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RESPONSE TO CLIMATE CHANGE IMPACT ON PADDY FARMING: THE SYSTEM OF RICE INTENSIFICATION (SRI)

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ABSTRACT

The global climate system began posing risks for human and natural systems on all continents and across oceans. It is therefore essential to identify and adopt solutions that sustainably increase rice production and strengthen crops' resilience to climate variabilities. The ecosystem-based crop management technique of the System of Rice Intensification (SRI) is an alternative solution in environmental development plans. In line with the need of developing climate-smart farming management, this narrative review aims to address to SRI adoption as a transition to more productive, inclusive and sustainable agriculture that promotes the use of climate-resilient crops. The review provided evidence that SRI is beneficial to address sustainable agricultural practices and enhance resilience against climate change. In conclusion, SRI-based paddy farming responds to the need for a sound functioning of agriculture management and build climate resilience.

Keywords: Paddy farming management, system of rice intensification, climate resilience, sustainability

INTRODUCTION

Climate change is a change in the characteristics of the climate system that persists over some time. Climate change can be the result of natural processes, such as solar variability, volcanic eruptions, and for circulation; or due to human influences that impact the composition of the atmosphere or land use. Human causation has been resilient climate by the United Nations Framework on Climate Change (UNFCCC) secretariat which defines climate changes as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods. *Agriculture* is the science of cultivating the soil, growing crops and raising livestock. The major agricultural products can be broadly grouped into foods, fibres, fuels, and raw materials (Ali Fazal & Abdul Wahab, 2013).

Since the 1950s, agriculture has changed dramatically and become dependent on technologies, mechanisation, and chemical use. A growing movement has emerged during the past two decades to question the role of agriculture as an integrated system of production practices that satisfy human food, enhance the environment, sustain the economic viability and quality of life in the long term. Sustainable agriculture, in opposition to conventional agriculture, emerged as an alternative to the better enhancement of natural and human resources and fed the world’s growing population.

System of Rice Intensification (SRI) is an agroecological climate-smart rice production methodology developed by Fr. Henri de Laulanié in 1983 in Madagascar. Since 2000, it has been proven to be successful in many other countries and currently in practice in 60 countries. SRI challenges the standard agronomic management by demonstrating that altering the management system of soil, nutrient, plant and water has beneficial impacts by requiring a fewer amount of external inputs. Unlike conventional agricultural practices, SRI does not rely on new varieties, fertilisers, pesticides, or infrastructure to improve rice yield. Instead, SRI principles and practices are the results of knowledge-based management that allow the plant to express their genetic potential better and adapted to suit farmers’ local conditions.

LITERATURE REVIEW

The Relationship between Climate and Agriculture

Recent climate changes have had widespread impacts on human and natural systems. Agriculture is inherently sensitive to climate conditions and is among the most vulnerable sectors to the risks and impact of global climate change (Parry & Carter, 1989). Agriculture, which is generally well adapted to mean or average conditions, is indeed susceptible to unpredictable or extreme conditions such as more frequent droughts and deviations from ‘normal’ growing season conditions (Reilly et al., 1996). Early (first-generation) impact assessment models provided estimates of the overall agricultural impacts or damages of climate change based on the assumption that no adaptations would occur (Rosenzweig 1985; Smit et al. 1989). Later (second-generation) impact assessment models arbitrarily assigned adaptations to climate change, assuming adaptive responses on the part of agricultural producers or the system as a whole concerning changes in average temperature and moisture conditions (Adams et al. 1995). More recently, impact assessments have recognised the importance of farm-level decision-making in the adaptation process, mainly when climatic extremes are considered (Smit & Skinner, 2002). As impacts of climate change have become apparent around the world, adaptation has attracted increasing attention. The impacts are expected to be particularly severe in the developing world and among marginalised communities because of limited adaptive capacity (IPPC, 2014).

Disaster risk management and adaptation to climate change consist of reducing exposure and vulnerabilities to potentially negative climate impacts. Where exposure depends on geographical and demographical factors, the vulnerability can be addressed with more sustainable agricultural management and practices. Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management (Smit & Skinner, 2002). This broad objective of this article is to address to System of Rice Intensification (SRI) adoption as a management transition to a more productive, inclusive and sustainable farm production practice that promotes the use of climate-resilient crops.

