A GENERIC CROP SIMULATION MODEL FOR AGRICULTURAL PLANNING[+]

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EPIC, (Erosion Productivity Impact Calculator), is a mathematical model, composed of physically based components, that simulates erosion, crop production, and related processes using a daily time step. It was assembled by a team of US research scientists who were asked to report on the impact of long term soil erosion on the productivity of American farmland in 1985.

EPIC was developed specifically to investigate productivity problems caused by soil erosion and therefore concentrates on those aspects. Because erosion is a slow process, the model can simulate long periods of cropping, e.g. 100 years, from a single execution. It is capable of simulating complex crop rotations for a variety of soils and climatic situations. The model also includes components for assessing the cost of erosion, and for determining optimal management strategies.

Since the original assignment was completed in 1985, some members of the EPIC research team have continued to expand and develop the model in order to make available a generic crop simulation model that can simulate growth and management of a wide range of crop species including crops as diverse as sugarcane, wheat, maize, pastures, kenaf, guayule, and pine trees.

AUSCANE - Simulating growth of sugarcane in Australia

In 1987, the EPIC model was adapted to simulate cane growth under typical Australian conditions and the AUSCANE model was developed (Jones et al 1988). It simulates the major physical and biological processes of the canegrowing system including:

- weather
- soil temperature
- hydrology
- erosion, by water (and wind if necessary)
- tillage
- nutrient cycling
- crop growth and yield
- crop management practices such as irrigation, drainage, fertilization, and liming
- economics

AUSCANE contains a modified version of the EPIC growth model capable of simulating phenological development, leaf area, stalk weight, root growth, and sugar concentration in the cane stalk. Crop growth is directly affected by soil and air temperatures,

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solar radiation, and soil water (deficit or surplus). There are several stresses such as soil strength, base saturation, and nitrogen or phosphorus shortage, as well as three possible nutrient deficiencies or toxicities specified by the user, that can affect growth rate. The growth and development of different varieties can be simulated by the model if required.

For application to the Australian sugar industry, the model was modified to predict ccs (commercial cane sugar content) in the cane stalk as well as estimate yield. As the cane crop matures, the sugar concentration in the cane stalk usually increases. Cane variety and environmental conditions are the main factors that affect sugar content while low temperature, and mild stress from water shortage and lack of nitrogen promotes concentration of sugar in the cane stalk.

AUSCANE is a complex model with many interacting components. As a result, its validation presented many problems. First, validation of individual components does not necessarily assure the model builder that the whole model functions properly. Second, validation of individual components, or of the entire model for one set of environmental conditions, cannot be used to infer anything about its behaviour under other conditions. Third, separate data sets should be used for model calibration and for validation. However, few sets of weather, soils, and crop response data even approach the level of detail needed for validation of such a comprehensive model.

Testing of many of the components of EPIC has been reported previously (Jones et al., 1984a, 1984b; Nicks, 1974; Richardson, 1981, 1982; Sharpley et al., 1984; Williams and Renard, 1985; and Williams et al., 1984, and further testing of the behaviour of these components under Australian conditions has not been undertaken. However, several espects of sugarcane production including biomass production, cane yield, and sugar content of the cane, have been modelled and the results compared to actual or experimental data where appropriate. Some comparisons have also been carried out between weather data generated by the model and long term average weather data recorded at the centres chosen for close study.

Several sources of data were used to calibrate and test the model. Data from field experiments on the Bundaberg Sugar Experiment Station where cane was planted at four times during the year and harvested and ratooned six, nine, twelve, and fifteen months later, were used for calibration.

The model was used to estimate cane production using generated weather data and typical soils and management data for five of the main canegrowing areas in Australia, namely Innisfail (wet tropics, non-irrigated); Burdekin (dry tropics, irrigated); Mackay (sub-tropical, irrigated and non-irrigated); Bundaberg (sub-tropical, irrigated); and Condong (sub-tropical, non-irrigated, one-year and two-year cane).

Simulated cane yields were compared with average commercial yields over the past 10 years in Table 1. In all cases, the average simulated yields were within 10 per cent of recorded yields.

The harvest index variable in EPIC (HI) was used to estimate ccs in AUSCANE. Unlike many crops in which economic yield results from the irreversible development of fruit, grain, or seed, sugar accumulation in sugarcane is a reversible process. As the cane stalk matures, its sugar content normally increases as sucrose is stored in the more mature internodes and there is a smaller fraction of young internodes in the whole stalk. Mild stress from low temperatures, water deficit, and shortage of nitrogen promotes sugar storage at the expense of fibre production and all of these functions are incorporated into AUSCANE.

