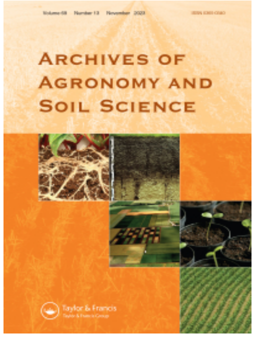

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Introducing the RICE framework in paddy-duck farming: a novel approach to enhance the adaptive capacity of paddy farmers among asnaf community in managing the risk of climate change

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ABSTRACT

The industrial revolution marked a transformative era in the history of rice cultivation, bringing significant changes to meet growing demand and addressing food security concerns. Maintaining paddy production through conventional practices has become increasingly challenging, particularly considering the projected impacts of climate change on both paddy productivity and farmers' livelihoods. According to recent studies, rice-duck system application decreases nitrogen fertiliser by 57%, herbicides by 50%, expenditures by \$296.3 M, increase income by \$1523.9 ha^{-1}, and cleaner production using organic waste recycling. The present study introduces the RICE (restore, integrate, circular, enhance) framework, proposed as an instrumental approach to explore strategic and sustainable solutions that go beyond a production-centric mindset. This framework considers the balance between present production demands and potential losses of ecosystem services in the long run. The RICE framework has the potential to serve as a strategic environmental, social, and governance (ESG) instrument for lembaga zakat negeri Kedah (LZNK). It promotes regenerative agriculture and seeks to improve the livelihoods of asnaf farmers within the smart sawah berskala besar asnaf (SSBA) scheme. By adopting this approach, LZNK can contribute to sustainable development by ensuring that present needs are met without compromising the ability of future generations to fulfill their needs.

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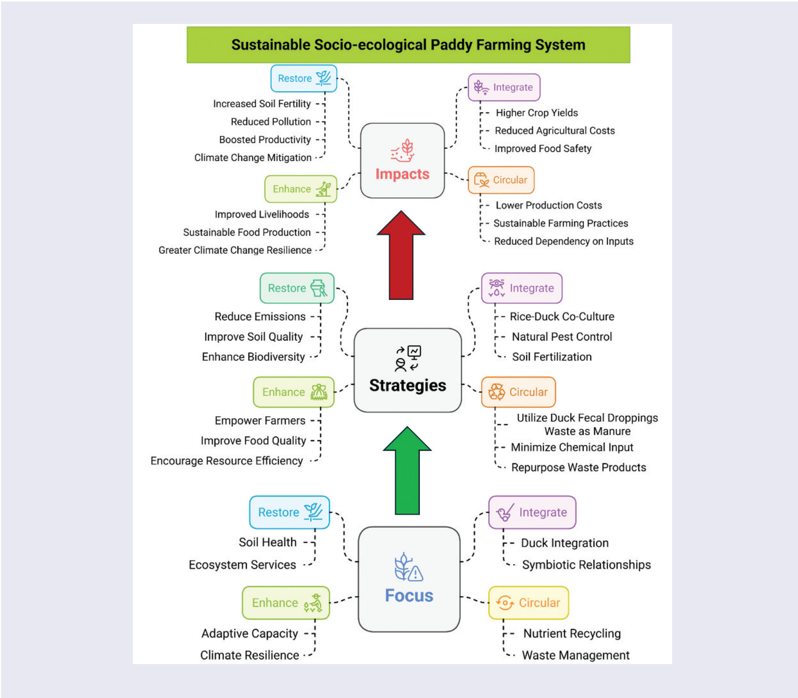

Introduction

Rice accounts for 26% of the total caloric intake of individual Malaysian per day. Approximately, 67% of the rice in Malaysia is produced locally at around 60–70% self-sufficient level (SSL), suggesting positive progress of rice production since the 1940s (Arshad et al. 2011; Siwar et al. 2014). Such positive progress is due to intervention measures (subsidies) by the government to absorb about 50% cost of paddy production (Yahaya 2016; Ibrahim et al. 2017). In fact, twelfth Malaysia plan (12MP) has set a target of national rice self-sufficient level (SSL) by 75%. This can be achieved through the Smart Sawah Berskala Besar Asnaf (SSBA) programme (Business Today Editorial 2021). The model of SSBB is more flexible, allowing industry players to 'customize' their role at any level of the value chain of the paddy and rice industry. Innovation in paddy farming practices may result in a low-risk and low-cost rice cultivation process, ultimately, improve the income margin of farmers and advances them to grow out of poverty.

The smart agenda by the government has inspired local religious body Lembaga Zakat Negeri Kedah (LZNK) to develop their land assets through a noble program known as SSBA. The flexibility of the scheme allows innovation at any level in the value chain of paddy and rice industries within the asnaf farmer community. However, the challenge of sustaining paddy production in alignment with SSL targets is becoming increasingly daunting, due to the projection of climate change (its adverse impact on paddy productivity) affecting the livelihood of farmers and emerging pollutants (Sayed et al. 2024).