This article traces the current effects of climate change on paddy farming; more specifically, it assesses for SRI in Malaysia as a management response to climate change about its sustainable intensification and resource-use efficiency. The paper introduces previous climatic impact research by developing links amongst climatic change scenarios, and paddy yield responses to climatic change. The possible impacts of climate variabilities in Malaysia have only started recently. Malaysia rice production is a significant mean of viability and a significant contribution to the national economy; hence, adjustments to Malaysian paddy management could benefit throughout the nation. The literature collection is based on formal and grey literature and the experiences of the authors.

Effects of Climate Change on Malaysian Paddy Farming

In Malaysia, agriculture is one of the mainlands uses. In 2016, the production of rice amounted to 2,252,388 tons on a harvested area of 708,148 hectares (FAOSTAT, 2016). Rice is a crucial part of everyday Malaysian meals, consuming about 82.3 kilograms per annum on the average (Shamshiri et al., 2018). Moreover, it provides the livelihood to 172,000 paddy farmers in the country (Ramli et al., 2012). Considerable studies have been undertaken recently to simulate climate change issues and vulnerabilities in Malaysia. The pioneer studies are prepared by the Malaysian Metrological Department (MMD), National Hydraulic Research Institute of Malaysia (NAHRIM) and Institute for Environment and Development (LESTARI) in Malaysia.
According to MMD (2009), the sensitivity of agricultural properties to climatic change in Malaysia is as follows:

Temperature

Outputs generated to show an increase in temperature for Peninsular Malaysia, Sabah and Sarawak. Further analysis shows that the increase in temperature is most apparent in the late 21st century (2090 – 2099).

Table 1.
Annual mean temperature change (°C) relative to 1990-1999 period

Region	2020-2029	2050-2059	2090-2099
North-West PM	1.3	1.9	3.1
North-East PM	1.1	1.7	2.9
Central PM	1.5	2.0	3.2
Southern PM	1.4	1.9	3.2
East Sabah	1.0	1.7	2.8
West Sabah	1.2	1.9	3.0
East Sarawak	1.4	2.0	3.8
West Sarawak	1.2	2.0	3.4

Rainfall trends and projections

As for the change in rainfall, there is no clear trend. Projected rainfall changes for the early 21st century, middle of 21st century and the late 21st Century (2090 – 2099). Annual rainfall change indicates that west coast of Peninsular Malaysia has an increase of 6 - 10 % in rainfall amount, whereas a decrease of 4 – 6 % of rainfall amount over central Pahang and coastal Kelantan. As for East Malaysia, Sarawak has an increase of 6 – 10 % in rainfall amount and Sabah has an increase of more than 10%. The projections for the 21st-century exhibit an increase in precipitation over the West Coast states and a decrease over the East Coast states of Peninsular Malaysia.

Table 2.
Annual rainfall changes (%) relative to the 1990-1999 period

Region	2020-2029	2050-2059	2090-2099
North-West PM	-11.3	6.4	11.9
North-East PM	-18.7	-6.0	4.1
Central PM	-10.2	2.3	14.1
Southern PM	-14.6	-0.2	15.2
East Sabah	-17.5	-12.8	-3.6
West Sabah	-8.9	-1.2	0.3
East Sarawak	-9.1	-1.3	6.2
West Sarawak	-8.8	3.8	14.6

Emission of greenhouse gases

The various sub-sectors in the agriculture category in Malaysia release mainly methane (CH4), with a small amount of nitrous oxide (N2O) and carbon dioxide (CO2) (INC, 2000). It was found that carbon dioxide emission rates are more than double in generated scenarios towards the end of the century. Therefore, given the long lifetime (~100 years) of carbon dioxide in the atmosphere, the global surface temperature is expected to continue increasing.

Global and regional simulations are only indicative, due to the variability of the interactions among the atmosphere, ocean and land. This uncertainty, however, can be coped with an early intervention towards climate adaptation. As climate change plays a significant role in determining crop performance, the primary concern is the potential threat to food security and livelihoods.

