WORKSHOP

SOIL CONSERVATION AND MANAGEMENT IN THE HUMID TROPICS

EVALUATING SYSTEMS OF SOIL CONSERVATION RESULTS FROM A BIO-ECONOMIC MODEL

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INTRODUCTION

Farming systems in the lowland humid tropics as elsewhere, are a consequence of the interaction of complex bio-physical and socio-economic relationships. Further, the time sequence of the flow of inputs, many of which are beyond the control of the farmer, and the flow of output results in the farmer operating in a dynamic, uncertain environment.

It is within such a conceptual framework that the evaluation of soil conservation and associated management strategies should ideally take place. However, whether the evaluation of alternative soil management strategies does take place within such a framework is affected by a number of consideration. Among the more important are:

a. the current state of knowledge concerning the relationships of the system;

b. the cost, time involved, and technical feasibility of gathering additional information; and

c. the techniques available for analysing the information.

Past attempts to evaluate soil conservation strategies have been limited for a number of reasons. First, the analytical models used were deterministic, no provision being made for the variable nature of the erosion process with its resultant influence on costs and returns and so on patterns of farm income through time. Second the data used were usually highly specific for example, with respect to management strategies, soil types and weather conditions which limited the generality of the conclusions drawn from the study. Third the models developed represented marked abstractions from reality, due in part to a lack of knowledge concerning system interrelationships but also due to computational limitations of the techniques used.

One means of overcoming some of the above restrictions is through the use of simulation techniques which are ideally suited to the analysis of complex systems [Dent and Anderson, 1971]. In a simulation study a model is constructed which is anticipated to behave in the same manner as the system does in the real world. The "performance" of the system under alternate input patterns and decision rules may then be studied in an experimental environment without actually incurring the penalties of putting the system into operation. There are of course, many difficulties associated with both model construction and subsequent experimentation. These problems include identifying the important variables defining the structure of the model: the availability of data for specifying relationships in the model; validation of the model and its components and the interpretation of results obtained from experimentation with the model.

In this paper a simulation model designed to evaluate various soil conservation practices is discussed. The study area for which the model was built is an intensively cropped region with a relatively high potential for soil erosion in the sub-tropical wheat growing areas of east-central Australia.

THE BIO-ECONOMIC MODEL

Figure 1, taken from Dumsday [1971], depicts the more important relationships included in the bio-economic simulation model of the soil conservation system. The circled factors in Figure 1 represent the points of entry into and exit from the system. For example, specification of soil type determines the internal factors of inherent soil erodability, infiltration characteristics and depth of soil horizons. The choice of cropping system implies a possible set of cultivation practices, sowing dates and so on. The factors of weather, cropping system, soil type, topography, management control practices, production costs, and input-output prices set the boundaries of the system to be synthesised. The values adopted for these factors, in association with the assumed bio-physical relationships between the internal factors, ultimately determine the output from the system of prime interest, in this case, net revenue.

Space does not permit a detailed description of the model which has been reported by Dumsday [1971, 1973]. Suffice it to mention that the model was based largely on data and relationships reported by Australian Fertilizers Limited [1968], Boughton [1965], Fawcett [1968], Flinn [1968],

