts between universities, research institutions, and palm production companies to accelerate innovation in sustainable palm cultivation.

FUTURE RESEARCH:

For future research on climate-smart integration of rice and local palm production: enhancing resilience and sustainability in tropical agroecosystems could be explored:

1. Integrated Land Use Planning: Research on integrated land use planning strategies that optimize the coexistence of rice farming and local palm production. Investigate spatial planning approaches that balance agricultural productivity, biodiversity conservation, and ecosystem services to minimize environmental impacts and maximize socio-economic benefits.

2. Economic and Social Dimensions: Investigate the economic implications of integrating rice and local palm production systems, considering market dynamics, profitability, and livelihood impacts for smallholder farmers and local communities. Analyze the social acceptability and adoption barriers of integrated farming approaches among different stakeholder groups.

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