Simulating growth and development of lowland rice in APSIM

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Abstract

A lowland rice module operating in the APSIM framework was developed based on ORYZA-2000. This required rewriting the code to simulate rice physiological processes as intended in ORYZA while using the existing APSIM suite of modules for water and nitrogen. The model can now be used to simulate rotational systems. This paper describes the key features of APSIM-ORYZA, including its input requirements, interactions with other components of APSIM (e.g. evapotranspiration, soil water balance, soil nitrogen dynamics, etc) and output. We also test the model's performance against some original ORYZA test data. The future development needs are highlighted.

Media summary

Based on a stand-alone rice model (ORYZA-2000), APSIM-ORYZA was developed to allow the simulation of cropping systems including lowland rice. The new module can now be used for cropping system simulations (e.g. intercropping, crop residue management, interaction between crop and soil fertility status). The module has been tested using limited data sets and will be fully validated under different environmental conditions.

Key Words

Crop modelling, rice, APSIM, ORYZA, cropping systems

Introduction

There have been intensive efforts on studying rice production system resulting in the development of several rice simulation models (Bouman et al., 2001; Ritchie et al., 1986). ORYZA2000 is one of the most advanced and has been intensively tested (Bouman et al., 2001, and references therein). However, it is a single-crop model addressing crop growth, development and crop response to environmental constraints. It does not simulate crop rotations or carry-over effects although there is an increasing demand for the ability to simulate rice-based cropping systems (especially the intensive agriculture system in China and southeast Asia countries). Such a systems capability will allow investigation of N dynamics, crop sequence, intercropping, crop residue management and soil management (eg. soil erosion and fertility). The cropping system model, APSIM (Agricultural Production System Simulator, Keating et al., 2003) is designed for the simulation of complex cropping systems and their management. System-related processes are available to any crop module through APSIM's infrastructure and generic crop libraries (Wang et al., 2002), greatly increasing the efficiency of model development by reducing redundancy and potential for error.

Collaborative research efforts between Wageningen University, IRRI (International Rice Research Institute) and APSRU (Agricultural Production System Research Unit) have now resulted in the incorporation of ORYZA into the APSIM modelling framework. This paper describes features of APSIM-

ORYZA, its requirements and compatibility with other components of APSIM library of modules. Testing on the module continues.

Model description

Crop modules in APSIM simulate crop phenology, leaf area development, biomass production, yield and nitrogen accumulation in response to environmental variables such as temperature, solar radiation, soil water and nitrogen supply. Rice-specific processes as simulated in ORYZA were implemented within APSIM. Table 1 summarises the input requirements and key parameter values for APSIM-ORYZA.

Table 1. Input variables for key physiological processes simulated in APSIM-ORYZA and their links to other APSIM-modules.

Simulation	Input requirement	Value	Source	Output
Phenology	Meteorological data – daily max & min temp, rainfall, solar radiation;	Time series data	'met' module in APSIM	'report' module in APSIM
	Base, optimum and maximum temperature;	8, 30, 42?C	Oryza	
	Transplanting shock index.	0.4	Oryza	
CO2 assimilation and yield formation	Extinction coefficients for visible light and for N distribution in the canopy;	function of development stage	Oryza	'report' module in APSIM
	Initial light-use efficiency of a single leaf;	function of temperature	Oryza	
	Leaf N content;	calculated	Oryza	
	Spikelet formation factor.	65 spikelets/g DM	Oryza	
Water and nitrogen uptake by plant	Potential evapotranspiration;	calculated	'eo' module in APSIM	Deltas sent back to 'soilwat2' and 'soiln2' modules in APSIM for water and N balance calculation
	Water availability in soil profile;	calculated	'soilwat2' module in APSIM	
	Soil nitrogen supply.	calculated	'soiln2' module in	

Temperature is the main driving force for phenological development (Bouman et al., 2001, and reference therein) and is used to calculate the timing of the start of photoperiod sensitive phase, panicle initiation, anthesis and physiological maturity. The development rate is calculated from hourly temperature (which is in turn estimated from daily maximum and minimum temperature, Bouman et al., 2001) using three cardinal temperatures: base temperature (8?C), optimum temperature (30?C) and maximum temperature (42?C). Transplanting shock reduces this rate and so does water limitation. Crop development ceases (ie. death) when daily average temperature falls below 12?C for three consecutive days. The model calculates the effective leaf area index by taking account of leaf rolling under stress and light interception from stems. The instantaneous assimilate rate of a single leaf depends on leaf nitrogen content. The assimilation rate of whole canopy is obtained by integrating the instantaneous value over canopy depth and sinusoidal course of the day. Growth estimates of different organs are achieved via dry matter partitioning, leaf death and loss, maintenance respiration and growth respiration. The number of spikelets at flowering is calculated from an empirical index of spikelet formation factor which was derived from field experiment (Bouman et al., 2001). The final spikelet number for yield formation is adjusted by a spikelet sterility which is a function of high or low temperature and water limitation.

Water availability is determined via the APSIM-Soilwat2 (note that while water ponding is implemented, simulation of paddy N chemistry is not simulated). Crop water uptake is based on potential evapotranspiration which is computed in APSIM-Eo. Soil nitrogen supply is calculated by APSIM-Soiln2 and APSIM-Fertiliz if nitrogen fertilizer is applied. APSIM maintains mass balance for all processes.

