Research article

Development Challenges and Directions of Climate Change Measures in Paddy Agriculture in Southeast Asia

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Abstract The world's population is growing rapidly. Ensuring global food security is becoming increasingly urgent. Adapting to changes caused by climate change while maintaining food security and agricultural sustainability is difficult, and inter-state conflicts, together with energy and value chain issues, complicate food issues. There are synergies and trade-offs between agriculture and climate change which must be analyzed to inform future strategies. With the world population expected to exceed 9.7 billion by 2050, rice consumption is expected to increase significantly. Paddy farming is essential to meet demand in Southeast Asian countries where rice is the staple food, but its expansion can cause environmental problems due to methane emissions from paddy fields and the large amounts of water required for cultivation. Paddy farming in Southeast Asia is the main source of water consumption often exacerbating water scarcity in some regions due to water competition with other sectors. This study focuses on the synergies and trade-offs related to improving paddy farming in Southeast Asia. Improving rice production requires adaptation to climate change including drought and flooding, and the availability of water resources, fertilizer management, and smarter labor, leveraging synergies among these items to increase productivity and sustainability. On the other hand, these items also involve numerous trade-offs, such as increased greenhouse gas emissions labor costs, and labor demands. Therefore, we reviewed the literature on management strategies for rice production in the context of climate change. We focused our review on farmers' participatory water management and the application of the Alternate Wetting and Drying Method and biochar for adaptation strategies for climate change. The results indicate that farmers are taking charge of irrigation systems through Participatory Irrigation Management (PIM) and Irrigation Management Transfer (IMT), giving them control over water use and maintenance. Alternate Wet and Drying (AWD) and biochar methodologies are climate change adaptation strategies for farmers that can maintain a favorable balance between synergies and trade-offs in promoting appropriate future water use in paddy fields.

Keywords synergies, trade-offs, climate change, water management

INTRODUCTION

The world's population reached 8.1 billion in November 2022 and is projected to reach 9.7 billion by 2050 (United Nations Department of Economic and Social Affairs, Population Division, 2022). Southeast Asia's population is projected to reach 723 million by 2030 (World Economic Forum, 2023). This rapid population growth puts a significant strain on agricultural land and the global food system, as there is more demand for food but limited available resources. One of the challenges to ensuring global food security is climate change. Climate change is already affecting agricultural production in many parts of the world. Climate change can be defined as a shift or change in climatic patterns, such as changes in temperature and precipitation patterns, extreme weather events, rising sea levels, and related driven primarily by greenhouse gases (GHG) naturally or by human actions (Hamann et al., 2021). Increased frequency and intensity of droughts, floods, and typhoons damage crops and disrupt agricultural productivity. These changes are likely to continue, making it increasingly difficult to produce adequate food to feed the growing worldwide population. Southeast Asia is one of the most vulnerable regions of the world related to climate change (Hijioka et al., 2014), due to various factors such as seasonal monsoon patterns, long coastlines, heavy reliance on agriculture, fisheries, and forestry. (IPCC, 2014).