Table 2 shows simulated ccs for the five commercial canegrowing areas in comparison with the seasonal average ccs over the past 10 years. CCS simulated over three crop cycles was within 3 per cent of the actual ccs for all sites. The characteristic increase in ccs as the crop approaches the normal harvesting period, followed by the decline in ccs which normally occurs as temperatures rise and rainfall increases at the end of the harvesting season, was also reproduced by the model.

Experimental yields and model estimates for both cane yield and ccs at Kununurra in the Ord River Irrigation Area are presented in Table 3. The estimates of cane yield were within 7 per cent of actual yields recorded in the experiments although ccs estimates did vary by up to 16 per cent from the experimental data.

The model has therefore been tested in all of the main environments where sugarcane is, or is likely to be, grown in Australia.

It is important that the sugar industry accurately anticipate the consequences of major changes in farming and industrial practices such as those which are currently being proposed for the industry (Borrell and Wong, 1985, Connell and Borrell, 1987). Extending the crushing season, for example, may result in more effective utilisation of milling capacity, but the low sugar content of cane at the start, and at the end of the crushing season, combined with the effect on yield of the subsequent crop, if cane to be ratooned is harvested late in the season, could offset the possible gains.

The industry needs reliable methods to estimate the size of these effects and also needs to be able to examine possible ways of overcoming them by changes in varieties, through growing more stand-over cane, by changing fertilisation and irrigation practices, by the use of chemical ripeners, or by other changes in farming practices.

The sugar industry could use the model to assess the risks and the benefits associated with changing tillage, fertilizer, drainage, and irrigation practices, and harvest management. It could also be used to estimate the effects of adverse weather conditions and to predict cane yields and sugar content at the block, farm, mill, or regional level.

Evaluating land use options with simulation modelling

The model is now being used to evaluate land utilisation options in the Moreton Mill area of southern Queensland. This is a canegrowing area close to Brisbane where urban incroachment from a rapidly developing tourist and retirement centre is creating substantial problems for the sugar industry. The agricultural land within the mill area has been subject to two detailed assessments by staff of the Queensland Department of Primary Industries.

While adequate land resources are available in the area to ensure the survival of the industry in the medium term, these land resources vary substantially in their canegrowing capability.

From a planning perspective, there is value in using the information from the land use assessments as the basis for further analysis, using the AUSCANE simulation model, to determine production levels from varying combinations of land resources. The effects of climatic variability from year to year on variation in the overall level of cane supply is also worthy of detailed study.

Moreton Mill Area Study

Alternative land use options in the Moreton Mill area will be evaluated by a series of experiments using the simulation model AUSCANE and this will provide valuable new insights into the physical and economic impact of changes in policies and practices now being proposed for the sugar industry. The Moreton Mill area will be used as a pilot study, however the procedures developed for this study will be generally applicable to all other canegrowing districts.

This study is designed to reflect the response of a whole mill area, comprising 130 farms, to changes in the mix of land resources, farming practices, and industry policies which are superimposed on a canegrowing environment that is characterised by a high level of climatic variability.

At the present time, cane is produced from the following soil types:

Soil type	Per cent of Mill area
Humic gley	41
Peaty gley	23
Humus podzol	11
Yellow podzolic	16
Red earth/Earthy red podzolic	5
Krasnozem	4

Basic climatic data from at least five stations within, or closely adjacent to, the mill area are available to describe the weather variables required for the study.

The land resources available for expansion of canegrowing in this mill area have been mapped by the Department of Primary Industries (Capelin 1979) with the conclusion that the main area for expansion comprises coastal lowland soils with a very high sand content. These humus podzol soils currently comprise only 11 per cent of the mill area. This group of grey-brown soils have uniform texture, with organic matter in the surface layers and quite low water holding capacity. There is a cemented hard pan at a depth of 70 cm. They also suffer from severe phosphorus and potassium deficiencies and they respond to applications of calcium and magnesium so that fertilizer costs for cane grown on this soil type will obviously be higher than for other soils that do not have such extensive nutrient deficiency problems.

On the positive side, cane grown on these soils is usually above average in ccs.

While this group of soils has a short canegrowing history, they have an important long-term role in the future of the industry in this mill area.

Simulation as an optimising technique

It is generally considered that the use of simulation as a management aid is restricted by its limited ability to indicate optimal management policies. Although simulation is not primarily an optimising technique, various methods have been devised to determine management policies that are optimal, near-optimal, or at least improved with respect to existing policies. The comparison of management alternatives usually takes the form of a search over the spectrum of feasible alternatives. The performance of the system is simulated for various combinations of the controllable variables. The search pattern may be viewed as an experimental design and the controllable variables as the experimental factors.

Methods for determining optimal policies by simulation studies are generally divided into two groups depending on whether the analyst predetermines the pattern of search or specifies the procedure by which the steps will be selected. The first group contains various well established experimental designs, e.g. factorials. They may be used to compare a fixed set of policies, to locate a response surface, or to relate various measures of performance to appropriate input variables.

