Simulation modelling of alternative strategies for climate change adaptation in rainfed cropping systems in North-Western Cambodia

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Abstract
Cambodia experiences a tropical monsoon climate with the wet season from May to October and the dry season from November to April. The average annual temperature ranges between 25 and 30 °C but has been increasing by 0.18 °C per decade since 1960. Cambodia's average annual rainfall of around 1,400 mm has not changed significantly since 1960 and is not expected to change significantly into the future, but projections indicate a trend for less rainfall early in the wet season and a later finish to the wet season. The objective of this study was to examine impacts and adaptation options to existing and potential climate variability and change among smallholder farms in the rainfed upland regions of North-West (NW) Cambodia. In recent years, these farmers plant crops on isolated rain events in the dry season from February onwards and their crops often fail because of drought and high temperatures at crop flowering. The main wet season crop is generally planted in July-August and crops can be lost from damage by heavy rain at harvest. APSIM was used to explore options to reduce crop climate risk by varying sowing date, applying alternative crop sequences and crop residue management. The potential climatic and agro-ecological constraints to adoption of safer and more profitable cropping strategies in the rainfed upland of North-West Cambodia are discussed.

Key words
Cropping; climate change; impacts; adaptation; APSIM

Introduction

There is a growing concern about the impact of climate variability and change on agricultural production across the world (Kotir, 2011). Increasing temperatures and changing rainfall patterns may contribute to increased frequency of extreme climatic events worldwide, thereby increasing production risk and crop yield losses. The severity of impact is likely to vary for individuals, systems and regions (Smith et al., 2001). Developing countries are more vulnerable to adverse impacts from increased climate variability and change because they are more reliant on agriculture for their livelihoods (Kotir, 2011).

Cambodia experiences a tropical monsoon climate with the wet season from May to October and the dry season from November to April. Rainfall generally begins in February and ends in November, with the highest rainfall months being September and October. The average annual temperature for Cambodia ranges between 25 to 30°C, but has been increasing by 0.18°C per decade since 1960 (McSweeney et al., 2012). The target region for this study is North-West (NW) Cambodia centred on the city of Battambang (13°05' N, 103°13' E, elevation 39 m). Battambang's average annual rainfall of 1,327 mm has not changed significantly since 1960. However, records show a trend towards less rainfall early in the wet season and a later finish to the wet season. Local farmers perceive rising temperatures, changing precipitation patterns and delayed commencement of the wet season (Touch et al., 2014). In NW Cambodia, farmers plant crops on isolated rain events in the dry season from February onwards. Crops often fail because of drought combined with high temperature at flowering which results in poor seed set, especially in maize. The main wet season crop is generally planted in August and crops can be lost from damage by heavy rain at harvest. Farmers reported they experienced crop failures, yield losses and associated income losses and they assumed climate was the main cause of the problems (Touch et al., 2014). On-farm research in NW Cambodia has shown that the main factors affecting maize yield are drought stress, declining soil fertility and weed competition (R. Martin pers. comm.). Research has also shown that reduced tillage and preservation of crop residues on the soil surface can conserve soil moisture and result in reduced risk of crop failure and increased yields (Montgomery pers. comm.). Therefore, this study aimed to improve understanding of how climate variability affects crop production on smallholder farms in NW Cambodia and to explore options to reduce climate risk. This was achieved by using the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003) to explore the impacts of varying sowing date, crop sequence and crop residue management under current and projected future climate scenarios.

Methods

Descriptions of field and simulation experiments

To calibrate APSIM, data were used from field experiments conducted between 2009 and 2013 at two locations with contrasting rainfall: Samlout (>2,000 mm p.a.) and Pailin (approximately 1,200 mm p.a.). Seven field experiments were carried out between 2009 and 2013 (ACIAR 2015) at including Samlout and Pailin. All experiments were conducted on a Ferrosol – which has a red, clayey surface soil with a friable structure and clay subsoil. The experiments were laid out in a randomised complete block design with three replicates. The experiments included early and main wet season maize nutrient experiments in 2009, examining the grain yield responses of different rates of urea applications: 0, 50, 100, 150, 200, 250, 400 and 450 kg/ha (5 experiments in Samlout and Pailin). Additionally, a sunflower plant population experiment conducted in the main, wet and dry seasons of 2012 – 2013 (both in Samlout and Pailin) tested different plant populations (i.e. 1.5, 1.9, 2.3, 3.0, 3.9, 5.2 and 6.7 plant/m^2).

The soil characteristics of a ferrosol soil from Kingaroy Australia (APSOIL #65) which closely matched the study sites were used in the simulation. The soil parameters were adjusted using soil data from the regional and experimental sites, thereby reasonably representing the soil characteristics. The default cultivar parameters of maize (cultivar Pioneer 3527) and sunflower (cultivar SunGold) in APSIM 7.7 were used. The simulation designs for sowing times, plant populations and fertilizer applications were in accordance with the field experiments. Rainfall data used for the simulation validations were from the Pailin weather station (12°52' N, 102°36' E, elevation 170 m) and the Maddox Jolie-Pitt Foundation field headquarters at Samlout (12°40' N, 102°45' E, elevation 180 m).

