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Distributional Impacts of Climate Change and Food Security in Southeast Asia

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Abstract: *Climate and agriculture are closely linked, as weather and climate are the primary factors in agricultural production. Due to high levels of CO2, future projections of climate change indicate increasing temperatures and varied rainfall, both which will have major impacts on the agricultural sector. In this context, this paper assesses food security with respect to climate changes over Southeast Asia, with a focus on southern Viet Nam. This multidisciplinary study integrates regional climate modelling, agricultural science-crop modelling and risk assessments, which form the base for the creation of regional/local information products that will have direct societal applications. This study is useful for assessing socio-economic risks and leads to opportunities for interdisciplinary collaboration, which will bring direct benefits to the Southeast Asian/Association of Southeast Asian Nations region to develop adequate adaptive practices towards risk management, food security, diversification, and planning.*

Keywords: Climate Change, Floods, Droughts, Risk Management, Food Security, Policy

JEL Classification: Q18, Q54

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1. Introduction

The general view is that food prices are likely to increase in the coming years as global food production is unlikely to keep up with the demand given adverse climatic conditions that affect harvests, degrade soils, and cause water scarcity for irrigation with increasing population and rapid urbanisation. If climate change projections are included, most of today's key agriculture regions are likely to experience more extreme rainfall distributions that can highly impact food production through more frequent and extreme events such as droughts and floods.

The National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) have stated that the globally averaged temperature over land and ocean surfaces for 2014 was 0.69°C above the 20th century average, the highest since 1880. This also raises the question of the impacts such temperature changes would cause to crop growth and food productivity.

The reports of the Intergovernmental Panel on Climate Change (IPCC) suggest that the mean surface air temperature over this region has increased 0.1°–0.3°C per decade from 1950–2000 (IPCC, 2007; IPCC, 2014). The number of extreme weather events such as hot days/warm nights or the number of heavy storm events and tropical cyclones has also increased. These climate changes impact on other physical systems — increasing temperatures and increasing extreme weather events lead to a decline in crop yield in many Southeast Asian countries (Thailand, Viet Nam, and Indonesia); massive flooding in Ha Noi and Hue (Viet Nam), Jakarta (Indonesia), Vientiane (Lao PDR); landslides in the Philippines; and droughts in many other parts of the region. Water shortage, agriculture constraints, food security, infectious diseases, forest fires, and degradation of coastal and marine resources have also been increasing.

With respect to precipitation, it has been reported that future increases in precipitation extremes related to the monsoon is very likely in Southeast Asia. Temperatures may see increases by 3°–4°C and rainfall increases by 40% at the end of the century in Southeast Asia. The strongest and most consistent increases are seen over northern Indonesia, Singapore, and Malaysia in June, July and August, and over southern Indonesia and Papua New Guinea in December, January, and February. The IPCC report also states that under scenarios of high levels of global warming, models based on current agricultural systems suggest large negative impacts on agricultural productivity and substantial risks to global food production and security, and that there is high confidence in the adverse link of climate change on crop and food production in several regions of the world, including that over Southeast Asia (IPCC, 2014).

This existing knowledge on these possible climate changes is broader, globally and regionally, but their impacts at sub-regional scales (over relatively smaller agrarian regions) are still unclear. This requires information on sub-regional/local scales that could be provided by regional climate models (that downscale global climate models at desired spatial resolutions).

However, very few studies have been done underpinning the link of climate change and its impact on crop productivity over Southeast Asia. In this context, this paper attempts to evaluate the vulnerability of crop yields under future climate changes over southern Viet Nam (Mekong River Delta (MRD) using the outputs of regional climate models coupled to an offline physical crop model.