According to the ADB (2009), report, climate change in Southeast Asia is expected to lead to significant variations in weather phenomena, such as increased and erratic precipitation patterns, increased severe weather events, higher temperatures, and rise of sea level in coastal areas. These changes will adversely impact agricultural yields, biodiversity loss, availability of clean water, and the quality of life. Rice is one of the most important foods in the world with several billion people dependent on rice as a source of their food and livelihood (Redfern et al., 2012). Southeast Asia is a major rice producer which represented 27% of the rice harvested globally (Frazier et al., 2022). In recent years, rice production in Southeast Asia has become increasingly threatened by the effects of climate change (Masutomi et al., 2009). Increased temperature and drought stress have led to decreased production of rice. According to ADB, 2009, a mean temperature increases of 1°C is associated with a 10% decrease in yield, while a 15% decrease in dry season rice yield in the Philippines was reported by Peng et al. (2004), related to an increased temperature of 1°C. Additionally, it is estimated that 50% of the world's rice production is affected by drought (Bouman et al., 2005). Likewise, flooded rice systems contribute to global agricultural GHG emissions (Smith et al., 2008). Carlson et al. (2017), state that rice production is estimated to release roughly half of total global crop production emissions in terms of carbon dioxide equivalents per kilocalorie produced. Similarly, methane and nitrous oxide are primary sources of GHG emissions caused by high inputs of carbon and the decomposing of rice roots and crop residues under anaerobic conditions (Le Mer and Roger, 2001). Without adequate climate change adaptation strategies, Southeast Asian farmers face an uncertain future, as they struggle to cope with the increasingly severe impacts of climate change on their livelihoods. Climate Smart Agriculture (CSA), as defined by FAO (2013), is an approach that guides the actions needed to transform and restructure agricultural systems to support sustainable development effectively and to ensure food security in the face of climate change. Water management strategies are one of the technologies identified for CSA (CCAFS, 2018). This review study focuses on Participatory Water Management (PIM) and Irrigation Management Transfer (IMT) which gives farmers control over water use and maintenance. It also notes Alternate Wet and Drying (AWD) and biochar methodologies as climate change adaptation strategies for farmers which can maintain a favorable balance between synergies and trade-offs in promoting appropriate future water use in paddy fields.

METHODOLOGY

We conducted a systematic literature review in December 2023, using the "Google Scholar" database. The search was performed with combinations of search terms that corresponded to geographical specificity and subject matter interest. The former focuses on Southeast Asia, while the latter focuses on the different components of climate change affecting the rice production system. The search criteria used in this research were rice production, climate change, climate change adaptation and mitigation strategies, water management, synergy, and tradeoffs.

RESULTS AND DISCUSSION

Overview of Rice Production in Southeast Asia Facing Climate Change

Southeast Asia witnessed a remarkable transformation in rice production over the past half-century, characterized by intensified cropping practices and elevated yield averages (OECD and FAO, 2017; Frenken, 2012). This resulted in robust and consistent rice surpluses within the region's river basins and deltas. These surpluses not only secured regional food security but also significantly contributed to the global food supply (OECD and FAO, 2017; Dawe et al., 2014). On the other hand, Southeast Asia is expected to be seriously affected by the adverse impacts of climate change (IPCC, 2007), affecting rice production. In recent years, there has been an increased frequency of floods, droughts, and cyclones resulting in the decline of soil and water resources (Redfern et al, 2012). The annual mean temperatures in Indonesia, The Philippines, Vietnam, and Thailand are projected to rise by 4.8°C by 2100, and the global mean sea level will increase by 70 cm (ADB, 2009). In Southeast Asia, small changes in rainfall patterns are predicted to continue until 2040 (Cruz et al., 2007), with an increased occurrence of extreme weather events including heatwaves and erratic precipitation patterns. Studies based on historical data analyses indicate large interannual fluctuations in the yield of three major staple crops (rice, wheat, and corn) from 1979 to 2008, of which 32% to 39% were caused by climate change (Lesk et al., 2016). Rice yield is affected by extremely high and low temperatures, droughts, and extreme precipitation during the growing period (Chou et al., 2021). Fluctuations in these climatic variables not only affect the growth duration but growth pattern and productivity as well. These changes further aggravated by climate change effects may cause a decline in rice production in the world (Furaya and Koyama, 2005; Li and Wassmann, 2011). Rice yields in Southeast Asia are predicted to decrease due to future climate change events which include drought, increased temperature, increased CO_2 concentration, and fertilization (Murdiyarso, 2000). In Indonesia, The Philippines, Thailand, and Vietnam, rice yield is projected to decrease by approximately 50% by 2100, if no adaptation measures or technical improvements are applied. Drought stress which is aggravated by climate change is a significant factor in rice production in Southeast Asia as current rice production relies on ample water use. Drought stress is the most significant restraint to rice production as most rice varieties are vulnerable to drought stress (Serraj et al., 2009). Long-term annual average rainfall has been below since 2009, in Southeast Asia, particularly in Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam (Redfern, 2012). In rainfed agricultural systems such as in Cambodia, any variation in climate will impact rice production (Shrestha et al., 2018). Increased frequency and intensity of droughts is a major concern. Redfern et al. (2012), highlight how Southeast Asia's rice production systems, heavily reliant on water, are particularly vulnerable. Likewise, Kawasaki and Herath (2011) show that rising temperatures, particularly night-time temperatures, can lead to increased spikelet sterility in rice, significantly reducing grain yield. Therefore, adaptation to climate change is considered a fundamental requirement in combatting the effect of climate change on rice production as well as mitigation strategies.