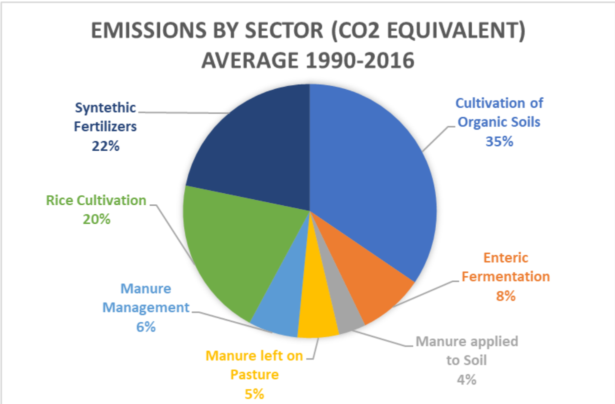

Figure 1. *Emissions by sector (CO2 equivalent) average 1990-2016*

Generally, long periods of sunshine are favourable for high rice yields as sunlight is the source of energy for plant life. Growth is optimal when the daily air temperature is between 24°C and 36°C. The difference between day and night temperatures must be minimal during flowering and grain production, with 30°C during day time and 20°C during night time as most favourable conditions. An irrigation water temperature of not less than 18°C is preferred (INC, 2000). A study to assess the impacts of climate change on the paddy sector has only started in recent years. Alam et al. (2009) asserted that paddy production could be affected by climate change as changes may cause a shortage in water and other resources, which eventually would affect soil fertility and lead to pest and disease outbreaks.

The main climate variables important for crop plants, as for other plants, are indeed temperature, solar radiation, water, and atmospheric CO2 concentration (Reilly et al., 1996). Singh et al. (1996) reveal that the actual farm yields of rice in Malaysia vary from 3 to 5 tons per hectare, where potential yield is 7.2 tons. The study also unfolds that there is a decline in rice yield between 4.6 per cent and 6.1 per cent per 1C temperature increase and a doubling of CO2 concentration (from the present level of 340 ppm to 680 ppm), which may offset the detrimental effect of a 4C temperature (Ali & Ali, 2009). They indicate that a rise in temperature above 26°C will increase plant respiration and shorten the grain-filling periods. The periods become shorter as the plant growth rate increase and the growth duration decrease (Firdaus et al., 2012). Vaghefi et al. (2011) used ORYZA 2000 crop growth model to simulate the effect of temperature and CO2 growth and yield of rice in Malaysia.

Findings revealed that an increase in both factors would have profound adverse effects on the rice yield. Rice paddy is regarded as one of the essential sources of anthropogenic carbon emissions. CH4 emissions from paddy fields account for 11 % of the global CH4 emissions (IPPC, 2014). Al-Amin et al. (2011) recently made projections on rice agriculture up to the year 2080 and possible vulnerabilities by looking at Malaysian rice Self-Sufficiency Aspiration (SSL) by 90% from the current level of 70%. With approximately 296,000 paddy farmers in Malaysia, almost 40% of them cultivate on a full-time basis (Elenita & Ema, 2005), climate impacts endanger food security and livelihood. Nonetheless, the local supplies still lag in catering to local demand, as Malaysia is still dependent on imported rice.

Year	*2020*			*2040*				*2060*			
CO_2 (ppm)	*400*	*400*	*400*	*CO_2 (ppm)*	*600*	*600*	*600*	*CO_2 (ppm)*	*800*	*800*	*800*
Temp. increase °C	*0.3*	*0.85*	*1.4*	*Temp. increase °C*	*0.4*	*1.4*	*2.4*	*Temp. increase °C*	*0.6*	*2*	*3.4*
Rainfall Change (%)				Rainfall Change (%)				Rainfall Change(%)			
14%	21.5	21.5	22.0	23%	24.0	24.0	24.0	32%	26.0	26.0	26.0
7%	23.0	23.0	23.25	11%	25.0	25.0	25.0	15%	27.0	27.0	26.0
0.40%	22.5	22.5	22.75	0.70%	24.5	24.5	24.5	1%	26.0	26.0	25.0
0	22.0	22.0	22.0	0%	24.0	24.0	24.0	0%	26.0	26.0	26.0
–0.40%	22.0	22.0	22.0	–0.70%	23.5	23.5	23.0	–1%	24.0	24.0	22.0
–7%	17.6	17.6	17.0	–11%	19.2	19.2	18.7	–15%	18.0	18.0	15.6
–14%	15.4	15.4	15.4	–23%	15.6	15.6	14.9	–32%	14.3	14.3	13.0

Note: Yield expressed in tonnes/ha/yr

Potential Paddy Farming Management to Cope with Climate Change: System of Rice Intensification