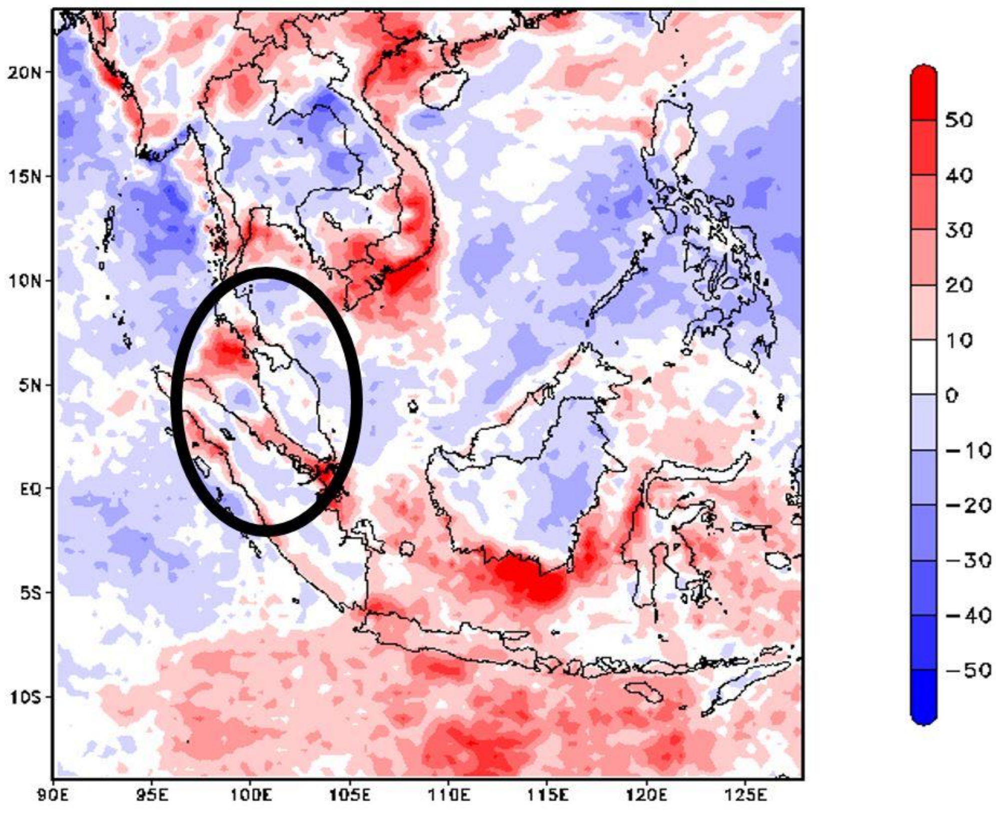
In this study, we applied high resolution climate outputs from a regional climate model (Weather Research and Forecasting(WRF)) as input data to the Decision Support System for Agrotechnology Transfer (DSSAT) cropping system model (Jones et al., 2003). Soil data and crop phenology, planting and harvesting, and management information were obtained from field measurements conducted in the Kien Giang Province. We selected winter-spring (winter), summer-autumn (summer) and autumn-winter (autumn) seasonal rice as indicator crops to quantify impacts for irrigated and rain-fed rice cultivation in future climate over MRD. The fragrant rice (OM4900), a short duration cultivar, was investigated as it is the most cultivated rice type in southern Viet Nam.

2. Background and Methodology

A recent regional dynamical downscaling climate study (Liong and Raghavan, 2014) conducted at the Tropical Marine Science Institute suggests likely varied rainfall patterns in the future over Southeast Asia with some regions experiencing wetter conditions and some regions, drier, indicating possible floods (over some parts of Viet