The earth's climate is currently undergoing rapid changes, and these changes carry significant implications for agricultural output (Gornall et al. 2010; Stern 2017; Otto et al. 2020). These changes encompass intensified levels of carbon dioxide (CO_2), escalating global temperatures and erratic shifts in rainfall patterns (Haliza Abdul Halim 2009; Kryzanek and Karreth 2018; Anwar et al. 2019). Note, the majority of greenhouse gas emissions stem from agricultural activities like crop cultivation, deforestation, and animal husbandry (Duxbury and Mosier 1993; Bennetzen et al. 2016; Ghosh et al. 2020). Subsequently, Cloy and Smith (2017) stated that the main sources of these emissions are methane (CH_4) produced through biochemical processes, nitrous oxide (N_2O) resulting from soil management as well as carbon dioxide (CO_2) released from the use of fossil fuels and changes in the land use. This sector contributes about 20% of the emissions, as estimated by the Inter-Governmental Panel on Climate Change (IPCC) and Food and Agriculture Organization (FAO) findings in 2014. Moreover, the forecast of the rise in the occurrence of heat waves indicates that heat remains a threat to the steadiness and productivity of food systems (Fahad et al. 2018). As indicated by Hussain et al. (2020), depletion of the organic layer of the stratosphere and increasing greenhouse effect influence the increase in climate-induced soil degradation and reduced natural nitrogen inputs, which ultimately drive the need for more chemical fertilizers. This results in a significant amount of N_2O emissions due to the usage of chemical fertilizers, or about 65–80% of which arises from the microbial reduction of NO_{2-} and NH_{4+} predominantly in water and soil. These developments could potentially undermine the ongoing initiatives of the LZNK aimed at enhancing the well-being of the asnaf community through the paddy industry in the forthcoming years. The community engaged in paddy farming heavily depends on this crop as its primary source of income and sustenance, particularly for those individuals involved in small-scale agricultural endeavours. Notably, around 40% of those engaged in agriculture rely exclusively on paddy cultivation (Firdaus et al. 2020). Hence, there is a pressing need for strategic measures to be implemented in paddy farming within the asnaf community, designed to effectively manage the risks posed by climate change.

However, in the context of current rice production and food security paradigm, the concern is more on satisfying the demand of 'present' due to critical issues like self-sufficiency level and income generation for the rural community. Inspired by the national food security agenda of Malaysia, Lembaga Zakat Negeri Kedah (LZNK) has undertaken a commendable initiative called Smart Sawah Berskala Besar Asnaf (SSBA) to develop its land assets. If the trade-off between demand for paddy production and ecosystem losses is not addressed sustainably, it may hinder the ongoing efforts by LZNK to improve the livelihoods of asnaf community through the paddy industry in the future. Fortunately, the flexibility of the SSBA scheme allows strategic innovations at various levels of the paddy and rice value chain within the asnaf farmers' community.

The novel aspect of this study lies in the adoption of RICE (restore, integrate, circular, enhance) framework, which departs from traditional, production-centric approaches to rice cultivation. This framework provides a holistic solution that balances immediate production needs with long-term sustainability. The RICE framework integrates principles of regenerative agriculture, environmental stewardship, and socio-economic enhancement (compared to already well-known facts), making it a comprehensive tool for achieving sustainable development goals. The primary objective of the present study is to introduce a strategic framework and enhance the resilience of asnaf farmers by adopting the concept of 'ecosystem restoration' as its core principle. Here, the term 'ecosystem' refers to the paddy field, while 'restoration' encompasses strategies to reduce pollution, introduce poultry integration, enhance soil fertility, and increase farmers' resilience in line with the sustainable development principles defined by the world commission on environment and development.

Impact of climate change on paddy farmers

As stated by the Food and Agriculture Organization (FAO) in 2015, the agricultural, aquacultural, and forestry sectors are predicted to have a vital role in ensuring food security for a population of 10 billion people by the year 2050. This is in response to the projected requirement for a 60% increase in global food production. Given the current and alarming shifts in climate patterns, attaining the objective of food security takes on paramount importance, particularly in developing countries. Climate change has been observed to exert influence on both the physical and economic aspects of agriculture. The impact of climate change is detrimental, leading to changes in plant productivity, the proliferation of diseases, shifts in weed dynamics, alterations in soil quality, and shifts in microbial composition within agricultural systems (Kryzanek and Karreth 2018; Anwar et al. 2019; Hussain et al. 2020).

The occurrence of climate change bears a range of notable effects on rice producers worldwide. Farmers are susceptible to climate change's repercussions, due to their dependence on environmental conditions for their livelihood (Rahmat et al. 2018; Mashizha 2019). Climate change carries significant ramifications for multiple facets of the food system, farmers' earnings, and food security (Firdaus et al. 2019; Anríquez et al. 2019). According to the literature, on the relationship between crop yield and growth, meteorological factors play the biggest role. Small changes in temperature as well as precipitation patterns and occurrence of extreme weather conditions have adverse impacts on the crop growth and the yields (Haliza Abdul Halim 2009; Gornall et al. 2010; Stern 2017; Kryzanek and Karreth 2018; Otto et al. 2020). Thus, Bandara and Cai (2014) observed that either inadequate rainfall or too much of it could lead to crop damage or low yields detrimental to the farmers' income. Furthermore, high temperatures were established as enhancing the degradation of organic matter (OM) as well as encouraging other physiological activities, such as nutrient uptake, nitrogen fixation and root development (Pregitzer and King 2005; Kafeel et al. 2022; Zhao et al. 2023; Jumrani et al. 2024). However, in regions undergoing climate change, when temperatures exceed their optimal range, this results in an accelerated release of CO_2 and a decline in photosynthetic activity. These factors collectively influence plant physiology and ultimately impact crop yield (Hussain et al. 2020). In addition, according to Khanal et al. (2018), a rise in night temperatures by just 1°C can cause a reduction of 10% in rice yield. Similarly, Subash and Mohan (2010, 2012) demonstrated a clear correlation between the global temperature increase and its implications on rice yield and production. Furthermore, extended periods of drought and persistent rainfall leading to flooding have significantly diminished crop production (Rahmat et al. 2019; Firdaus et al. 2020).