The System of Rice Intensification is a holistic agro-ecological paddy management technique seeking alternatives to the high-input oriented agriculture and one among the scientific management tool of allocating irrigation water based on soil and climatic condition to achieve maximum crop production per unit of water applied over a unit area in unit time (Pandian, 2014). SRI is indeed an emerging water-saving technology, with many folds increase in crop yield (Laulanie, 1993). As a paddy management strategy, SRI makes changes in age-old practices for managing rice plants, soil systems, irrigation and soil nutrient amendments that can increase crop yields by 50–100%, and sometimes by more, while at the same time reducing farmers’ requirements for seed, water, fertilizer, agrochemicals, and often even labor (Uphoff, 2003). By adopting this innovative system of cultivation, we could save water, protect soil productivity, save the environment by checking methane gas from water submerged paddy farming practices, bring down the input cost, besides increasing the production for providing food to the growing population (Krishna, 2008).

SRI is based on four main principles that interact with each other: early, quick and healthy plant establishment, reduced plant density, improve soil condition through enrichment with organic matter, and reduced and controlled water application. Following these principles, Uphoff (2009) summarises the concrete practices that are expected to be adapted empirically to local conditions:

- Transplant young seedlings: small plants are grown in a nursery and transplanted when 8-12 days old;
- More extensive space between plants: seedlings are planted singly at a distance of at least 25cmx25cm;
- The soil in the field is kept moist but not continuously flooded: the soil is intermittently wetted and dried so to stay aerobic;
- Control weed with repeated use of weeder: weed is removed and the soil aerated;
- Enhance soil organic matter as much as possible: soil structure is improved, and plants are provided with complete nutrition.

Hill & Pittman (2013) identified several disaster risk reduction (DRR) strategies that have been developed in the agriculture sector, and that is embraced by the principles and practices of SRI. Among those, there are sustainable intensification and resource-use efficiency.

Sustainable intensification

Sustainable intensification has occurred through several ways and has involved the following innovations: crop improvements, agroforestry, soil conservation, conservation agriculture, integrated pest management, horticulture, livestock and fodder crops and aquaculture (Pretty et al., 2011). Concerning the crop improvement, the SRI method provides better aeration, more spacing, and less competition, which enabled the plants to thrive (Krishna, 2008). One hypothesis would be that plants having more extensive, more profound and longer-lived root systems are taking up not only more macronutrients but also more significant amounts of micronutrients, which are essential for their synthesis of the enzymes that guide and sustain plant metabolism (Uphoff, 2009).

Soil conservation is improved by increasing soil amendments of organic matter and active aeration of the soil during weed control operations (Thakur et al., 2010). Passive soil aeration, resulting from not keeping fields continuously flooded and letting them dry out, even to the surface-cracking point, several times during plants' vegetative growth, is undoubtedly necessary for active soil aeration to be adequate. When soil is mostly aerobic, mycorrhizal fungi can thrive and provide rice crops with the benefits that most other terrestrial plants receive from these symbionts' services (Uphoff, 2009).

Moreover, increased soil organic matter through SRI practices improves the soil with more organic matter application and increased root exudates thus growing stronger and healthier plants. Thicker tillers, deeper roots, and broader spacing greaten the resistance towards rain and wind, among others climate variations. The sustainable intensification strategy contributes to the enhancement of crop resilience and sustainability to cope with climate changes.

Resource-use efficiency

Efficient resource-use helps reduce vulnerability to multiple hazards in several contexts. In a general sense, increased efficiency typically leads to reduced vulnerability through decreased dependence on critical resources (e.g. fertiliser, water) and more sustainable resource management. Water use efficiency when dealing with drought for irrigation agriculture is an obvious example (Hill & Pittman, 2013). For millennia, it has been assumed that rice plants benefit from inundation. The main benefit to farmers from flooding their rice fields is actually to suppress weeds, thereby saving labour otherwise required for weeding. Applying just enough water to meet the needs of the growing plant – and of the aerobic soil organisms that coexist with it in the rhizosphere (the soil layer surrounding plant roots) – is demonstrably better for plant health than flooding. It is thus explainable why reducing applications of irrigation water can enhance crop growth and productivity (Uphoff, 2009). Another contributing factor to such plant performance could be a higher microbial activity associated with more extensive root systems, which are continuously involved insolubilization of non-available forms of nutrients (Uphoff, 2009).