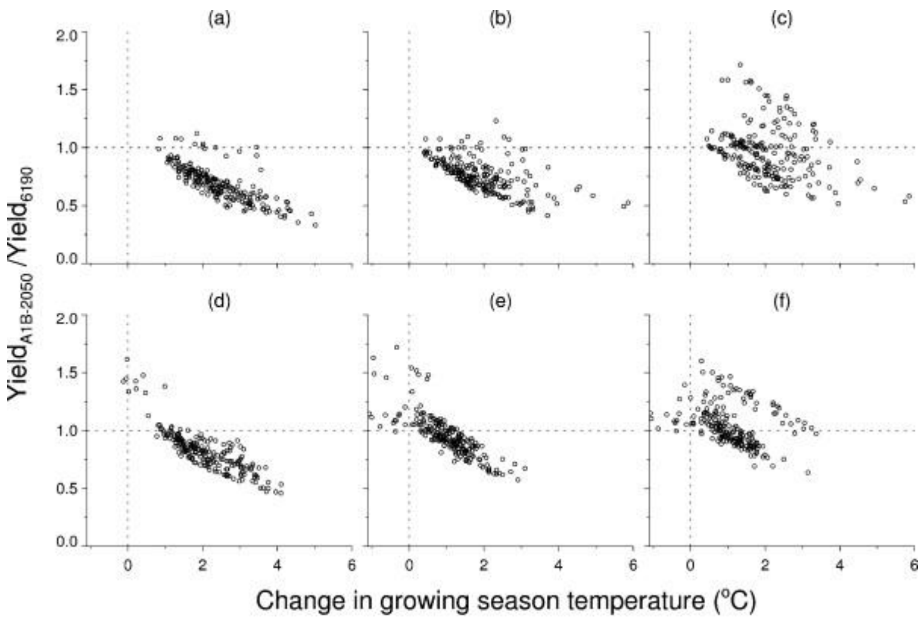
Nam, Indonesia, Malaysia, Thailand) and droughts (over northern Thailand, Lao PDR, Cambodia, and some parts of Viet Nam and Indonesia) (Figure 1). These findings are significant because these projected changes are likely to affect major agricultural regions such as the Red River Delta (Viet Nam) and south Viet Nam, of which MRD is part (circled in the figure). Studies on droughts over central Viet Nam (Vu et. al., 2014) and on floods over the Dakbla river basin, Viet Nam (Raghavan et al., 2014) provided some assessments on future climate impacts and highlighted the importance of using regional climate models for impacts studies.

Figure 1: Percentage change in future rainfall over Southeast Asia (2011–2040 relative to 1961–1990)



Source: Liong and Raghavan (2014).

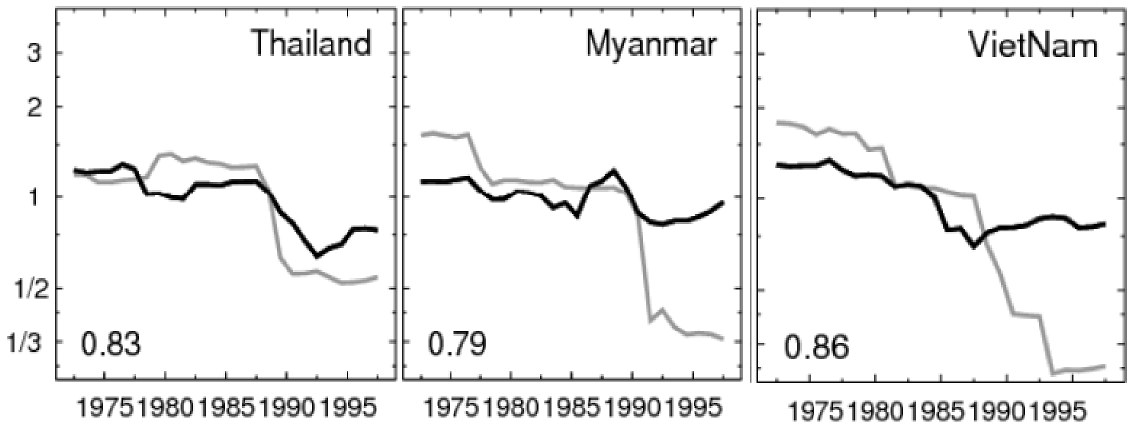
Figure 2. Relative change in yield against absolute change in growing season temperature for soybean (a–c) and spring wheat (d–f) simulations with No Adaptation (a, d), Altered Sowing Date (b, e), and Altered Sowing Date and Variety Switch (c, f).