On the other hand, the influence of chemical applications on the diversity of soil biota residing in paddy soil serves as a pivotal indicator of changes within ecosystems (Kennedy 1999). As per Aktar et al. (2009), the excessive use of chemical fertilizers and pesticides affects soil microbial populations, with herbicides being identified as disruptors of typical biogeochemical processes and the diversity of soil microorganisms. These disruptions lead to alterations in the conversion of atmospheric nitrogen into nitrates. Previously, Nicomrat et al. (2016) observed that pesticide application has detrimental effects on soil microorganism diversity, potentially resulting in shifts in soil composition and suggesting an ecological imbalance in terms of species' susceptibility to soil-based environmental factors. The soil's bacterial communities play a pivotal role in determining soil fertility, as fertility isn't solely determined by soil textures but also by the soil's biological capacity (Rahman et al. 2020). The utilization of pesticides can bring about unfavourable consequences for soils, non-target species, and water bodies upon direct contact, as highlighted by Barbieri et al. (2021). Furthermore, the contamination of irrigation water with pesticides can potentially lead to detrimental impacts on biodiversity (Pandey et al. 2020).

In addition to, during instances of flooding in rice fields, the absence of oxygen supply from the atmosphere to the soil leads to anaerobic conditions, prompting the anaerobic fermentation of soil organic matter (Jia et al. 2020; Liu et al. 2023; Das et al. 2023; Rajbonshi et al. 2024; Joe et al. 2024). Within this anaerobic setting, methanogen microbes within rice fields become responsible for generating CH_4, which accounts for approximately 14% of greenhouse gas emissions in the environment (EPA 2006).

Climate change and food security

Climate change presents a notable obstacle in achieving sustainable development goals (SDGs), especially SDG 1 - eradicating poverty, SDG 2 - Zero Hunger and SDG 13 - Climate action. The incorporation of climate change adaptation strategies in the paddy sector encompasses a range of techniques devised to counteract the detrimental impacts of climate change on rice cultivation and ensure a steady rice supply.

During the 2010 hague conference on agriculture, the Food and Agriculture Organization (FAO) introduced the concept of 'climate-smart agriculture (CSA)'. They defined CSA as an agricultural approach aimed at enhancing productivity sustainably, bolstering resilience to climate change, mitigating greenhouse gas emissions when feasible, and contributing to both national food security and development objectives (McCouch et al. 2020). The fundamental elements of CSA encompass the adoption of sustainable agricultural practices and food production practices, along with the implementation of appropriate policies and investments in environmental preservation (Williams 2010; Herforth et al. 2020)

In addition to, resilient crop varieties sustainable farming practices stand out as one of the adaptation strategies employed to address the challenges posed by climate change (High et al. 2004; Breitler et al. 2004; Mahmood-Ur-Rahman et al. 2007; Chen et al. 2011; Dhungana et al. 2015; Dixit et al. 2017; Bhattacharjee et al. 2021). Accordingly, Chapagain et al. (2011) reported that system of rice intensification (SRI) practices demonstrated a significant increase in root number by more than 30% and a higher harvest index compared to the conventional approaches. Notably, in terms of grain yield, productivity is higher than conventional practices. Additionally, the SRI-organic method yielded a higher harvest index of 58%, surpassing the harvest index of 50% achieved by conventional-inorganic management (Chapagain et al. 2011). Similarly, Hoang et al. (2019) reported mitigation of CH_4 and N_2O emissions in water saving paddy fields in Central Vietnam by incorporating rice straw. Moreover, Yang et al. (2014) discussed the reduction of the global warming potential of its gas emissions by controlled irrigation and drainage of a rice paddy field.

Given the fact that the agricultural industry faces limitations on resource availability and environmental conditions, i.e. water scarcity and environmental deterioration. Hence, the adaptation strategies using the concept of climate-smart agriculture (CSA) play a crucial role in effectively mitigating the detrimental effects of climate change, bolstering the economic well-being of farmers, and fostering the long-term sustainability of agricultural practices (Hailegiorgis et al. 2018). Accordingly, Leclère et al. (2013) reported that farmers exhibit independent adaptation on their production methods in response to the impacts of climate change. However, it is important to note that the independent adaption strategies employed by small farmers may not be viable in the long-term if there is no support system from the government agencies (Quan et al. 2019).

RICE as strategic framework

Envisioning the eco-social sustainability of asnaf farmers from a forward-looking stance, we introduce the RICE (restore, integrate, circular, enhance) framework to enhance the adaptive capacities of paddy farmers within the asnaf community. The primary objective is to effectively tackle climate change risk. This framework draws inspiration from the FAO-CSA concept and centers around restoration, which emphasizes reviving soil ecosystem services in paddy fields. Additionally, it emphasizes the enhancement of adaptation strategies through an integrated approach that combines duck and rice farming. Furthermore, the framework promotes circularity to amplify soil functionality and increases the resilience of asnaf farmers (enhance) by adopting the central tenet of 'ecosystem restoration'. Figure 1 shows a summary of the RICE framework for sustainable farming.