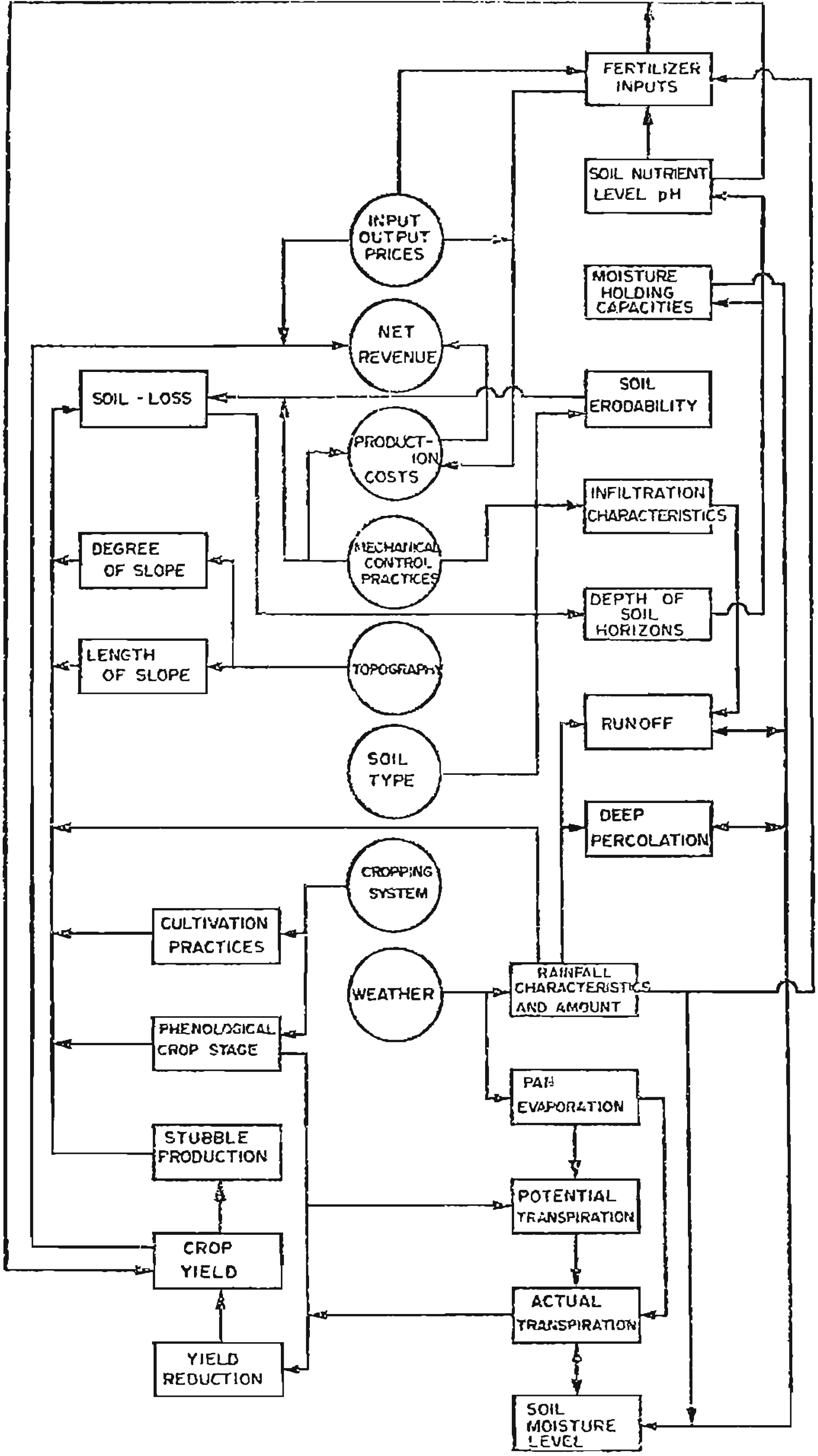

Fig. 1: Interrelationships of the soil conservation system

Wischmeier and Smith [1958, 1962, 1965], New South Wales and Queensland Departments of Soil Conservation and the Australian Bureau of Meteorology. The empirical form of these relationships are found, their use and limitations discussed in Dunsday [1973] (a copy is in the IITA Library). The more important relationships used in the rainfall-erosion component of the model are listed in Table 1.

Table 1 Relationships embedded in the erosion component of the simulation model.

Relationship	Source
weather sequences	from site and generated
kinetic energy of rainstorm, KE	W and S* [1958]
index of total storm erosion potential, EI	derived from met. data
inherent erodability of soil type i	W and S [1962]
expected ratio of soil loss, LS	W and S [1965]
LS and stage of crop growth	" "
LS under fallow/stubble	" "
LS under contour cultivation	" "
length limits for contour cultivation	" "
estimation of runoff	Boughton [1965]
stubble production	Fawcett [1968]

* W and S = Wischmeier and Smith.

The simulation model essentially consisted of two separate sections. The first dealt with bio-physical aspects of the system, the second with economic aspects.

The bio-physical section of the model was divided into three phases. The first phase inputs initial data concerning soil characteristics, topographical factors, mechanical control practices, soil plant relationships, plant-atmosphere relationships, soil loss ratios as related to stage of crop growth and stubble cover and potential crop yields for the specified soil type. The second phase of the section operated on a daily basis and was primarily concerned with computing, given the present state of the system, crop growth and soil loss as a consequence of the weather (pan evaporation and rainfall) which prevailed on that day. The only input to this phase was daily weather, which was either drawn from an historical sequence or generated from historical distributions. The final phase of the bio-physical section accumulated soil loss for each production period and adjusted the depth of each soil horizon to its value for the subsequent production period. The annual output of the model consisted of totals for climatic variables (evaporation, erosive potential of storm rain, rainfall) and system output (deep percolation, runoff, soil loss and crop yield).

The economic section of the model was initiated by setting prices for fertilizer inputs and crop outputs, costs of construction, maintenance and reconstruction associated with mechanical control practices, and those variable crop production costs which were held constant for a given simulation run. Parameter values were then specified for the fertility gradients of the soil profile, fertilizer response, proportion of land removed from production by mechanical control practices, and discount rates. The final inputs were the production data generated from the first section of the model. For each production period of the simulation run the model outputs were fertilizer allocation and discounted net revenue per acre for the specified discount rates.