Note: Each circle represents a single country-global climate model combination.

Source: Osborne et al. (2013).

Figure 3. Simulated (black) and observed (grey) changes to the inter-annual variability of national rice yield.



Note: Yield variability was found to have decreased over the past 50 years
Source: Adapted from Osborne and Wheeler (2013).

Few studies have also been undertaken on climate change and crop productivity. Osborne et al. (2013) simulated the response of wheat and soybean to numerous projections of future climate and found that yield declined with increasing temperature and that the potential for adaptation to offset such losses was greatest for countries at higher latitudes (Figure 2). Another study by Osborne and Wheeler (2013) examined how the year-to-year variability of national rice yield has altered between 1960 and 2009 for the major crops such as wheat, maize, and rice, and found that in a few Southeast Asian countries, including Viet Nam, the variability of rice production has decreased over time (Figure 3). There is a clear research need to examine whether rice production in this region can remain as stable in the face of further climatic changes.

In addition to changes in temperature, recent studies have indicated that water scarcity is projected to exacerbate with a 5%–15% decline in river run-off by end of the century (Haddeland et al., 2013; Schewe et al., 2013) and that the flood hazards are projected to increase, with global variations with an increase in Southeast Asia (Dankers et al., 2013). The frequency and intensity of droughts have also been projected to increase globally, affecting Southeast China and Australia among other Southeast Asian regions (Prudhomme et al., 2013). The Asian Development Bank (ADB) has also reiterated the need for more adaptive measures and strategies to mitigate climate change impacts over Southeast Asia (ADB, 2009). The reports of the IPCC and the ADB have strongly urged for much more detailed research for the Southeast Asian countries.

Osborne and Wheeler (2013) also stressed that both crop and climate variations indicate that a greater understanding of crops and climate might be achieved by considering them as a fully coupled system. What is more crucial for growing and harvesting crops in against the backdrop of climate change is when future rainfall may see deficient rainfall, although high rainfall may be detrimental due to flooding conditions. These studies reveal that food security is inextricably linked to climate and agriculture, as climate and weather conditions are key factors in agricultural productivity and crop growth.

Crop simulation models have been steadily developed and have been improved at large spatial scales (i.e., coarser than or equal to country size). Using a suite of crop models, many studies have been carried out to investigate the impacts of climate change on crop production (Balkovič et al., 2014), yield gaps and food security (Van Wart et al., 2013), adaptation options (Chen et al., 2012; Olesen et al., 2011), and strategies planning for policymakers (Ewert et al., 2011). For example, with sufficient global data sets such as crop planting and harvesting methods and dates, fertiliser and irrigation application, cultivated and harvested area, the GLAM (Challinor et al., 2004), PEGASUS (Deryng et al., 2011), and iGAEZ (Tatsumi et al., 2011) models were created to assess the impacts of climate change on global food production. Elliott et al. (2014) developed a global gridded crop simulation system (pSIMS) based on crop models, named DSSAT (Jones et al., 2003) and APSIM (Keating et al., 2003). However, these crop simulations at large scales were usually derived from remote sensing, country-level data, or expert judgements, which can be subject to many uncertainties, particularly in areas lacking good data collection and having a complicated crop system. Indeed, the global fertilisers and manure data set provides uniform values for some large areas or countries, particularly in the developing countries and the available variables and periods contained in the global data sets are far below the requirements of most process-based crop models (Xiong et al., 2016). Moreover, global climate data with coarse spatio-temporal resolutions cannot capture the high spatial variability in key climate variables, as in temperature and especially in precipitation, both of which highly depend on complex topography and physical processes.