Farmers' Participatory Water Management in Response to Climate Change

Participatory irrigation management (PIM) is an approach in which farmers participate in all stages of irrigation including development through operations and maintenance (O and M) and is implemented in many developing countries. Management responsibilities cover the O&M of irrigation infrastructure. Irrigation management transfer (IMT), a program of transferring the management of irrigation systems from the government to local user groups, has also been promoted (Hamada, 2011). Such water management in Cambodia, introducing co-management in irrigation projects developed by ADB and self-financed irrigation projects has led to better coordination with the administration, reduced water problems, and increased farmer autonomy (Perera et al., 2007). In Vietnam, because of the introduction of irrigation management by a farmers' organization, results indicate better performance of management models with increased involvement of farmers in the decision-making process (Trung et al., 2005). In some countries, such as India, Pakistan, and Nepal, they also include determining irrigation service fees and collection (Mukherji et al., 2009). Many countries are moving towards PIM and IMT by organizing farmers into water user groups and transferring certain levels of responsibility to them. Different countries have developed their water user associations (WUA) and IMT models based on their specific cultural, political, institutional, economic, and climatic conditions. In some countries, such as Mexico, Turkey, and Indonesia the system has made significant progress, while in others, such as India and Pakistan it faces organizational and institutional sustainability challenges (Peter, 2004). Farmer participation in irrigation management has brought many benefits (Xie, 2007; Peter, 2004; Facon, 2007). As water resources are under pressure due to the effects of climate change and diversifying water demands, it is necessary to promote initiatives to increase the productivity of irrigation water to contribute to foXiod security and the involvement of farmers, WUA's, and the government is inevitable in these initiatives (Barker et al., 1999). Water productivity can be increased by managing water at the irrigation system level rather than only in the field to reduce the amount of water used (Tuong, 2005). PIM and IMT represent a shift towards a more participatory and user-centered approach to water management. When implemented effectively, they can lead to improved water efficiency, equity, and sustainability in irrigation systems which can be a strategy for sustainable rice production in Southeast Asia.

Alternate and Drying Method (AWD) and Application of Biochar as a Strategy in Rice Cultivation for Climate Change Adaptation

The Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007) defines adaptation as adjusting systems to minimize climate risks and impacts. To cope with climate change's adverse effects on agriculture, adaptation is crucial for enhancing production resilience and sustaining rural livelihoods (Bryan et al., 2013; Smit and Skinner, 2002). Implementing adaptation practices can minimize crop yield losses, maintain farmer income, and ensure food security. CSA introduced by FAO in 2010 promotes resource efficiency, production system resilience, and adaptation while mitigating GHG emissions, aiming for sustainable agricultural development. According to FAO, rice cultivation accounts for 34-43% of global irrigation water use (Surendran et al., 2021). In Southeast Asia, where rice cultivation is a significant agricultural activity, water scarcity is a major problem. Additionally, climate change is expected to aggravate water crisis problems. On the other hand, rice cultivation is a major source of methane (CH_4) emission, which is produced during the decomposition of liable carbon in an anaerobic environment by methanogens (Conrad, 2002). Rice cultivation also releases nitrous oxide(N_2O), another important GHG, which is mainly generated from nitrification and denitrification processes (Bouwman, 1998). The practice of alternate wetting and drying methods (AWD) has been suggested to improve water use efficiency and the GHG emissions method of rice cultivation which is better than continuous flooding (CF). Studies have shown a significant reduction in water usage with AWD. This is due to the reduction of loss of water due to evaporation and providing water needed during growth without affecting productivity. Many studies have shown that reducing CH_4 emissions in rice paddies is achievable through strategies like reducing carbon inputs and managing water levels with drainage events (Feng et al., 2013; Haque et al., 2020; Jiang et al., 2019; Setyanto et al., 2018). Yagi et al. (2020) confirmed this in a Southeast Asia region meta-analysis, finding significant emission reductions of 35% with single or multiple drainage events like AWD irrigation. AWD irrigation curbs methane emissions by disrupting the methane-producing bacteria because they thrive in low oxygen conditions. Likewise, biochar shows promise for GHG mitigation in rice cultivation, with studies citing potential reductions of 0.3-6.6 $GtCO_2\ y^{-1}$(Feng et al., 2012; IPCC, 2022). It promotes plant growth by improving nutrient use efficiency and soil properties like pH, nutrient retention, and soil organic carbon sequestration (Zhang et al., 2010; Koyama and Hayashi, 2019). While biochar may also enhance drought resilience (IPCC, 2022), its use as a global mitigation strategy remains under development due to potential increases in CH_4 emissions under certain conditions (IPCC, 2022).

