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Resilience of Cambodian lowland rice farming systems to future climate uncertainty

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ABSTRACT

Rice production is the major source of food security in Cambodia where 85% of the total arable land is cultivated to rice with traditional transplanted medium and later maturity varieties accounting for >70% of the plantings during the monsoon period. Climate change poses risks and opportunities to the sustained productivity of rice based farming systems in Cambodia. The objective of this study is to evaluate adaptation strategies that support the replacement of traditional low input systems with a 'response' farming approach for better temporal utilisation of available labour, land and water resources. Options include replacing a traditional transplanted crop with short duration varieties, more efficient crop establishment methods and better agronomic and fertiliser management that responds to timing, intensity and longevity of the monsoon and has potential to mitigate effects of current and future climate variability. To achieve this, we apply the APSIM farming systems model to evaluate how adaptation options for smallholder farmers can increase or maintain overall productivity within present day climate variability and future climates, using downscaled GCM baseline and 2030 climate scenarios. To extend beyond the 2030 climate change scenarios, we also assess production risk from an increase in ambient air temperature of 1.4–4.3 °C, atmospheric CO_2 concentration of 545–885 ppm and variation in rainfall, for rainfed and irrigated systems to 2090. Modelled scenarios indicate a yield response to elevated CO_2 of 17.5% at a concentration of 680 ppm for current temperature and rainfall and are consistent with established physiological effects of CO_2 on crop yields. In response to temperature, yields decreased by 4% per degree increase from an average annual baseline temperature of 28 °C. Adaptation strategies involving deployment of short duration rice varieties, in conjunction with direct seeding and better N management, indicate comparable and improved production can be achieved to 2030 under likely future climate projections. However, beyond 2030, the distribution and timing of rainfall has a significant influence on rainfed lowland rice in Cambodia. In this case a more transformational approach involving widespread provision of irrigation water will be required to offset climate change impacts.

1. Introduction

Meeting future food security demands in the face of population growth, urban migration, loss of agricultural land and climate change is a major challenge for farmers, particularly poorer farmers from developing nations reliant on rainfed rice based agriculture. Seasonal climate variability and increased frequency of extreme events such as storms, floods and drought resulting from a changing climate, combined with vulnerability and weakness of regional social and economic structures; local trade policy and global markets (Schiavone, 2010) are recognised risks to regional food production and food security in South-Eastern (SE) Asia. While overall SE Asia is the predominant supplier of rice to world markets, accounting for over half of global rice exports (Schiavone, 2010), production of rice in Cambodia is still at a comparatively low level, with yields averaging ~3.0 t ha^{-1} (FAO, 2013). In recent years, Cambodia has become a net exporter of rice (Vuthy, 2014), yet many small-holder farmers produce inadequate levels of rice for household consumption and must purchase rice on local markets seasonally (Magnan and Thomas, 2011). In the case of Cambodian lowland rice farming, projections of future rice productivity vary

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between different studies, ranging from anticipated yield declines due to high temperature induced shortening of the rice growing period and increased flooding from higher precipitation (IPCC, 2012), to studies suggesting that the increase in annual precipitation and in CO_2 will more than offset temperature impacts and, at least in the medium term (2030–2050), lead to increases in rice productivity (Mainuddin et al., 2011). Magnan and Thomas (2011) evaluated climate change scenarios from 2010 to 2050 and concluded that under all future climates and overall regional conditions the current rice growing areas under rainfed cultivation in Cambodia would decrease by ~20%. These projected outcomes pose a substantial risk for Cambodian food security when 85% of the total arable area (2.3 million ha) is cultivated to rice, of which 90% is rainfed lowland rice grown primarily during the monsoon season (USDA, 2010).

With the exception of irrigated dry season production, traditional farmer practice relies on a transplanted single medium maturity rice variety (locally available) grown under rainfed conditions between June and November and is the baseline practice for comparison of adaptation strategies in this study. Traditionally, medium duration rice, maturing 120–150 days after sowing (DAS), accounts for over 40% of national production while late maturity varieties (>150 DAS) account for another 33%. Much of this production has been from local varieties maintained by individual farmers or localised to a particular region. In recent years it has become more difficult to achieve food security due to increased seasonal variability (both inter- and intra-season), particularly drought and flood (Schiavone, 2010), and changes to social and economic factors due to migration to urban areas and increasing rural labour costs (USDA, 2010). As a result, farmers are in need of adaptation strategies that enable a more dynamic and flexible response to unfolding seasonal conditions throughout the growing period and build resilience in response to future climate change.

