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AUSIM: A CROPPING SYSTEMS MODEL FOR OPERATIONAL RESEARCH

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1. INTRODUCTION

Some of the earliest examples of simulation models as management tools for natural systems concern crops and their environment. Nearly 40 years ago, Van Bavel, using punched data cards and a calculator automated for the purpose, used a simple water balance model to assess opportunities to improve crop, soil, and water management (1). Models of crops and environment, to say nothing of computers, have improved immensely since then, but development of capabilities to deal with cropping systems has taken a long time.

Several cropping systems models have appeared since 1980. These can be classed into two types on the basis of whether emphasis is on crop management or on soil/land management. The primary aim of the first type of model is to accurately simulate yield for a wide range of environmental conditions and genotypic characteristics, but to do so with widely affordable information requirements. This is largely achieved in models such as the CERES family by a pragmatic mix of empirical and mechanistic functional relationships (2). The scope of this type of model includes the climatic and soil variables and relationships that importantly affect crop yields in the short term. The merits of such models for crop management operational research have been expounded by Thornton and McGregor (3).

Models such as NTRM (4), EPIC (4) and PERFECT (5), represent the second type of cropping systems model. Emphasis here is on the influence of management on processes of soil loss and degradation. The expanded scope in modelled system and management perspective is illustrated in Figure 1, which is adapted from Cole et al. (4). Crop output is shown with its short-term dependence on climate and soil status (the totality of most crop models) in parallel with the soil properties important in the longer-term sustainability of the system; both are subject to management. In this second type of model, a large proportion of the computations deals with soil and hydrological processes, and a relatively simple generic model is considered adequate for simulating crop growth and yields.

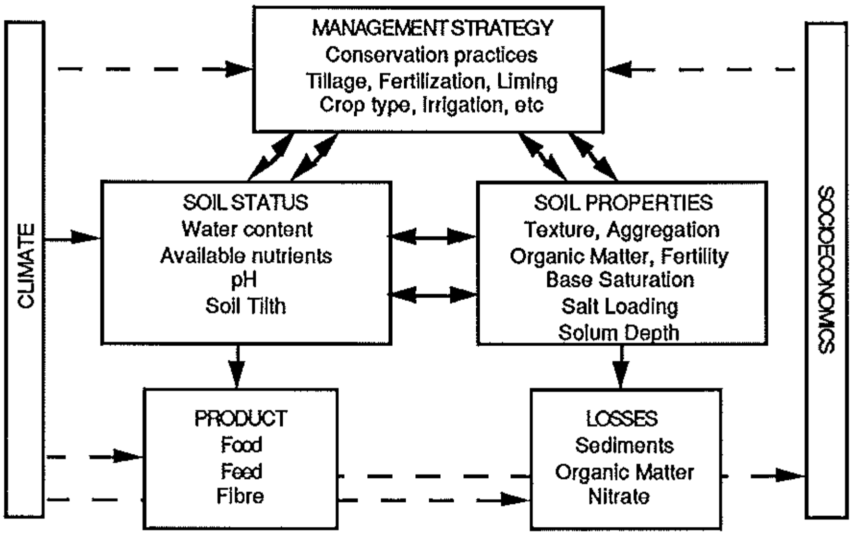

FIGURE 1.
Management of a cropping system for productivity and sustainability.
Adapted from Cole et al. (4)

2. THE ORIGIN OF AUSIM

The cropping systems model, AUSIM, is being developed as part of two projects concerning dryland cropping in the semi-arid tropics (SAT). These projects require a model that can simulate the performance of maize and sorghum in systems in which pasture or grain legumes occur in rotations or as intercrops. In addition, the model must accommodate no-tillage/mulch as well as conventional cultivation.

Research to provide these capabilities began with the evaluation of CERES-Maize (6). This model was selected as (a) having an appropriate level of treatment of relevant processes for our application and (b) embodying a large amount of research and modelling experience. The original model performs well in the cool SAT of Eastern Kenya (7) and, after modification, in the hot SAT of northern Australia (8). The model has subsequently been adapted to simulate grain sorghum production (9).

AUSIM has developed from CERES-Maize in response to four objectives: (a) to maintain a family of crop growth models with standardized features which all share the same subroutines that are not crop-specific, (b) to have a capability for combining crop growth models to simulate various cropping systems, (c) to improve the methods for modelling a crop, and (d) to improve the models of key soil processes.