Synergy and Trade-offs of Application of AWD and Biochar in Rice Cultivation as a Strategy for Climate Change Adaptation

It has been well documented that AWD effectively reduced CH_4 emissions and improved efficient water use in rice paddies, however, it can lead to a trade-off with increased nitrous oxide (N_2O).

This is due to increased periods with moderate oxygen levels in the soil. This creates ideal conditions for the microbes that produce nitrous oxide by dry spells. This trade-off raises concerns about the overall Global Warming Potential (GWP) of AWD compared to CF irrigation. Studies have documented varying degrees of N_2O emission increases under AWD compared to CF (Chidthaisong et al. 2018; Maneepitak et al. 2019; Sriphirom et al. 2019). However, even with this rise, the overall GWP of AWD often remains lower than CF due to the significant reduction in CH_4, a much more potent GHG. Additionally, AWD achieved lower GWP compared to CF, highlighting the net positive impact of the strategy despite the N_2O trade-off. While AWD irrigation appears promising for mitigating GHG emissions, its impact on rice yields remains a critical concern with potential implications for food security. Pandey et al. (2014) and Linquist et al. (2015), observed yield reductions ranging from 3.48% to 13.0% compared to continuous flooding. Others, like Carrijo et al. (2018) and Setyanto et al. (2018) found that crop yields varied with seasonal conditions. Sometimes yields increased, sometimes they decreased, and overall, there was no consistent pattern. Finally, Tran et al. (2018) documented yield increases ranging from 3.6% to 10.9% with AWD. However, emerging research suggests that combining AWD with biochar application may hold the key to unlocking a synergistic solution that tackles both climate change and food security. Pandey et al. (2014) suggest that the synergy between AWD and biochar holds immense potential in this regard. Biochar could address AWD's drawbacks such as improved water-holding capacity, enhanced nutrient retention, and suppressed nitrification.

CONCLUSION

The world's growing population is putting pressure on food security, especially in Southeast Asia, where rice is the staple crop. Rice farming is the main source of water consumption in the region, but climate change is making it more difficult to secure and manage water for rice production. Increased rice production is vital for meeting food demand but can also lead to environmental problems such as methane emissions and water scarcity. This study looked at adaptation strategies to improve rice production in Southeast Asia under climate change as a component of CSA. According to the results, farmers are taking a more significant role in managing irrigation systems through PIM and IMT. This gives them more control over water use and maintenance and is being used in many countries and can be adopted in Southeast Asia. Accordingly, farmers can use AWD and biochar as an adaptation strategy for climate change. AWD is an efficient way of using irrigation water and minimizing CH_4 emissions. However, it can affect productivity and lead to the release of N_2O. With the application of biochar in AWD, the problem of productivity and N_2O emission can be managed. This combination promotes environmentally friendly rice production by lowering water usage potentially reducing GHG emissions and increasing yields. Overall, IMT, PIM, AWD, and biochar offer a comprehensive approach to sustainable rice cultivation in Southeast Asia in the face of climate challenges by reduced water consumption through improved field management, improved yields by effective water management, and enhanced food security, with efficient water usage and potentially higher yields.

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