Simulation experiments

Two simulation experiments were run using climate data from Veal Bek Chan Meteorology Station at Battambang (13°05' N, 103°13' E), approximately 80 km from the study sites. Future climate projections for Battambang were derived from the BCC-CSM1.1 GCM (BC1) Global Circulation Model (GCM) under Representative Concentration Pathway Scenario 8.5 (RCP8.5) of the fifth phase of the Coupled Model Intercomparison Project (CMIP5). The BC1-RCP8.5 showed high capacity to simulate regional climate for the study site and the GCM downscaling processes and techniques were detailed in Liu and Zuo (2012). Plant densities per square metre were 7 for maize and 4 for sunflower.

Simulation 1 was designed to examine yield responses from various sowing months under current climate and future climate projection conditions. The current climate observations were collected at Veal Bek Chan Meteorology Station between 1982 and 2013. The projected future climate was grouped into two time frames; 2014-2057 and 2058-2100. Soil fertility was reset at each sowing time to avoid the confounding effects of declining soil fertility. This allowed the model to generate yield responses to climate and soil residual water only.

Simulation 2 was designed to investigate yield responses from a maize-sunflower crop sequence. Maize was planted on June 1, followed by sunflower sown on October 1, with various amounts of crop residues (i.e. 0, 1, 2 and 3 t/ha) being retained in the field. These two sowing dates were selected based on the outputs from Simulation 1. Soil fertility and soil water were not reset at each sowing in this simulation.

Results

Evaluation of model performance

The simulated crop yields were compared with the observed yields of the maize nutrient (a) and sunflower plant population (b) experiments. The determinant coefficient (R^2) and root mean squared error (RMSE) were utilised to qualify the model performance. The results showed that the simulations had strong correlations with the observations, with reasonably low values of RMSEs (Figure 2). This suggested APSIM could simulate maize and sunflower yields in NW Cambodia with reasonable accuracy.

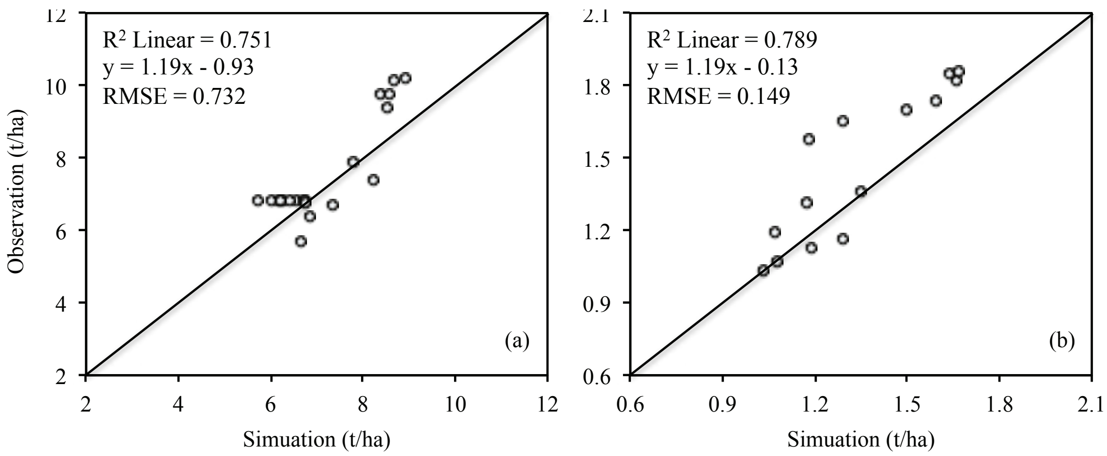

Figure 2. Observed and simulated yields of maize *(a)* and sunflower *(b)*. Perfect agreement between simulated and observed values is indicated by the 1:1 line.

Effects of sowing time on maize and sunflower yields

Preferred sowing dates for maize and sunflower under the projected future climate were similar to the best sowing dates under current climate (in August), and between June and September (Figure 3). Planting crops in February and March was risky in the current climate and even riskier with the future climate projection. The results showed there was a 25% chance of crop failure under current climate conditions (Figure 3a) and 50% chance of crop failure under the future climate projection (Figure 3b, 3c) for February sowing. The results suggested that farmers should consider adjusting their sowing dates to reduce the risk of crop failure in current as well as future climate scenarios (Figure 3).