3. FEATURES OF AUSIM

3.1 Flexible simulation of crops in various systems

AUSIM consists of a suite of standardized crop models together with soil models for water, nitrogen, and phosphorus, all of which respond to weather inputs. In AUSIM, the soil plus the climate routines comprise the most basic functional configuration. Crops can be absent (bare fallow), occur in a sequence, or occur in mixtures. Making the soil the centre of the simulation process allows the soil to cumulate the effects of sequences (or mixtures) of crops. Because the soil models are general, all crop variables, including roots, reside in the crop routines.

Crops growing in mixtures is an important configuration. Even where intercrops are not planted, weeds normally grow with crops and compete for resources; their omission from crop models is a major weakness of current modelling methodology. AUSIM treats, as a continuum, crop associations ranging from sequences, through degrees of overlapping in time, to synchronous crops. The same crop growth routines are used for simulation of all systems; the differences are achieved by variations in subroutine-calling strategies.

Even if crop models were not being used in combination, the structure of AUSIM has important advantages in maintaining software. Except for the crop-specific growth routines, there is only one set of code to be updated.

3.2 Developments in the crop submodel

The crop establishment model contains functions that include water stress and superoptimal temperatures during emergence, and water stress during early growth, none of which appear in CERES-Maize.

AUSIM contains an improved method for simulating crop leaf canopy development based on simulation of the size of individual leaves. This is made feasible by the discovery of a robust relationship between final size of a leaf and its ordinal number on the plant and this, in turn, on the crop's final leaf number. Carberry et al. (10) found that this approach accounted for nearly 90% of variation in leaf area among 12 cultivars of grain sorghum at three population densities at three locations and including both main culms and tillers. The relationships between leaf area and total leaf number of tillers were the same as for the main culm.

Two of these new developments combine to offer new potential for simulating tillering. Mechanistic treatment of tillering requires the capability to initiate, grow, and kill tillers. Use of the new method for developing leaf area combined with treatment of a tiller as an intercrop greatly improves the means for growing and killing tillers. The leaf information together with temperature inputs determines the time course of maximum leaf area development. "Actual" leaf area of a tiller is derived by discounting according to resource limitations, including the effects of competitive interaction with the main culm and other tillers.

3.3 Developments in crop environment submodels

An improved method for simulation of the soil water balance has been implemented in AUSIM. Although the layered-store model used in current water balance routines generally estimates changes in soil water adequately, we have experienced large under-estimation of flux, a serious problem to simulation of nitrogen losses. Paths for improvement of this model are limited by the remoteness of the model from the physical processes that determine water movement. Until now, Darcian flow theory has not been used in crop models because of (a) the high computing requirements of the numerical procedures required and (b) the low availability of soil hydraulic data. However, with judicious choice of numerical methods, the first of these problems can be avoided. This is demonstrated in SWIM (Soil Water Infiltration and Movement) (11), a model which uses a numerical solution of Richard's equation to route water through a soil profile. SWIM has been implemented in AUSIM to replace the use of USDA-SCS Curve Numbers for determining runoff and the currently-used "cascading" procedure for redistribution between layered stores. Run times are only 1.6 times those of the existing CERES model.

The soil hydraulic properties required for solution of the Richards' equation are the moisture characteristic and the hydraulic conductivity function. Simple models are used to describe these functions with only four parameters. This contributes to efficiency in both the numerics and the process of characterization of the hydraulic properties of each soil horizon. Data bases of the hydraulic properties for a wide range of Australian soils are under construction.

AUSIM's crop establishment model requires simulation of seedbed water and temperature, including the effects of mulch. The seedbed environment submodel being developed is the result of amalgamation of the models of Bristow et al. (12) and Ross et al. (13). As in SWIM, the model simulates water movement using Richard's equation, but soil strata are scaled to achieve high resolution of gradients in the seed-bed segment of the soil profile. The flux of water vapour and of heat are treated similarly, and work is currently underway to enable addition of a soil strength function.

AUSIM will have a more versatile nitrogen model than CERES. The main changes being made are (a) addition of a decomposition submodel for surface residues, (b) calculation of nitrate movement using transfer coefficients in the SWIM routine and (c) creation of a labile humic N pool. Recent studies demonstrate the need for the latter in rotations with a leguminous phase, where the original model greatly underestimates mineral N supply to the next crop.

4. FUTURE DEVELOPMENT

Additional crop growth routines whose construction or adaptation is now in progress or planned (kenaf, soybean, chickpea, peanut, mung bean, cowpea, wheat, and barley) are in keeping with a planned shift in focus to the subtropics.

A phosphorus submodel is under development at the International Fertilizer Development Centre, and we will be collaborating in its final development and testing.

In order to enable AUSIM to better deal with important long term soil change, increased emphasis will be placed on simulating runoff, erosion, organic matter change, and acidification as influenced by management.