Several studies on high resolution crop growth modelling have been performed in Asia, mainly in China and India, which used sufficient and well-qualified data, including climate, soil, crop yield, planted area, production, and crop management. Piao et al. (2010) found that improved regional climate simulations, especially for precipitation, were important to reach a more definitive conclusion of climate change impacts on China's water resources and agriculture. Another research done by Yao et al. (2007) showed that temperature increase due to climate change resulted in significant rice yield reduction in northeast China. In India, researchers found that climate change was likely to reduce rice yields under both irrigated and rain-fed conditions (Naresh Kumar et al., 2013). Chun et al. (2015) provided an overview of climate change impacts on rice productivity over Cambodia based on the field experiments. They showed that most of this region was projected to be affected by climate change and that the reduction in rice yields under climate change will be substantial (a decrease of approximately 45% in the 2080s under the Representative Concentration Pathways (RCP) 8.5, relative to the baseline period 1991–2000) without adequate adaptation.

With southern Viet Nam being one of the most productive rice-growing regions in Southeast Asia, many rice-importing countries rely on it. The Ministry of Agriculture and Rural Development of Viet Nam has also stepped up its efforts in agricultural resilience to make rice production a larger part of its economic growth (AG Professional, News). To this end, this paper has identified south Viet Nam as the main study region over which rice productivity will be assessed over a changing climate.

3. Study region

In Southeast Asia, where agriculture is a major source of livelihood, approximately 115 million hectares of land are devoted to the production of rice, maize, oil palm, natural rubber, and coconut (ADB, 2009). Rice has been feeding the region's population for well over 4,000 years and is the staple food of about 557 million people (Manzanilla et al., 2011). Viet Nam is one of the centres of origin of rice cultivation, and the world's fifth-largest rice-producing country. Rice occupies 74% of Viet Nam's 5.7 million hectares of arable land (IRRI, 2008). Rice production is dominated by small, irrigated farms based around the MRD in the south and the Red River Delta in the north, which accounts for 56% and 15% of total paddy production in Viet Nam in 2014.

Southern Viet Nam is dominated by a tropical climate and can thus be divided into two seasons, cold/wet and hot/dry periods. The hot/dry season is from November through to April, whereas the cold/wet season is from May through to October. These two seasons are distinguished by tropical monsoons occurring from May to October over the southern part of Viet Nam. The south-west monsoon brings heavier rainfall and strong winds, primarily the reasons for wetter and colder climate conditions. **Error! Reference source not found.**

The specific study site is Kien Giang Province, situated within MRD (Figure 4). Kien Giang Province was selected as a test-bed because (1) the agricultural land of Kien Giang Province is about 20% of MRD; (2) the cultivated area of Kien Giang is also about 18% of the total MRD cultivation; and (3) the rice production in Kien Giang is close to 20% of MRD. We assume that studying rice production over Kien Giang will be representative of MRD and believe that initial assessments from this study would also widen the scope to expand this study to other MRD regions.