Restore

Ecological restoration is implemented worldwide as direct response to the deterioration of ecosystems. Beyond its ecological significance, it holds substantial promise for enhancing the well-being of populations, socio-economic conditions and preserving distinct national and cultural identities. Acknowledging the pivotal role of restoration in maintaining ecosystem health, the United Nations (UN) designated the period from 2021 to 2030 as the decade of ecosystem restoration. In the context of local approach, the RICE framework aligns seamlessly with the call (UN decade) of which its structure is based on the FAO-CSA agenda. It is designed to curtail greenhouse gas emissions,

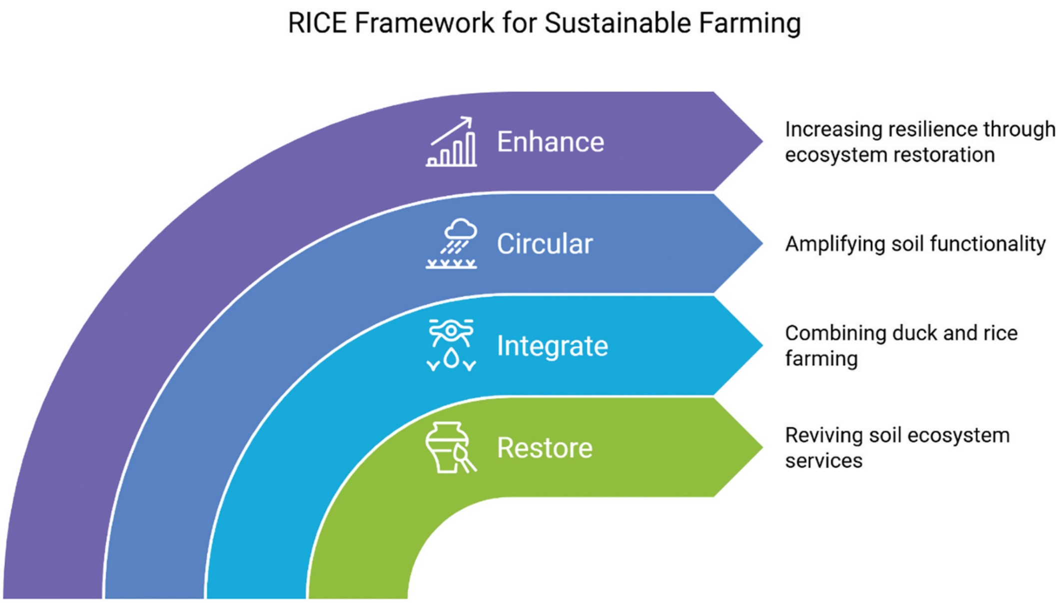

Figure 1. RICE framework for sustainable farming.

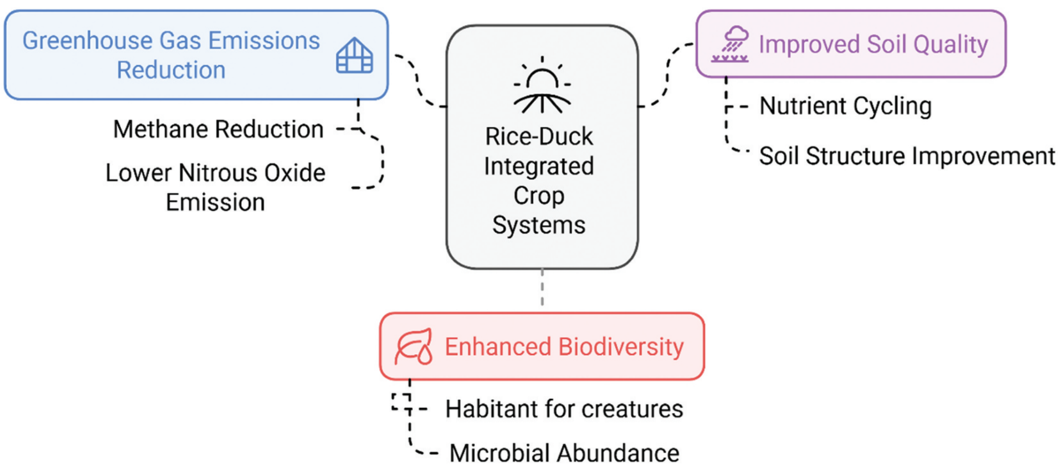

Figure 2. Restoration benefits of integrated rice-duck crop system.

increase the agricultural landscape's resilience against climate change, boost productivity, and contribute to both national food security and environmental conservation objectives. Figure 2 shows the restoration benefits of rice-duck integrated crop systems.

Rice-duck integrated crop systems have been promising in responding to climate change while offering ecological protection:

Greenhouse gas emissions reduction

Rice-duck systems significantly reduce methane (CH_4) emissions by 8.80–16.68% compared to conventional farming, thus reducing global warming potential (GWP) (Xu et al. 2016). The inclusion of ducks in ratoon rice fields can mitigate CH_4 and CO_2 emissions, resulting in a 19–25% reduction in GWP and a 22–32% reduction in GWP intensity without affecting the rice grain yield (Du et al. 2023).