5. FEATURES OF THE COMPUTER PROGRAM

The program is written in ANSI standard Fortran 77 with top-down design and a modular structure. The hierarchial modular structure and standardised module interfaces facilitate the concept of "plug-in", "pull-out" modules. This design allows easy updating, maintenance, testing and interchange. The visual / interactive capabilities developed for CERES-Maize (14) to aid investigation of intermediate processes are used. An executive routine provides convenient and flexible means for specifying and scheduling actions or strategies.

6. DISCUSSION

Evaluation of the relative merits of the two types of models has two major considerations: (a) adequacy of simulation accuracy, or sensitivity, and (b) affordability of information requirements. The simple generic crop model used in soil management models has appeal because of the generally lower cost of achieving a suite of relevant crop growth models. However, it is now becoming apparent that, while suitable for applications concerning soil loss and long-term changes in soil attributes, such models seem not to be sufficiently sensitive to environmental variables to provide an adequate operational research capability for crop management research (15). Thus far, our approach to the accuracy vs. cost issue has been to incorporate mechanistic relationships (in the interest of accuracy) where one of two situations exists that minimizes costs: either the added complexity corresponds to robust theory so that validation information is largely unnecessary (e.g. use of Richards' equation), or where there prove to be relationships that greatly simplify system parameterization (e.g. the close correlation between size of individual leaves and the final number of leaves on the plant).

As indicated, we plan to extend AUSIM to include soil loss and degradation processes. The existing type of crop model used in AUSIM is more "baggage" than is needed for the soil management mode. However, use of our existing validated crop routines is cheaper than using an additional, albeit simpler, model. When this dual-purpose model is used for crop management simulation studies, the soil loss and degradation subroutines can simply be switched off.

Much remains to be done in developing and testing this model before it can indeed provide the tool needed for operational research on both crop and soil management. But the signs are encouraging.

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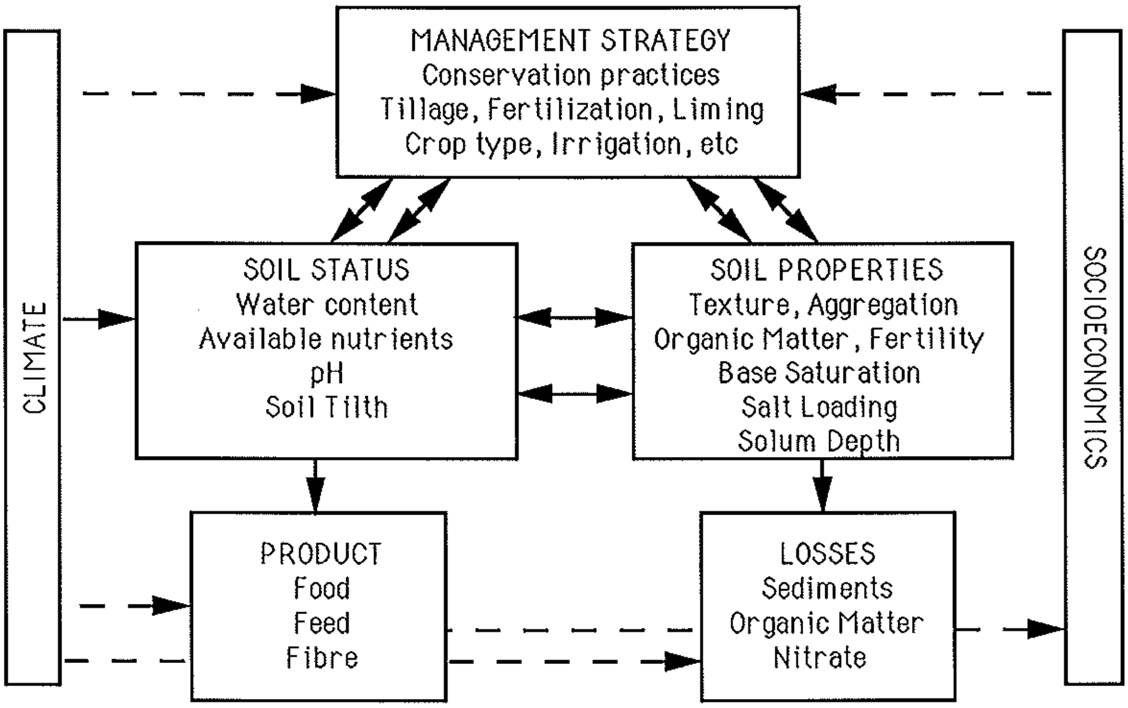

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