Figure 4: Study region: Mekong River Delta and Kien Giang Province

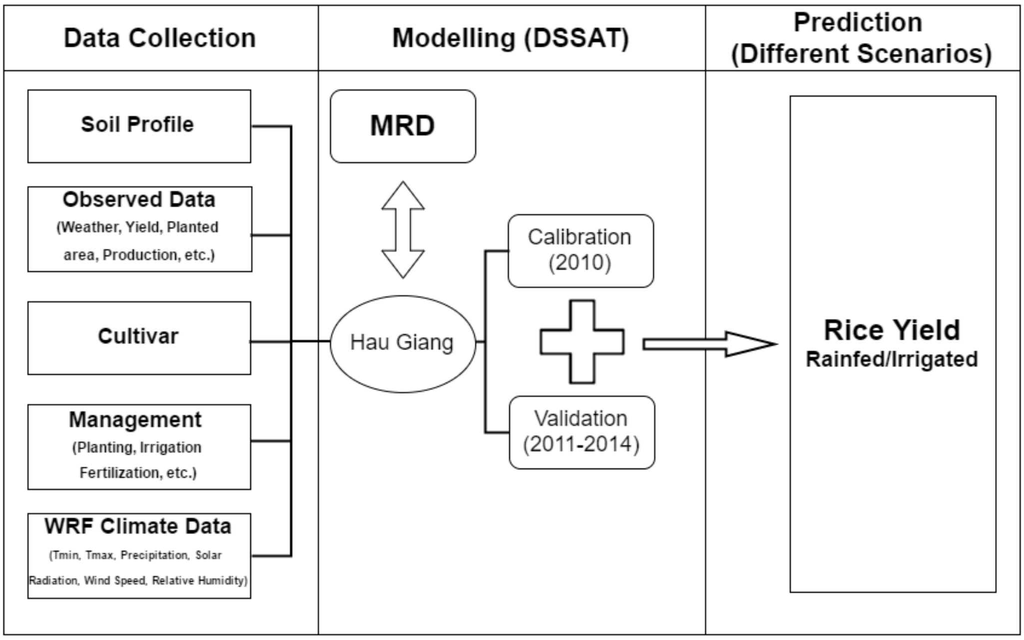
Source: Nguyen, et al. (2015).

4. Methodology

The climate data inputs for DSSAT were obtained through a dynamical downscaling of three global climate models using the WRF model. The WRF model was simulated at a spatial resolution of 30 kilometres over the study region and the large-scale driving fields for future climates were provided by the global models ECHAM5, CCSM4 and MIROC5, from the Coupled Model Inter-Comparison Project Phase 3, A2 emission scenario. Six variables, namely minimum and maximum surface temperatures, precipitation, solar radiation, wind speed and relative humidity, at daily temporal scales were extracted from the WRF model. The simulations for the historical period were done from 1961–1990 and for 2020–2050, for the future climate. For climate projections, the climate anomalies (difference between the future and baseline simulations) were considered. Also called as the 'delta factor' approach, this method gives a clear signal of climate change with the systematic biases in the simulations removed. The European ERA–Interim reanalyses driven simulations were also performed for 1961–1990 and for 2005–2014 baseline period for WRF model validations and for simulating historical yields, respectively.

The DSSAT model was used to simulate the future rice yield with the above-mentioned climate data (delta approach). It is to be mentioned that we consider only rain-fed and irrigated crop scenarios under one future climate scenario, A2. For brevity, the overall methodology, is shown in Figure 5.