According to Li et al. (2024), livestock emissions in their study totalled approximately 769.0 kt, and researchers predicted that adopting crop–livestock coupling could reduce emissions by 30.1 kt. This is due to the returning manure as fertilizer can cover 57.7% of cropland, saving 57% nitrogen and 20% phosphorus fertilizers, thus reducing costs by $296.3 million in the study area.

Improved soil quality

The continued addition of fecal matter and the scooping and churning of the soil by ducks in paddy fields improve nutrient levels in the soil quality parameters (Nayak et al. 2018). This improvement in soil health adds to the resilience of the system against climate change impacts.

Enhanced biodiversity

Rice-duck systems improve aquatic biological diversities such as planktons, soil benthic fauna, and microbial populations that are indicative of improved soil fertility and sustainable production in rice (Nayak et al. 2018). With this improved biodiversity, ecosystems are able to balance natural events brought on by climatic changes. While rice-duck systems tend to lower CH_4 emission, the N_2O emissions might increase by about 4.2 to 15.2% (Xu et al. 2016). However, the general GWP is still relatively low because of the greatly reduced CH_4 emissions by replacing chemical fertilizers with Hu et al. (2022), which comprised 85.8–96.2% of the total GWP.

Here, the strategy is to increase more organic manure input on paddy farms by partially replacing and reducing the chemical fertilizer input in a gradual fashion. In this case, one of the strategies is the adoption of integrated farming of which has proven to be beneficial for small and marginal farmers (Hu et al. 2022). For instance, Hu et al. (2022) reported decreased use of nitrogen fertilizers (10%) and herbicides (50%) in the rice planting process under the rice-duck farming system. This methodology combines various techniques with the goal of promoting efficient and sustainable practices, ultimately leading to increase production (Mamun et al. 2012). As highlighted by Rao et al. (2017), the implementation of integrated farming systems (IFS) has showcased multiple enhancements, particularly in terms of conserving natural resources, increasing resource productivity, and fostering adaptability to climate change. However, optimization is necessary as excessive application of manure reduces rice yield and enhances environmental pollution risk in paddy fields (Abe et al. 2016). According to Rao and Killor (2007), even though there were more nutrients available at 5% C treatments, using nutrient sources at these levels considerably decreased the yield of grains and nutrient absorption. Hence, the scholars concluded that Pongamia leaf litter application at 2.5% C is more effective than other treatments as it gives significantly higher grain yields and total dry matter. Furthermore, Han et al. (2023) reported paddy soil chronosequence and adsorption capacity changes due to potassium supply.

Overall, integrated rice-duck crop systems offer prospects in mitigating climate change impacts with ecological protection. Such systems minimize greenhouse gas emission, improve the quality of water in the soil, and increase biodiversity. Rice-duck integration can thus offer a balance between agricultural productivity and environmental conservation in light of increasing climate change as a form of sustainable intensification strategies. (Peterson et al. 2020; Sun et al. 2021)

Integrate

According to Nayak et al. (2018) the integration of rice duck farming holds the potential to enhance the productivity of rice crops. This is achieved by augmenting the count of effective tillers while concurrently curbing the growth of ineffective ones. Furthermore, this method has demonstrated the capability to elevate both the number and proportion of rice panicles, along with the rate of seed setting. These attributes collectively hold the promise of enhancing rice productivity. The literature shows that rice production in crop-livestock integrated farming is even higher than that of the conventional farming of rice. Previous studies have confirmed this, noting that the rice-duck co-culture system is capable of either maintaining or improving rice yields, all the time reducing the effects of the environment. According to Du et al. (2023) the present agronomic practice involved in ratoon rice-duck systems involving lower pesticide and fertilizer inputs showed comparable annual grain yields to ratoon rice monoculture. Similarly, Xu et al. (2016) revealed an improvement in yield by 0.76–2.4% in comparing integrated rice-duck system with the conventional system. However, the yield of rice is affected differentially depending on the integrated system and management practice. For instance, Zhang et al. (2023) reported that the yield of rice under rice-duck system was 4.1% per hectare higher than under the monoculture rice system, while it was 3.9% per hectare lower under rice-crayfish system and no change under the rice fish systems. These variations mean that the overall impact of crop-livestock systems needs to be evaluated together with the effects of variations at species level. In any case, it is possible to achieve a similar or even higher yield of rice as a result of applying integrated packages such as rice-duck and other integrated farming systems as compared with a conventional agricultural practice. Moreover, these systems reduce norms and benefit the environment, enhance soil productivity and give different sources of income to the farmers (Xu et al. 2016; Du et al. 2023; Zhang et al. 2023).

In this regard, as reported by Jiaen et al. (2017), it seems that ducks can be the potential opportunity to enhance rice growth by performing several activities which include weeding, insect and disease control, muddying and nutrient supply. On the other hand, Wang et al. (2016) also pointed out that rice-duck co-culture system suggests that through improving the quality of rice crops, they provided a way to make a considerable contribution to production of safe and high-quality foods. There is a definite way to make the soil of paddy ecosystem functional as it has been always: to reduce the usage of chemical fertilizers and pesticides and to replace them with natural ones. The use of integrated poultry-paddy practices in paddy fields presents some avenues to realizing this goal. Integrated farming system has now shown the possibility and sustainability in supporting soil fertility as most of them are affected by the consequences of modern day-intensive methods of farming (Lemaire et al. 2014).

