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Evaluation of the APSIM model in cropping systems of Asia

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ABSTRACT

Resource shortages, driven by climatic, institutional and social changes in many regions of Asia, combined with growing imperatives to increase food production whilst ensuring environmental sustainability, are driving research into modified agricultural practices. Well-tested cropping systems models that capture interactions between soil water and nutrient dynamics, crop growth, climate and farmer management can assist in the evaluation of such new agricultural practices. One such cropping systems model is the Agricultural Production Systems Simulator (APSIM). We evaluated APSIM's ability to simulate the performance of cropping systems in Asia from several perspectives: crop phenology, production, water use, soil dynamics (water and organic carbon) and crop CO_2 response, as well as its ability to simulate cropping sequences without reset of soil variables. The evaluation was conducted over a diverse range of environments (12 countries, numerous soils), crops and management practices throughout the region. APSIM's performance was statistically

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assessed against assembled replicated experimental datasets. Once properly parameterised, the model performed well in simulating the diversity of cropping systems to which it was applied with RMSEs generally less than observed experimental standard deviations (indicating robust model performance), and with particular strength in simulation of multi-crop sequences. Input parameter estimation challenges were encountered, and although 'work-arounds' were developed and described, in some cases these actually represent model deficiencies which need to be addressed. Desirable future improvements have been identified to better position APSIM as a useful tool for Asian cropping systems research into the future. These include aspects related to harsh environments (high temperatures, diffuse light conditions, salinity, and submergence), conservation agriculture, greenhouse gas emissions, as well as aspects more specific to Southern Asia and low input systems (such as deficiencies in soil micro-nutrients).

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1. Introduction

The world will need 70–100% more food by 2050 (World Bank 2008; Royal Society of London, 2009), and current trends in population and consumption growth will mean the global demand for food will increase for at least another 35–40 years (Godfray et al., 2010). Projections indicate that the production of cereals must increase by roughly 2% per annum over the next four decades to ensure food security in South Asia (Ray et al., 2013). From a sectoral perspective, the production of rice, wheat, and maize must increase by about 1.1%, 1.7%, and 2.9% per annum, respectively (Gathala et al., 2014). To meet this demand sustainably, crop intensification while increasing resource-use efficiency and reducing the environmental footprint, or 'ecological intensification' (Cassman, 1999; Cassman et al., 2003; Ladha et al., 2009; Hochman et al., 2013) or 'sustainable intensification' (Royal Society of London, 2009) will be obligatory. For example, the Indian Punjab has been heralded for its technical achievements in past decades but increasingly criticized for leveraging its success on the environment (Jalota et al., 2007). More recently, the debate about sustainable intensification is being extended to include aspects of resilience to climate change through the Climate Smart Agriculture framework (Campbell et al., 2014). Achieving such gains in productivity whilst reducing degradation of environmental resources will require a holistic systems approach, potentially incorporating the principles of conservation agriculture (CA), and judicious crop rotations (Hobbs 2007; Balasubramanian et al., 2012), amongst other potential adaptations. To complicate matters, any system advancements must be achieved under the overbearing shadow and uncertainty of a changing climate (Godfray et al., 2010). Cropping systems models have previously been used to explore the extent to which practices to manage climate risk can be judged to be climate smart (Hochman et al., 2017b).

There is a desire to investigate new practices in Asia with the aim of enhancing water productivity (WP) (Bouman, 2007), and cropping intensity (Dobermann and Witt, 2000) whilst maintaining environmental sustainability (Humphreys et al., 2010). Suggested pathways include the incorporation of non-flooded crops and pastures into traditional rice rotations (Cho et al., 2003; Singh et al., 2005; Zeng et al., 2007), changed agronomic and/or irrigation practices (Bouman and Tuong, 2001; Belder et al., 2007; Sudhir-Yadav et al., 2011a; Gathala et al., 2014), reduction of non-productive water losses (Humphreys et al., 2010), and genetic improvement (Peng et al., 1999; Sheehy et al., 2000; Bennett, 2003). Well-tested and locally-calibrated and validated simulation models are useful tools to explore opportunities within the context of a holistic systems approach – for increasing system productivity, assessing environmental trade-offs, and evaluating the effects of a changing climate.

Models such as DSSAT (Jones et al., 2003), ORYZA2000 (Bouman and van Laar, 2006) and Infocrop (Aggarwal et al., 2006a,b) have been widely used and tested in Asia, performing valuable studies on topics such as yield gaps and yield trends, evaluation of sowing dates and crop varieties, nitrogen and water management, environmental outcomes, and assessment of climate change impacts (Timsina and Humphreys, 2006a; Krishnan et al., 2007; Devkota et al., 2013). However for more in-depth evaluation of future farmer management strategies, there is also the need for a model which can more effectively simulate the performance of real farmers' decision-trees and management which changes from year-to-year in response to unfolding climate and environmental conditions. None of the aforementioned models is able to do this.

The APSIM cropping systems framework (Keating et al., 2003; Holzworth et al., 2014) is such a model, with a proven track record in modelling the performance of diverse cropping systems, rotations, fallowing, crop and environmental dynamics (Turpin et al., 1998; Carberry et al., 2002; Robertson et al., 2001; Verburg and Bond, 2003; Whitbread et al., 2010; Hochman et al., 2014). A distinctive innovation and philosophical departure from most other 'crop models' is APSIM's primary focus on simulating crop resource supply (rather than a primary focus on resource demand), with the soil forming the central simulation component. Crops, with their own resource demands impacted by weather and management, find the soil in one condition, and leave it in another condition for the next crop (McCown et al., 1996). This emphasis on simulation of soil resource dynamics positions APSIM strongly in comparison with other models for investigations into long-term changes to soil conditions and sustainability associated with different cropping strategies and practices. With particular focus on research into adaptation strategies, another notable strength of the APSIM model is it's unique capacity to capture intricate detail and subtleties of dynamic farmer management practices through a highly flexible 'Manager' Module allowing the user to specify detailed farmer decision-trees in simple 'if-then-else' logic (Holzworth et al., 2014). APSIM has recently been enhanced to simulate rice-based cropping systems and environmental dynamics of ponded systems (Gaydon et al., 2012a,b). Evaluation of APSIM is well-established and well-documented in Australia and Africa, however limited in Asia as the model's capability to simulate rice-based systems in this region is relatively recent. Also, rice is grown in more diverse cropping situations than most other crops (lowland (ponded), upland (un-ponded), puddled, un-puddled), necessitating more faceted evaluation. The first step in evaluating a model's credentials is to define model capacities required for addressing research questions around some of the aforementioned issues. We suggest that a model for simulation of cropping system performance in Asia should be capable of several key functions: (i) robust crop development and yield simulation for a wide variety of crops; (ii) the ability to simulate cropping sequences and the effect of different fallow management, tillage and residue management strategies on system performance; (iii) robust simulation of soil water and nutrient dynamics in conjunction with crop performance; (iv) flexibility to capture detailed farmer-imposed management practices,

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