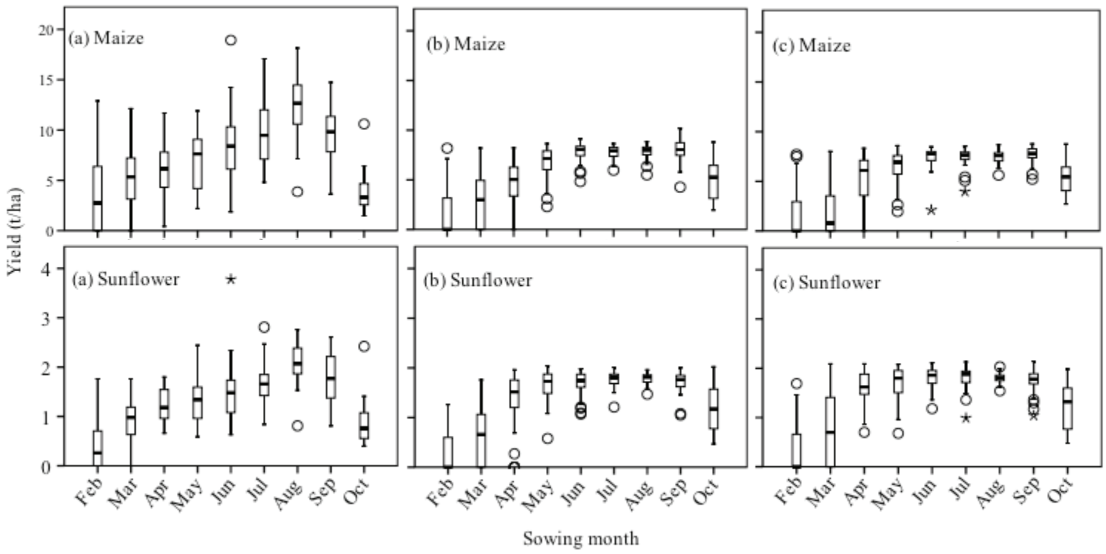

Figure 3. Effects of varying sowing months on simulated maize and sunflower yields planted on the first day of each month using observed current climate 1982-2013 and projected future climate between over 2014-2100. (a) refers to period: 1982-2013, *(b):* 2014-2057, and *(c)*: 2058-2100.

Maize-sunflower rotation as an option to adapt to projected future climate

Planting maize in June appeared to reduce drought impacts on crop growth. June planting also has reduced risk of wet weather damage during ripening and harvesting, compared with other crops such as soybean and mungbean. Sunflower planted in October was more likely to receive rain during the first 4-6 weeks of crop growth, but thereafter relied on residual soil water to grow to maturity. The results showed there was a significant maize yield response between 0 and 1-3 t/ha of crop residue retention at p-values ≤ 0.01 under current climate (1982-2013) and p-values < 0.001 under climate projection (2014-2100), but there was no significant difference between 1, 2 and 3 t/ha (Figure 4).

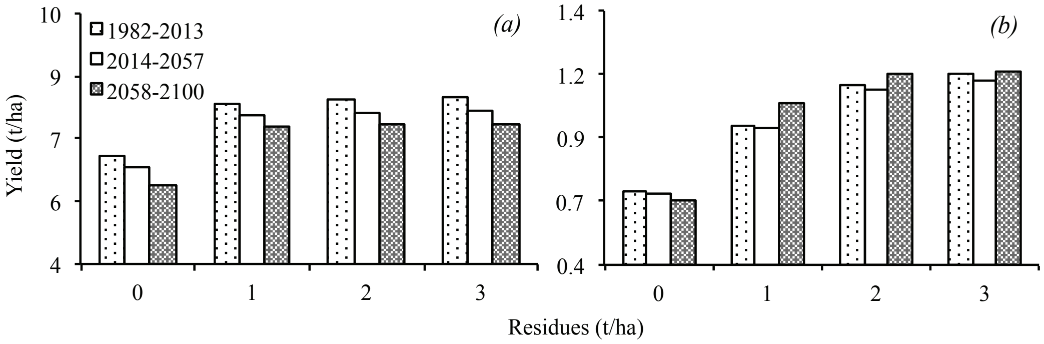

Figure 4. Comparing yields of maize (a) planted in June and sunflower (b) planted in October with varying levels of crop residue retention (0, 1, 2 and 3 t/ha) under current (1982-2013) and projected future climate scenarios (2014-2100).

Sunflower under current climate conditions, did not show a significant yield response (p-value = 0.061) when retaining residues of 1 t/ha. Significant differences (p-values ≤ 0.009) can be seen for retained residues of 2-3 t/ha. Under the future climate projection there was a significant difference (p-values < 0.001) between 0 and 1-3 t/ha of the residue retention; but not between 1, 2 and 3 t/ha.

Discussion and conclusions

We found that crops planted in February and March appear to be at risk of drought-induced crop loss under current climate conditions, and at even higher risk under potential future climate projections. This is consistent with observations by local farmers that there are major adverse effects from climate on their crop production (Touch et al., 2014). This risk, based on potential future climate projections, can be reduced by sowing the first crop in May and the second crop in September.

One alternative cropping strategy that is less risky than the current cropping practice is to sow maize in June followed by dry season sunflower planting in October, along with retained crop residues. Preserving crop residues has positive effects on crop yield, especially for the dry season crop. Under current climate conditions, maize yield was increased by 1.38 t/ha by retaining 3 tonnes per hectare of crop residues, while sunflower yield almost doubled. This study also highlights that crop models are useful tools to identify potential options for future climates which can then be verified in field-based experiments.

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