Ariani et al. (2021) have pointed out that incorporation of duck manure into the soil helps in increasing the SOC stock. This improvement has been associated with the SOM components in the duck manure, which points to an improvement in the general SOM. Notably, SOM represents the biotic portion of a soil made up of organic waste products of plants and animals, microbes and other living organisms in a state of equilibrium. Figure 3 shows the comparison of RICE framework practice and conventional rice farming practice.

Ducks have possibilities of upstream control of weeds through the edibility of weeds and pests, thus eradicating competition of water and nutrients. Independent engagement in feeding and

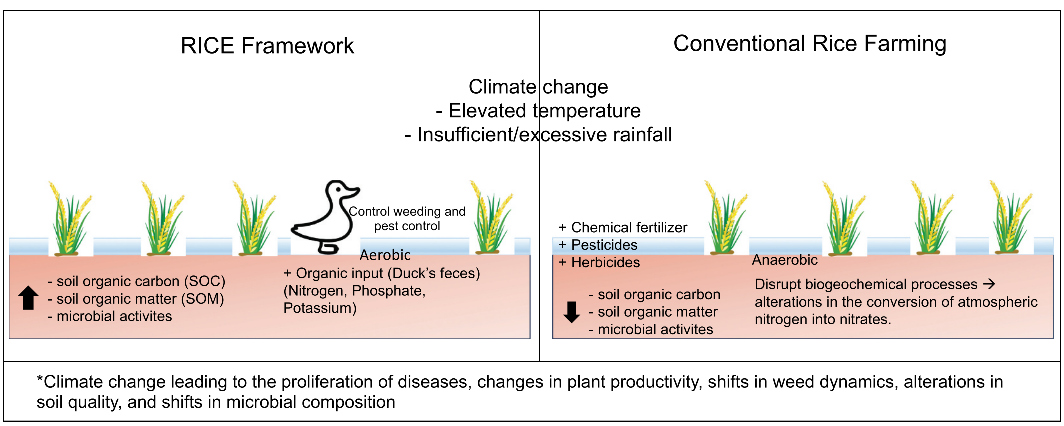

Figure 3. The RICE framework practices as strategy to support the adaptive capacity of asnaf farmers amid the emerging risk of climate change.

movement results in an effective technique for weed and rice pest control within fields (Teng et al. 2016). Similarly, Jin et al. (2020) has indicated that integrating ducks to the husbandry of paddy fields has been helpful in managing weeds and pests. As a result, one can grow rice in such a system naturally, without the use of even chemical fertilizers, pesticides or even herbicides. Grazing ducks into the paddy field acts as a tool for soil tillage and manipulation of water infiltration in a manner that reduces water logging and increases drainage. This, in turn, helps maintain the optimal water level for rice cultivation and reduces the likelihood of diseases associated with excessive moisture.

Moreover, the integrated practices not only contribute to the preservation of the paddy ecosystem but also offer an additional income stream for farmers. As demonstrated in a study by Elly et al. (2019), the integration of duck-rice farming has led to several benefits. These advantages encompass reduced production expenses attributed to decreased reliance on fertilizers, pesticides, herbicides, and labour costs for weed management. Furthermore, the rice produced in this system was organic and commanded higher prices in the market. Simultaneously, the land's quality and condition experienced improvement due to the limited use of inorganic fertilizers. Consequently, the adoption of integrated duck-rice farming practices has been proven to enhance farmers' earnings.

As outlined by Uddin et al. (2016), the integrated farming system is acknowledged for its capacity to endure environmental sustainability while effectively increasing farmers' income. Within this framework, the rice field assumes a dual role, providing a conducive habitat for ducks and serving as their sustenance source. In this model, ducks occupy space amidst rice seedlings during daylight hours, actively preying on rice pests and targeting weeds until the rice progresses to its flowering stage.

Circular

The circularity approach promotes the low waste usage of resources, especially poultry, by trying to recycle nutrients within the paddy ecosystem. Ideally, this process recycles waste materials in a way that turns them into a set of useful inputs. The fecal matter is from ducks; the droppings are made to act as organic manure in the paddy, thereby lowering the use of chemical fertilizers and in extension, the possibly hazardous effects on health (Long et al. 2013). For instance, Hu et al. (2022) reported that the application of nitrogen fertilizers and herbicides during rice cultivation in the rice-duck farming system has been reduced by 10% and 50%, respectively. Similarly, Li et al. (2024) reported that returning manure as fertilizer can cover 57.7% of the cropland, saving 57% nitrogen and 20% phosphorus fertilizers.

Although a slight yield decrease, the rice-duck farming method has resulted in an increase in economic income of $1523.9 per hectare (Hu et al. 2022). The increase in profit is linked to the simultaneous benefits of lower input prices and increased value from duck production. Similarly, Li et al. (2024) calculated that returning manure as fertiliser may cover 57.7% of cropland while saving 57% nitrogen and 20% phosphorus fertilisers, resulting in a -$296.3 million savings. The circular approach has the possibility to enhance the position of asnaf farmers in the paddy and rice industry value chain. As a result, the successful implementation of this strategy can only act to decrease their expenses and increase their profit margins. The essential components of the integrated duck-rice system incorporate efficient utilization of wastes and processes in one subsystem and use all these wastes as valuable inputs. It increases the role of sustainability, productivity and profitability at farming activities to a very high level (Nayak et al. 2018). Figure 4 shows the circularity approach in an integrated crop-livestock system.