Moreover, paddy fields are considered as a significant source of methane (CH4) and nitrous oxide (N2O) emissions, which have attracted considerable attention due to their contribution to global warming (Adhya et al. 2000; Bouman et al., 2007; Yang et al., 2012). Flooding the soil creates anaerobiosis and conditions favourable for CH4 production and emission (Adhya et al., 2000). Methane and nitrous oxide are the two principal greenhouse gases contributing 15% and 5%, respectively, of the enhanced greenhouse effect globally (Suryavanshi, 2013). In 1994, flooded rice fields accounted for 252 Gg of CH4 emissions and 0.054 Gg of N2O emissions from burning of agricultural residues (INC, 2000). Therefore, the development of efficient irrigation water management would minimise the emission of these gases from paddy soil. The resource-use efficiency strategy contributes to the increase in the crop's adaptive capacity.

DISCUSSION

Based on the measures of the present-day sensitivity of agriculture to climatic change, the findings of this article revealed that SRI is a paddy farming management response to climate change impact on paddy farming. Available literature showed that temperature has an inverse relationship with a yield at the upper range of the optimum growth curve, i.e. higher temperatures should lead to a corresponding decrease in yields (Ali & Ali, 2009; Firdaus et al., 2012; Vaghefi et al., 2011). Rainfall is a critical determinant in paddy farming as any shortage or excesses of rainfall gives way to a reduction in yields. Besides, paddy farming is one of the primary sources of greenhouse gases thus directly affecting the atmosphere and contributing to climate change (IPPC, 2014; INC, 2000; Adhya et al. 2000; Bouman et al., 2007; Yang et al., 2012). Adaptation strategies could help mitigate the impact of climate change on Malaysia's rice farming, and management practice is one of the critical strategies to overcome the adverse effects of climate change on rice production (Matthews et al., 1997).

Agronomic practices such as transplanting, fertiliser application, weed control, and water appliance need to be adjusted under the changing climate. SRI management responses to agriculture, climate security and food security by higher crop productivity (Krishna et al., 2008; Pandian et al., 2014; Shamshiri et al., 2018; Uphoff, 2003), facilitates adaptation (Abraham et al., 2014; Geethalakshmi et al., 2016), and helping promoting mitigation (Gathorne-Hardy et al., 2013; Rajkishore et al., 2013; Setiawan et al., 2014). It indeed sustainably increases rice production, strengthens crops' resilience to climate change and variability, and reduces rice production's contribution to climate change. Such farm-level management adjustments are interventions that have been addressing the increasing demand for agricultural researchers to have a greater understanding of the farming-systems context of management change, as it is seen as necessary in order to prepare agricultural agencies for the process of 'scaling' a new farming practice (Kuehne et al., 2017). Adaptation needs to be undertaken at many levels, including community and government levels. On a community level, the agricultural farmers should understand the impacts of uncertain climate, thus arrange proper soil, nutrient and water management. On a government level, in order to achieve a higher quality of life for Malaysians through sustainable development, the Government has to adopt an integrated approach towards attaining both environmental and developmental objectives.

In conclusion, SRI is an integrated innovation to improve agricultural productivity and agroecosystem resilience (Noltze et al., 2012) and a paddy farming management that grows a healthy crop in a sustainable manner (Mishra et al., 2006).
This knowledge can then, therefore, be used to better estimate responses to future climatic variation and changes and address SRI as an alternative and sustainable solution. The review provided implications for policy, practice and research. Future studies should include further data on views and experiences and prioritize: improvements in the understanding of the relationships between changes of climate and changes in paddy systems in specific areas; more comprehensive consideration of the range of policy responses to effects of climatic change on agriculture, at the regional, national and international levels (Parry and Carter, 1989).

CONCLUSIONS

This review attended to assess for SRI in Malaysia as a management response to climate change about its sustainable intensification and resource-use efficiency. The methodology involved formal and grey literature that specifically researched on various scenarios of changes in climate and its impacts on rice production in Malaysia. The reviews indicated that there would be adverse effects on rice yield and hence, risks for farmers' livelihood and national food security. Rice is indeed a staple crop in Malaysia, with Malaysian meals consuming about 82.3 kilograms per annum on average (Shamshiri et al., 2018). Thus, adaptive paddy farming management needs to be adopted to minimise and consequently overcome the adverse impacts of climate change to ensure the sustainability of rice production in Malaysia.

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