Figure 5: Study Methodology

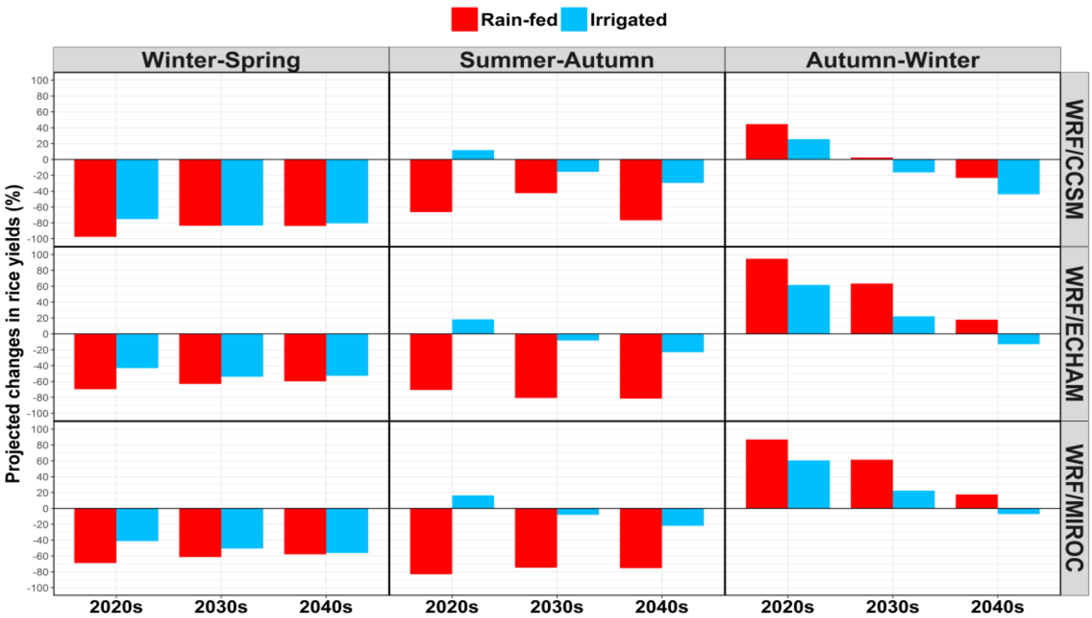


DSSAT = Decision Support System for Agrotechnology Transfer, MRD = Mekong River Delta; WRF = Weather Research and Forecasting.
Source: Author.

5. Results and Discussions

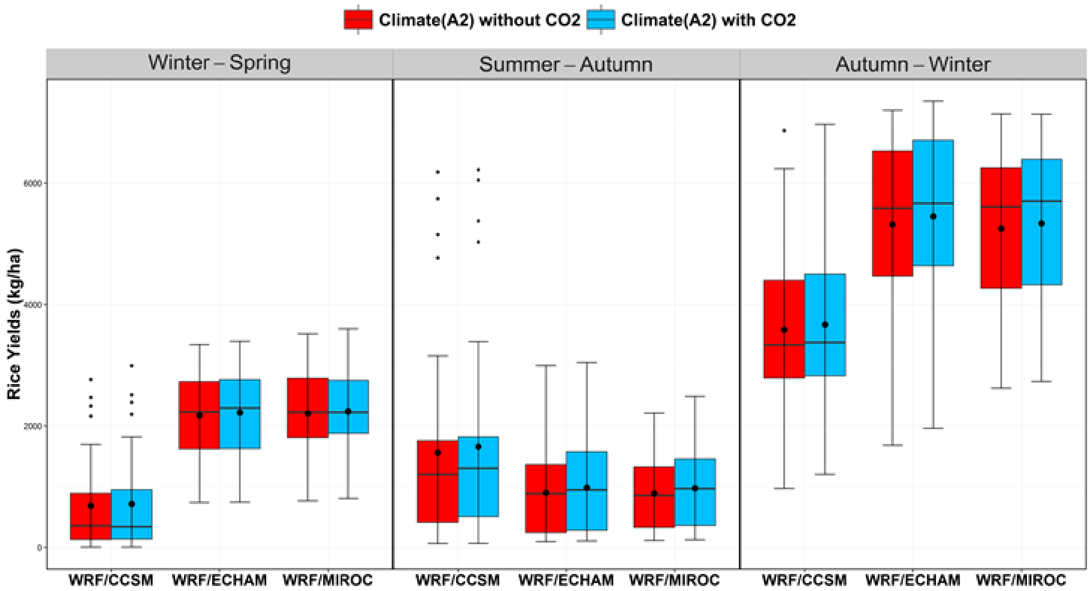
The changes in rice yield over the future period (2020–2050) were assessed using DSSAT over three seasons, winter-spring, summer-autumn and autumn-winter, for rain-fed and irrigated crop scenarios (Figure 6). During the winter-spring season, the crop simulations indicate that climate change is likely to reduce rain-fed rice yields, on an average, by ~80% in 2020s (2020–2029), by ~70% in 2030s (2030–2039), and by ~90% in 2040s (2040–2050) climate scenarios. The summer-autumn seasons also suggests strong decreases in rice yields while the autumn-winter season shows prospects of increased yields during the 2020s compared to the other decades.

Figure 6. Projected Future Rice Yields in Kien Giang.



Source: Author.

Figure 7. Box plots of simulated rice yields: With and Without CO2



Source: Author.