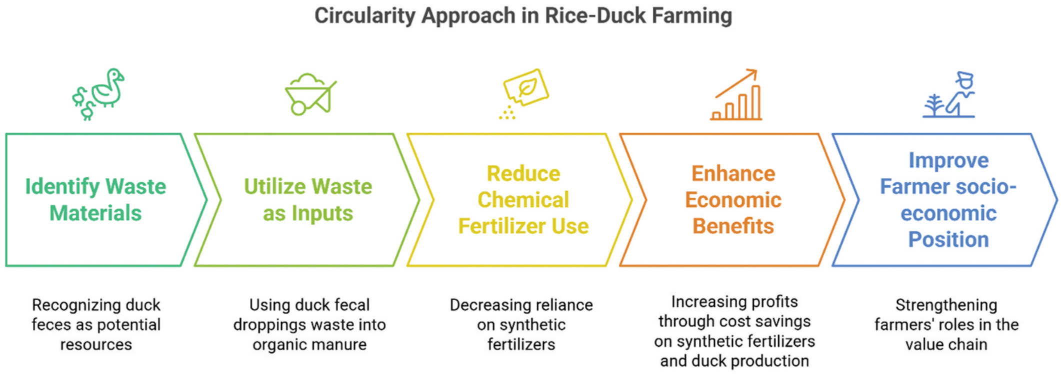

Figure 4. Circularity approach in rice-duck farming system.

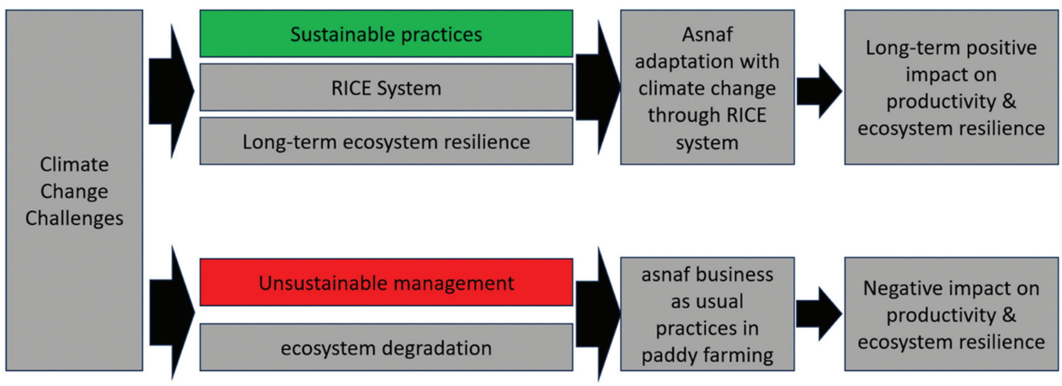

Figure 5. The role of RICE system in supporting the adaptive capacity of asnaf farmers to address the impact of climate change on food security (RICE support mechanism is through supporting the long-term resilience of paddy ecosystem).

Enhance

The rice-duck integrated farming system illustrates an environmentally friendly technique of co-production, whereby ducks freely roam in paddy fields, mainly feeding on weeds and insects. Further, the use of natural sources of fertilization and pest control also open a good prospect for improvement of quality and safety of the paddy crops, thus making it competitive in the market. Figure 5 gives a clear view of sustainable and unsustainable management in the paddy industry. The local RICE framework described earlier comprises a combination of practices that unite poultry-paddy cultivation, with the primary accent on the recovery of the soil ecosystem. This strategy holds the promise of supporting the adaptability of asnaf farmers in the face of climate change risks. Moreover, it advocates for the sustainable utilization of resources, pollution reduction, and the overall enhancement of farmers' livelihoods.

Pros and cons

The integrated rice-duck farming system offers significant advantages in terms of environmental and economic benefits. Figure 6 shows the comparison of the integrated rice-duck system and the conventional system.

In summary, there are following advantages of rice-duck farming system:

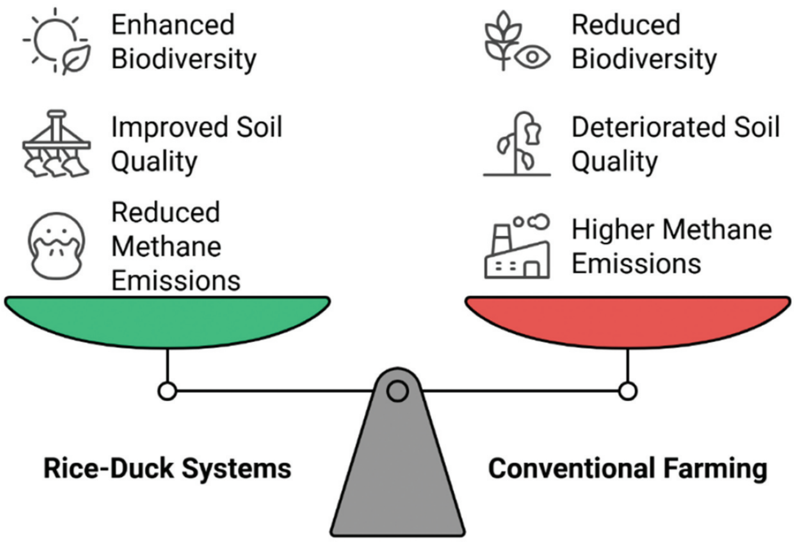

Figure 6. Comparing environmental factors of integrated rice-duck and conventional system.

