The Crop Calculators – from Simulation Models to Usable Decision-Support Tools

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Keywords: *Simulation models, system architecture, crop management, N fertiliser, irrigation*

EXTENDED ABSTRACT

Crop & Food Research has developed a set of simulation-based Crop Calculators as precision management tools for optimising nitrogen (N) and water management of wheat, potato and maize crops. Their main purpose is to provide best practice N-fertiliser and irrigation management schedules for user-specified crops, or to predict the likely consequences of management decisions. Both economic returns and environmental impact (N-leaching) are taken into account. The Calculators have also been very useful in identifying production constraints. In some cases these have been able to be overcome, or in others inputs have been reduced to avoid environmental impacts and unnecessary costs. They provide a rapid method for assessing the effects of changes in management on production, soil resources and profitability.

The Calculators are based on daily time-step simulation models. Each Calculator has a unique crop model simulating plant growth and development, with responses to variable water and N conditions, but all interact with a common soil model. The system model has CROP, SOIL, WEATHER and MANAGEMENT modules (Figure 1). During each daily time-step, CROP grows to a new state according to current soil state, weather and management conditions; and SOIL changes to a new state according to current crop state, weather and management conditions. MANAGEMENT has details of irrigation and N fertiliser application schedules, which may be specified by users to affect soil conditions in one way, or be generated by the system according to soil state and management rules to advise user for decision support in another way.

Plant growth potential and the effects of water and N limitations were simulated. The levels of drought and N-deficit were quantified by simulating the changes in plant available water (balance between rainfall and irrigation versus evapotranspiration and drainage) and mineral N (balance of organic N mineralisation and N fertilisation versus plant N uptake, N leaching and emission) in soil profiles. Crop N demand was calculated as the sum of the N demand for various plant tissue categories. Crop N uptake was driven by the demand, but limited by soil mineral N availability. Effects of drought and N-deficit on crop growth were quantified by reducing leaf area expansion, accelerating leaf senescence, and reducing radiation use efficiency.

The Calculators were validated against field-grown crops. Their prediction on crop growth and yield matched measurements from the crops well under various irrigation and N fertiliser applications and across a wide range of weather and soil conditions. Their effectiveness as management tools was demonstrated through significant reductions in fertiliser applications without reducing yield, especially for potato and maize.

The features of the systems include: keeping it simple; appropriate compromise between accuracy and convenience; the use of real system constraints together with simulation results for suggesting management.

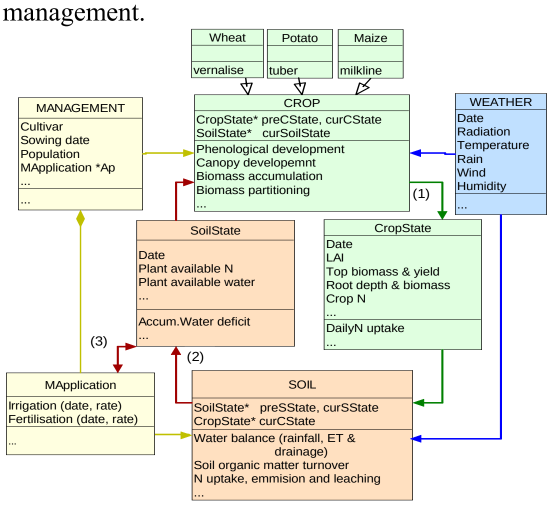

Figure 1. Simplified system architecture of the crop calculators, showing how (1) CROP and (2) SOIL changes to a new state during a daily time-step, and (3) how irrigation and N fertiliser application schedules affect to, or are generated from soil state.

1. INTRODUCITON

The crop calculators are precision crop management tools for optimising nitrogen (N) and water management of crops. Currently, the set includes the Sirius Wheat Calculator (Jamieson *et al.* 1998; Jamieson & Semenev 2000; Armour *et al*. 2002), the Potato Calculator (Jamieson *et al*. 2003; Jamieson *et al.* 2006) and the AmaizeN Calculator (Li *et al.* 2006a; Li *et al.* 2007a). More tools are in the chain to be added for crops such as forage brassicas (Wilson *et al*. 2004) and peas (Li *et al.* 2006b). Each crop calculator has been developed as a standalone system, and has a unique crop model simulating plant growth and development under variable water and N conditions, but all the crop models interact with a common soil model. The calculators have similar user interfaces and system architecture, and use the same method in dealing with weather conditions and crop management.

In this paper we briefly describe the functionality and operation of the crop calculators, present the merged system architecture that can be used to develop new tools for other crops. The tools may also be deployed in one system for modelling crop rotation and intercropping (Zyskowski *et al.* 2007a). Description of the underlying crop-soil interaction models is given, with emphasis on how simulated water and N limitations affect crop growth and yield. Finally, we provide the methods and principals we used to convert the simulation models into usable decision support tools.

2. SYSTEM FUNCTIONALITY

The operation of the crop calculators needs cultivar specific parameters, soil description, and weather data. These data are deployed as a database (files) with the system, and new data can be added easily if they do not exist. Cultivar specification requires numeric growth and development parameters, such as thermal time or photoperiod responses that determine when a cultivar reaches a particular phenological stage. Soil description includes organic N content, water-holding capacity and permeability. Weather inputs are daily solar radiation, rainfall, and maximum and minimum temperature, and optionally wind and humidity.

The system is arranged so that a user may select a cultivar, soil type and weather station by name. They must specify sowing date and population, and provide values of initial mineral N contents and moisture deficit in soil profile. The cost of crop management (irrigation and fertiliser applications) and the price of crop products also may be input for financial analysis.

There are several ways that the crop calculators may be used. At the beginning of the season they may be used to select combinations of cultivar and sowing date, and for planning irrigation and N-fertiliser application regimes. During the crop season irrigation and N-fertiliser schedules may be updated using up-to-date weather, soil and crop conditions. They may recommend the irrigation and N-fertiliser application schedule for best yield based on the site-specific conditions, and assess the likely financial and environmental impact. They may be used to answer "what-if" questions, by calculating the likely consequences of any user-specified management decisions, so can also be used as a rapid method for assessing the effects of changes in management on production, soil resources and profitability. They may also be used as a diagnostic aid in identifying production constraints by comparing crop performance with prediction. In some cases these can be overcome, or in others inputs can be reduced to avoid environmental impacts and unnecessary costs.

The outputs of the calculators include a series of tables and graphs showing crop phenological development, canopy expansion, biomass and harvest yield accumulation, and soil N and moisture dynamics to inform users' decisions..

3. SYSTEM ARCHITECTURE AND CROP MODELS

The engines of the crop calculators are daily time step crop-soil interaction simulation models. Figure 1 is a simplified system architecture diagram, showing the main processes of crop-soil interaction during a daily time-step. Under the control of WEATHER conditions and MANAGEMENT interventions, CROP grows to a new state (daily growth) depending on the SOIL state, and SOIL proceeds to a new state (daily change) depending on the crop state. MANAGEMENT applications (irrigation and fertiliser application rate and date) affects or modifies soil state. Alternatively, soil state and plant demand are used to generate irrigation or nitrogen applications in concert with management rules.

3.1. Crop models

Each crop calculator contains a unique crop model simulating plant growth and development. Currently , the models are Sirius wheat (Jamieson *et al*. 1998), Sirius potato (Jamieson *et al*. 2003) and Amaize (Li *et al*. 2006a). The crop models all