Cambodia has limited infrastructure to respond to stress associated with climate change (Murphy et al., 2013) and this has triggered increased research activity in Cambodia. One such initiative is the Adaptation to Climate Change in Asia (ACCA) project funded by the Australian Centre for International Agricultural Research (ACIAR), using a mixed methods approach comprising livelihoods and adaptive capacity assessments, on-farm research and modelling to extrapolate climate feasibility of new practices, which is described in detail by Roth and Grünbühel (2012). ACCA aimed to contribute to developing multi-scale adaptation strategies for farming communities in rice based cropping systems in four Asian countries including Cambodia. In Cambodia the focus has been on working with rice farmers in Svay Rieng province (11.143 N, 105.829 E) to evaluate a range of measures and farming practices that will contribute to building adaptive capacity at regional and national scales.

While on-farm research is essential for evaluating the benefits of an individual practice or changes to a farming system, it would require a significant financial investment in long-term field-based research in order to experience and experimentally evaluate all potential climatic variations. Complex interactions between many crop, soil, weather and management factors require integrated tools such as biophysical process models to understand this complexity (Rotter et al., 2011). The **A**gricultural **P**roduction Systems **Sim**ulator (APSIM) (Holzworth et al., 2014) has been extensively employed as a research tool to evaluate interaction between these key processes at the field, farm and regional scale. APSIM has been calibrated and validated for rice based systems in Cambodia using detailed characterisation of soils, local rice varieties and agronomic management for local climatic conditions (Poulton et al., 2014; Dalgliesh et al., in press) and has been employed to examine rice-based farming systems in the wider South-east Asia and South Asia regions (Gaydon et al., 2014 Gaydon et al., in press).

In an earlier study, Poulton et al. (2014) evaluated potential errors and gauged the level of uncertainty in modelling results using the APSIM-Oryza model for Cambodian rice growing conditions through a staged process of model calibration, validation and sensibility testing. In our present study, crop simulation modelling was employed using the previously calibrated and validated APSIM model to investigate the risk from projected increases in temperature and atmospheric CO_2 and variation in rainfall, on rainfed and irrigated rice production in Svay Rieng Province, located in South-Eastern (SE) Cambodia. The response of the model to changes in ambient temperature, CO_2 and rainfall was compared with known physiological responses of rice to elevated CO_2 and temperature. These results lend credibility for the subsequent use of the APSIM model in comparison and evaluation of the following scenarios:

1. Rice production for a current baseline climate period (1978–2011) and future climate period (2021–2040) from two downscaled Global Circulation Models (GCMs) for the A2 (IPCC, 2000) emission scenario.
2. Potential variation from current rice yields for projected climate change scenarios for 2020–2090 using a multi-factor sensitivity analysis.

2. Data and methods

2.1. Rice farming systems in SE Cambodia

Traditionally, land is first cultivated at the start of the monsoon when water starts to puddle on the soil surface. As a general rule ~20 mm ponding of an uncultivated field is the trigger for land preparation. The APSIM rice model was configured for ponding of >5 mm on the soil surface (equivalent of ~20 mm for an uncultivated field) as the trigger for preparation for sowing or transplanting. Preliminary water balance modelling for the Svay Rieng region for 1978–2011 found that initial surface ponding of 5 mm occurs between May 3 and July 10 from rainfall accumulated after March 31, with accumulations of 153–473 mm. These observations are consistent with traditional farmer practice of land preparation in early to late June. With arrival of the monsoon, seedling nurseries are established between May 24 and June 15 with planting after June 22 until the end of the planting window in the first week in August. At planting/sowing animal manure of 300–600 kg ha^{-1} is applied. Inorganic N fertiliser of between less than 20 kg ha^{-1} and 50 kg ha^{-1} is applied, split evenly between sowing or transplanting and panicle initiation (PI). The crop is then transplanted following a second cultivation. It is this transplanted crop that is the baseline practice for comparison of adaptation strategies evaluated in this study.

2.2. Strategies to manage climate risk in SE Cambodia

The Cambodian Agricultural Research and Development Institute (CARDI) is developing and releasing modern high yielding, short maturity rice varieties (90–120 DAS) and provides farmers with access to cost effective and labour saving rice establishment technology (ie. wet seeding using drum seeders or dry direct seeding using power-tiller mounted seed drills). The availability of mechanised sowing and harvesting has increased small-holder farmers' flexibility in timing of crop establishment while economically improving overall on-farm production due to crop intensification (Fukai and Ouk, 2012). These opportunities have contributed to the development of the concept of 'response' farming (Dalgliesh et al., in press). A response farming concept is premised on the assumption that, rather than a fixed-rule approach applied every year, a number of strategies are available to farmers