In the second group, the search steps are selected within the simulation run. Two possibilities exist. Levels of each controllable variable may be chosen at random, as in Monte Carlo programming methods, with each set of inputs being selected independently of previous solutions. A large number of solutions may be obtained in this manner and these may be subsequently ranked according to specified criteria. A modification of this method is to adjust the probabilities of selecting those variables that consistently result in higher performance during the computer run, so that selections are concentrated most heavily in a particular region (Eisgruber and Lee 1971).

The alternative involves progressive adjustments of the controllable variables in those directions that lead to an increase (or decrease if appropriate) in the value of the objective function. Each new case to be examined is explicitly related to the cases that have previously been evaluated during the search.

There are a number of such "hill-climbing" methods, including steepest ascent, parallel tangents, and contour tangent elimination (Wilde 1964), and a selection of these will be used in the study to try to identify the most efficient. The simplex procedure (Meier 1967), which should not be confused with the simplex method of solving linear programming problems, and the method of conjugate directions (Emshoff and Sisson 1970) have also been suggested for simulation studies where optimisation is the objective. More recently, quasi-Newton methods have been developed for problems that involve maximisation or minisation of an objective function (Broyden 1977).

Selection of the appropriate search procedure for this particular study has not been decided although a number of the methods mentioned will be tested in an attempt to identify the most efficient for this type of study. Some guidelines have been laid down by previous investigators (Harrison 1976, Powell 1964). The evidence suggests that designs which simply enumerate alternatives, e.g. factorial designs, or employ random search methods and improve one variable at a time, are quite inefficient and often give unreliable results.

Random search methods (perhaps with adjustment of probabilities) may be the only workable alternative where variables are restricted to integer values. While steepest ascent has been used in a number of economic simulation studies (Toft 1970, Zusman and Amiad 1965), it is regarded as a relatively unsuccessful approach. Methods that involve improving one variable at a time appear to be least successful when a high degree of interaction exists between variables. The simplex procedure appears quite satisfactory for a small number of variables but it is less satisfactory if more than three variables are considered. The method of conjugate directions is judged to be relatively efficient and also highly robust. Quasi-Newton methods seem to be the most efficient of all those devised to date although they are still subject to failure on certain problems.

The choice of search procedure is influenced by the nature of the problem to be analysed. The presence or absence of constraints on the variables, e.g. the limited area of each class of land suitable for cane production, is important in determining the most appropriate search procedure. In general, problems that involve optimisation of constrained variables are more difficult to analyse, and they require more sophisticated procedures, than those where the variables are unconstrained. Where constraints are present, these may sometimes be removed through the use of transformed variables or by barrier - penalty functions.

Options to be considered for simulation

The effect of changes in three groups of controllable variables will be assessed using the simulation model. These groups comprise:

- changes in the land resources available for growing cane
- changes in farming practices
- changes in industry policies

Land resources

Some of the existing land used for canegrowing in the Moreton Mill area is under threat from urban encroachment but the mill owners have shown a desire to remain in production, and to expand if possible, so that the opening of new areas for canegrowing is being considered. Investigations by the QDPI Division of Land Utilisation show that most of the land that could be used to expand the area under cane which comprises a soil type that is not currently used to a great extent for canegrowing, and was not used at all for that purpose, before the 1980-81 expansion of the industry.

The various soil types identified in the land use studies, their associated climatic limitations, and accepted farming practices, particularly in regard to cane varieties selected because of their suitability to certain soils, will constitute major constraints in the simulation model.

Farming practices

To some extent as already indicated, farm practices are also determined by soil type, e.g. underground drainage is essential for satisfactory crop production on some soils but is not required in others. Irrigation is not normally used for cane production in this mill area.

The level of fertilizer applications are also affected by soil type as the data on the following table shows. These figures summarise farmers' existing fertilizer application practices.

Major fertilizer inputs revealed by farm survey

Soil type	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Humic gley	200	25
Peaty gley/ recent aluvium	180	20
Humus podzol	240	30
Yellow podzolic	200	30
Krasnozem, Red earth, Red podzolic	180	25

Source: Kingston and Linedale, 1987

Because of reduced sugar prices over the past seven years, canegrowers generally have reduced fertilizer application rates. Although these reductions have not resulted in any apparent yield decline, a continuation of this practice would ultimately affect productivity. The interaction between fertilizer inputs and climatic variability needs to be modelled in order to evaluate the level of risk associated with fertilizer decisions.

Canegrowers have only limited control over the final yield and sugar content of their cane crops at harvest because of the need to maintain a regular supply of cane to the mill throughout the crushing season. However, decisions regarding whether cane is burnt prior to harvesting or cut green, affect ccs levels and provide growers with the option, with substantial cost implications, of retaining trash after harvest, or using conventional tillage techniques, for weed control.