On the other hand, under irrigated conditions, the crop model results indicate that climate change is likely to reduce rice yields by nearly the same amounts to that of rain-fed yields, during both winter-spring and summer-autumn seasons. The irrigated yields during the autumn-winter show larger increases during 2020s than 2030s and 2040s. Therefore, based on these results, we reckon that climate change is likely to affect rain-fed rice crop production by about 80% in the whole of MRD, during both winter-spring and summer –autumn growth seasons, which is a highly significant reduction compared to the current productivity over the region, despite some positive impacts of yields are seen during the autumn-winter season.

We also analysed the positive effects of elevated CO2 for crop growth, for the 3 seasons, winter-spring, summer-autumn and autumn-winter, under rain-fed conditions (Figure 7). Results showed that the highest rice yields are likely during the autumn-winter season than the other two seasons.

The findings from this study suggest that rain-fed crops, in general, produce fewer yields than irrigated. Though irrigation could significantly improve crop yields, the main challenge is to find water sources given decreases in rainfall. MRD falls in the category of high vulnerability to climate changes, given other risks such as sea level rise and saltwater intrusion, droughts, and floods. Hence, prudent planning is necessary to counter such natural risks and the risks to lives and economy. This study provides some preliminary assessments of possible changes in the future and by no means, exhaustive in its findings as the science is growing with more research remains to be done both on the climate and crop modelling aspects. However, while these are in progress, it is important to have reliable seasonal forecasting to help farmers get an early warning on the evolving weather-climate patterns so that they have adequate time and adaptive measures for their cropping patterns and harvests, in order to make best use of the rains. It is also time to consider new breeds of rice cultivars which require less water consumption and high tolerance of soil salinity droughts and floods.

Combined with responses to high temperature and variations of precipitation, it appears that without adaptation measures yield reduction from severe climatic changes cannot be compensated, even accounting for the fertilising effects from CO2. Reduced number of rainy days during the dry season along with an increased number of rainy days during the wet season is likely to cause considerable negative effects during both growth seasons.

Changes in seasonal rainfall patterns might also increase the risks of harvests due to unexpected rains during dry periods when the time may be appropriate for harvests. Hence, a real-time seasonal forecast is necessary to observe the near-time changes in the seasonal dynamics of the weather conditions so that the farming community can be better advised of their planning.

The large reduction in rice yields is also likely to affect exports and the entire regional supply chain due to higher demands. This could also influence the insurance markets and inflate the prices to a larger extent disrupting the economic stability.

The reduction of crop yields over the Mekong delta due to climate changes is crucial as the regional climate change is also likely to impact neighbouring regions in Thailand or even India. Should Mekong have lower yields, it is likely that the yields could be lower in parts of Thailand, Indonesia and/or India. This should be borne in mind when it comes to the regional influences of climatic conditions.

6. Summary and Conclusion

This paper describes a study that investigated rice crop productivity in a future climate (2020–2050) over the Kien Giang Province located in the Mekong Delta Region of southern Viet Nam. The DSSAT crop simulation model was used to assess crop yields driven by the climate data generated from the WRF regional climate model, under different global climate model realisations. Changes in rice production under both rain-fed and irrigated crop scenarios were considered during two main rice growth seasons, winter-spring and summer-autumn. The results suggest that climate change is very likely to reduce crop yield in MRD, Viet Nam by about 80%, which is highly significant, given the current productivity in the MRD region.

Adaptation does not necessarily intend acting on the negative consequences of climate change but also harness the positive changes when appropriate as in the case of the season when higher productivity can be obtained.

Therefore, a holistic approach and concerted effort to address these challenges in a broader perspective is needed. A joint effort on a regional scale and sharing of the science and adaptive measures with the entire regional community could benefit each other and effective planning could help mitigate the harsh impacts considerably.

As the science of climate change is evolving and newer climate scenarios are being developed, these changes from this study, yet serve as an early warning signal so that the local agricultural sector is wary of such possible changes to come and to be prepared for drastic changes and risks to be effectively countered.

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