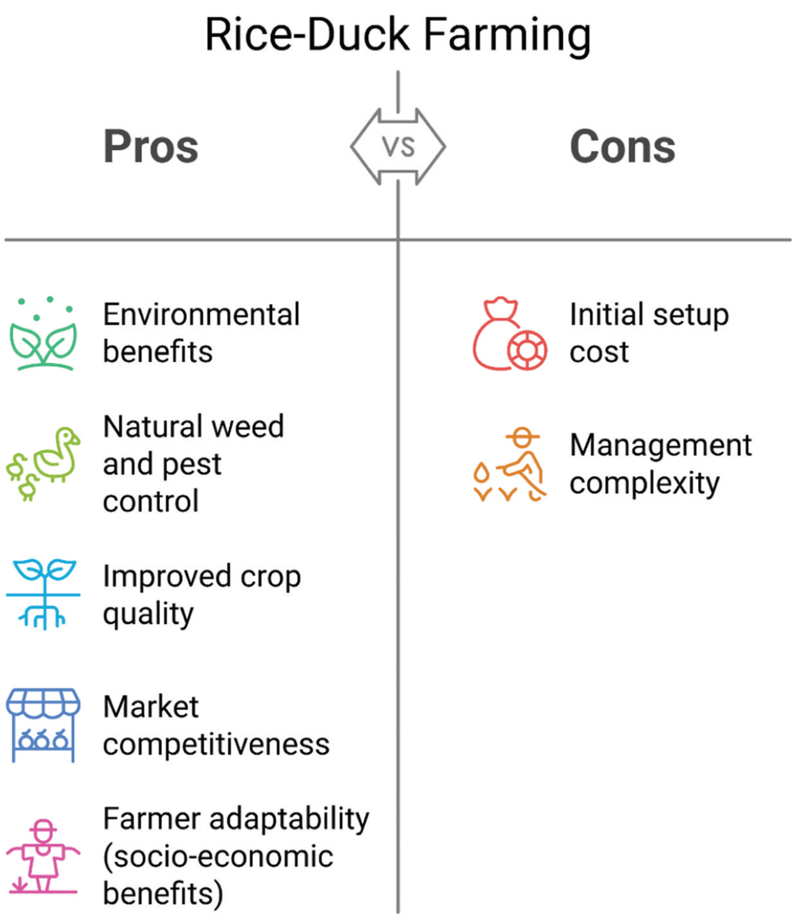

Figure 7. Pros and cons of the integrated rice-duck farming system.

(a) **Reduction in Inputs**: The use of nitrogen fertilizers and pesticides in rice production under the rice-duck farming system has decreased due to the application of duck droppings as manure, while grazing ducks in the fields additionally mitigate weed and pest issues. This practice contributes to decreased chemical usage and promotes sustainable agricultural practices.
(b) **Economic Gains**: The rice-duck farming system has demonstrated an increase in economic income for farmers. This increase is attributed to the dual benefits of reduced input costs and the added value derived from duck production. In addition to, organic farming practices enhance soil quality, resulting in enhanced crop quality that increases market competitiveness. Furthermore, improved soil quality reduces the downtime for soil nutrient regeneration and facilitates more crop rotation, resulting in higher yields of various crops.
(c) **Cleaner Agricultural Production**: The integration of the rice-duck farming system provides an effective pathway to reduce GHG emissions, nitrogen and phosphorus runoff pollution. This system aligns with the goals of cleaner production by minimizing chemical inputs, recycling organic waste into valuable manure, enhanced biodiversity, improved soil quality, and reduce GHG emissions.

These benefits underline the potential of the rice-duck farming system as a sustainable and economically viable alternative to conventional rice farming practices.

The limitations of the integrated rice-duck crop system include: 1) To implement the technology of coexistence of rice and ducks in a large region, unified management is needed. 2) To encourage farmers to continue to implement the plan, it is necessary to purchase additional field ducks. Figure 7 shows the pros and cons of the integrated rice-duck farming system.

Conclusion

The proposed RICE framework introduces an innovative approach aimed at augmenting the adaptive potential of paddy farmers within the asnaf community. RICE integrates comprehensive ecosystem restoration strategies with the inclusion of duck-based poultry-paddy operations. Potentially, the integrated duck-rice farming plays a pivotal role in fostering sustainable and resource-efficient agricultural practices by contributing to biological weed control, pest management, nutrient recycling, and organic fertilization. Employing a circularity approach not only aligns with ecological principles but also supports farmers' financial returns, diminishes reliance on synthetic inputs, and significantly contributes to ensuring not only food security but also the food safety and quality concerns. The incorporation of poultry into the paddy ecosystem emerges as a solution to the climate change challenge while concurrently promoting the sustainability of the asnaf socio-ecological system. The research underscores the necessity of supporting governmental measures to promote adoption.

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Consent to Publish

I have not submitted my manuscript to a preprint server before submitting it to the Archives of Agronomy and Soil Science.

Data availability statement

Data will be available on reasonable request.

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