Model testing

The performance of APSIM-ORYZA under potential production conditions (non-water and non-nitrogen limiting) was tested on a field experiment conducted in IRRI farm in Philippines in 1991 by simulating the dry weight of the whole panicle, total dry weight of above-ground biomass and leaf area index (Figure 1). Simulated vs. measured data showed good agreement and was the same as results obtained when using ORYZA-2000. Overall, simulated LAI matched the pattern of growth, with the model slightly under-simulating the maximum leaf area. This is probably due to the inaccuracy of the parameter of specific leaf area in the late period of leaf growth. The calibration of that parameter would produce close simulation of LAI to the measurement.

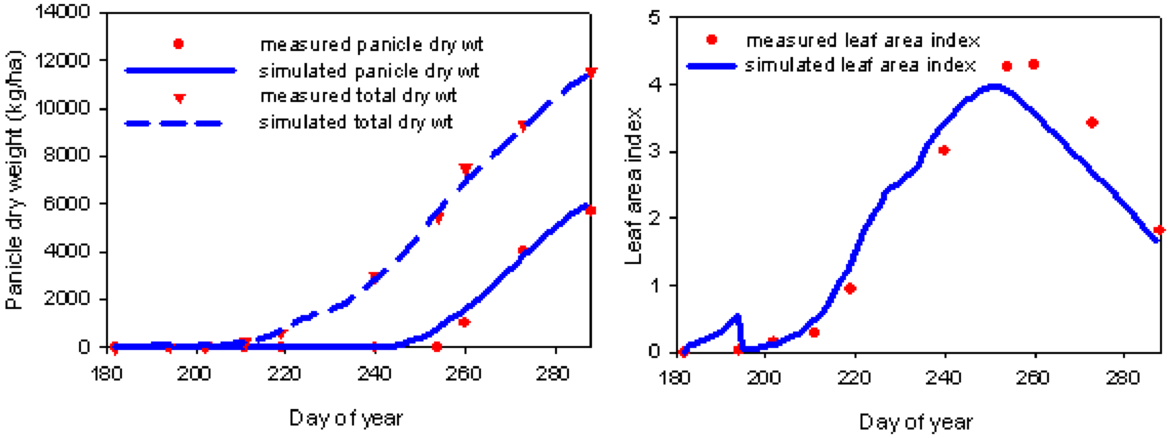

Figure 1. Measured versus simulated biomass production and leaf area index of *Oryza sativa* cv. IR72. Measured data were obtained from a potential production experiment conducted by IRRI in Philippines in 1991

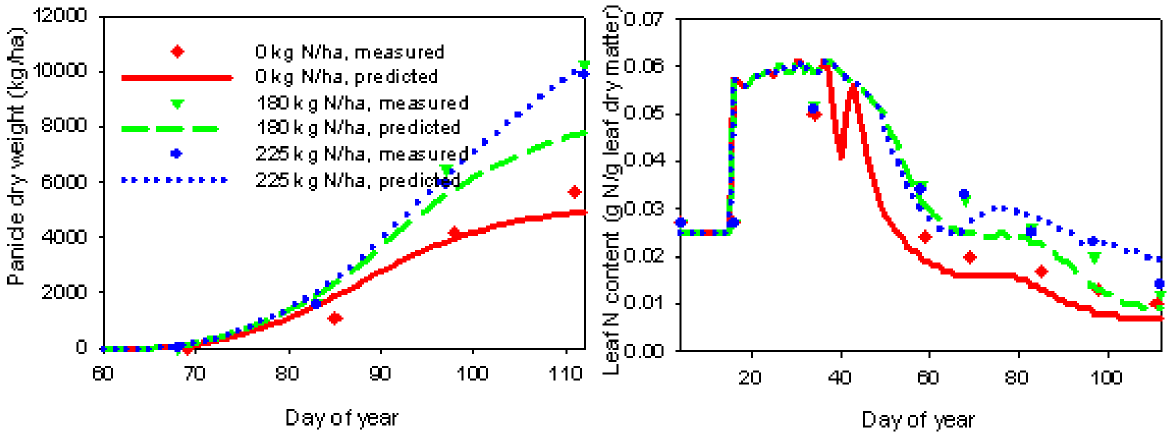

Figure 2. Actual versus predicted yield production and nitrogen concentration in leaves of *Oryza sativa* cv. IR-72. Measured data were obtained a field experiment with three levels of nitrogen fertilizer application conducted by IRRI in Philippines in 1992

Model performance was further tested under nitrogen-limited conditions (Figure 2). The test data were derived from a lowland field experiment with three levels of nitrogen fertilizer application conducted by IRRI in Philippines in 1992. Results showed that the simulated leaf nitrogen concentrations are lower than measured values in 0 kg N/ha and 180 kg N/ha treatments and higher/lower in 225 kg N/ha treatment. Although Figure 2 showed good agreement between simulated and measured dry weight of total panicles under 0 and 225 kg N/ha conditions, the model did not reproduce the high yield in 180 kg N treatment. Neither ORYZA-2000 nor APSIM is able to simulate the nitrogen dynamics of a paddy soil, ie. the transformation of nitrate and ammonium in an anaerobic environment. Thus the simulation of soil nitrogen supply using the dryland nitrogen module in both models is inadequate and further development must address this issue.

Conclusion

APSIM-ORYZA aims to simulate growth and development of rice with the capacity to deal with other important features of rice cropping system such as N dynamics, crop sequence, intercropping, crop residue management and soil management (eg. soil erosion and fertility). Preliminary testing of the module's performance using two independent data sets without water and nitrogen-limiting conditions shows reasonable agreement between predicted and measured values for crop biomass production and yield of storage organ. However there are some discrepancies between the simulated leaf nitrogen concentration and yield of storage organ and the measured values under different nitrogen application conditions. The results highlight the need to develop module to simulate nitrogen dynamics in paddy soil, which is underway. At the same time, APSIM-ORYZA needs to be further tested under different field-management and cropping systems.

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