Industry policy

The BAE (now BARE) recently estimated that savings of the order of $50 to $130 million could be available to the industry by adopting different industry management policies (Borrell and Wong 1985, Connell and Borrell 1987). A newly introduced policy of the Queensland Central Sugar Cane Prices Board allows canegrowers to increase the area used for growing cane, although the strict industry policy on the area that can be harvested, remains. In places where land is not limiting, this new policy should allow growers to achieve a higher level of productivity.

Other changes being discussed within the industry could lead to an extension of the harvesting season beyond the 20 to 22 weeks now regarded as normal. Such changes would have profound effects on grower's incomes as cane crushed early or late in the season normally has lower sugar content. Harvesting of cane to be ratooned late in the season has substantial adverse, carry-over effects on the yield of the subsequent crop.

As recently as at last month's National Outlook Conference, the concept of appropriate pricing policies for "risk" sugar were again discussed. It was predicted that the industry could increase earnings substantially if there were adequate incentives for growers to produce sugar in addition to the requirements of Australia's usual buyers.

Objective function

One of the difficulties of simulation studies such as this where optimisation of policy and other objectives is attempted, is specification of an appropriate objective function. Harrison, in his study of the optimal growth strategies for farms in the Fitzroy Basin Brigalow area, developed a multi-dimensional objective function that included maximisation of expected terminal net worth, subject to satisficing levels of viability and consumption (Harrison 1976).

The objective function for this study could be specified in either physical or economic terms.

A physically based objective could be used to simulate a combination of options based on various levels of land resources, canegrowing activities, and industry policies designed to achieve maximum cane production subject to conditions such that the level of cane production in any one year should not be less than the average of the past 10 years, or perhaps be subject to some growth factor. Similar conditions could be applied to the level of ccs, and constraints setting a minimum level of cane to be available for crushing each week of the season may also be necessary.

Because maximum physical production is rarely consistent with economic efficiency, an economically based objective would be much more acceptable. Such an objective function would aim to maximise the net revenue from cane production from the whole mill area subject to similar constraints to those just described.

Aggregation problems

Another significant problem to be addressed in this study arises from the need to aggregate results from very small areas currently simulated by the model, (approximatelly one hectare in extent), to realistically represent the whole mill area of about 6 000 hectares. This area is comprised of six major soil types and is located over sufficient distance to warrant the use of data from separate climate stations for parts of the mill area.

Practical considerations dictate that cane has to be available at the factory continuously during a normal crushing season that extends from early July until mid- or late-November. Simplifying assumptions with respect to time of harvest will therefore be necessary to keep the number of simulations that are required to a manageable level.

Other crops

As an example of the application of simulation modelling to broad scale agricultural planning, preliminary versions of a simulation model based on AUSCANE have been developed for some crops that are currently not grown on a commercial scale in Australia such as kenaf and guayule. This research has shown that the model, when combined with appropriate climatic and soils data, can determine likely levels of yield for these new crops in parts of Australia where field trials have yet to be undertaken.

There are obvious advantages in locating the limited number of field trials that can be carried out before a new crop is established in those areas that have the greatest potential to produce economically viable yields. These areas can now be decided with a reasonable level of certainty using simulation modelling.

Experimental data may be extrapolated to other areas with greater confidence when simulation studies have shown acceptable correlations between model results and actual data from field trials or commercial production.

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Table 1: Comparison of average cane yields with model estimates

	Cane yield (tonnes cane per hectare)		
District	Average prodn 1977-86	Range	Model estimates (3 crop cycles)
Innisfail	78.6	66-96	82.8
Burdekin	112.7	103-120	100.7
Mackay	73.5	65-88	84.5 irrig
			59.7 unirrig
Bundaberg	81.0	74-93	82.5
Condong	85.7	82-90	47.6 one-year
			94.1 two-year cane

Table 2: Comparison of seasonal average ccs with model estimates

District	Average ccs 1977-86	Range	Model estimates (3 crop cycles)
Innisfail	12.7	12.1-13.5	12.6
Burdekin	14.5	14.2-14.8	14.3
Mackay	14.0	13.0-15.2	13.6 irrigated
			14.3 unirrig.
Bundaberg	13.6	12.3-14.4	13.4
Condong	11.6	11.0-11.9	10.3 one-year
			13.5 two-year cane

Table 3: Comparison of experimental yields and model estimates, Ord River Irrigatrion Area

	Cane yield		CCS	
	Expt	Model	Expt	Model
Plant cane	149.1	138.9	12.7	14.8
First ratoon	136.6	143.5	14.9	15.4
Second ratoon	125.4	133.3	15.0	15.9
Third ratoon	131.7	124.3	13.3	15.4
Average	137.5	135.0	14.9	15.4