SOIL MANAGEMENT PRACTICES

A farmer is faced with a large array of alternatives for manipulating those factors in his farming system which are under his control. The managers problem is to select within his constraint set, those policies or decision rules which, when implemented, assist him in moving towards his personal goals. When considering soil management, there are three groups of practices, discussed below, which will importantly determine the rate of soil loss, crop yields and as a result farm profits over time.

One set of decisions concerns the choice of length and type of summer fallow. Because much of the annual rainfall in the study area is received in the summer most farmers fallow their land at this time for 4 to 6 months. An increase in the length of fallow may, in many seasons, result in an increase in the quantity of moisture stored for use by the subsequent crop. However, there will also usually be a concomitant increase in the frequency of cultivations and in the exposure of soil to erosive storms.

For a given length of fallow the frequency and type of cultivation may be varied or intra-fallow cultivation may be replaced by chemical weed control.

A second set of decisions concerns the treatment of crop residues. Crop stubble may be mulched or burned. The effectiveness of stubble mulching in reducing erosion during fallow and the early stages of growth of the following crop will largely depend on the quantity of stubble which in turn varies with the production of vegetative matter by the previous crop. Disadvantages of stubble mulching may be an increased requirement for applied nitrogen and mechanical difficulties in cultivating where large quantities of stubble are present. (In the study area approximately 50 percent of farmers burn their stubbles while the other 50 percent practise stubble mulching).

The third set of decisions concerns the use of mechanical control measures. These measures included contour cultivation, contour strip cropping, and contour and graded terrace (or bank) systems. Terrace systems divide slope into discrete segments, effectively reducing slope lengths. Various terrace types, spacing and capacities will result in different levels of soil and moisture conservation and different costs.

In addition to the three sets of management decisions discussed above, the model takes specific account of the effect of soil loss on the optimal rates of fertilizer application. That is, the trade off between substituting fertilizer for eroded top soil could be assessed within the model.

DESIGN OF SIMULATION EXPERIMENTS

The model could be used to run numerous experiments to compare large number of treatments. However, in common with most research projects, available time and funds imposed limits on the amount of experimentation actually performed.

Each of the selected treatments were run over 5 separate 50 year periods using statistically generated weather data. The choice of a 50 year period was largely arbitrary, however a number of considerations led to the use of this time horizon. First, experience when developing the model had shown that the differences between most treatments had become established within a period of 20 to 50 years. Secondly, farmers in the study area seemed to regard 50 to 70 years as an upper limit to their planning horizons. Thirdly, uncertainty concerning future technological and economic change increases with time and has the effect of reducing the usefulness of information generated for distant time periods. Finally, for the non-zero discount rates chosen the relative weights assigned to net revenues became small by the time the fifth decade was reached.[1]

Ten "environments", Table 2 (which consisted of two soil types with various depths of A and B horizon, length and degree of field slope) and

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[1] Discount rates were chosen to represent a zero of time preference (0 percent), an opportunity rate of return on low risk investment (6 percent), medium risk investment (10 percent), and marginal investment (25 percent).

eleven management systems (Table 3) were selected to give 110 experimental treatments. The choice of environments covered extremes from low levels of erosion hazard (environments 4, 9) to high levels of erosion hazard (environments 2, 7) and was centred on modal combinations of soil depth and field slope for each soil type. The choice of management systems covered extremes from low (system 10) to high (system 9) potential rates of use of soil resources and was centred on management practices most likely to be relevant to existing or potential cropping systems for the study area.

BEST MANAGEMENT SYSTEMS FOR EACH ENVIRONMENT

The most profitable management system of those tested in each environment, at each discount rate, was selected on the basis of the mean and coefficient of variation[2] of the cumulative net revenue generated by the simulation model for a 50 year period. The management systems selected on this basis are presented in Tables 4 and 5 along with the mean soil loss and cumulative net revenue corresponding to each system. In general, systems incurring high rates of soil loss also suffered low mean levels of cumulative revenue and high coefficients of variation.

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[2] As the coefficient of variation gives a measure of the relative dispersion of outcomes about the mean, it was used as an indicator of the level of risk associated with a particular management system. Decision-making criteria which take explicit account of risk have been described [e.g. Dillon 1971, Dillon and Anderson, 1971] and could be employed in analysis of the output generated by the model.

Table 2 Experimental environments used in simulation runs.

Environment Number	Soil Type[a]	Depth of Horiz. A	Depth of Horiz. B	Length of Field Slope	Degree of Field Slope
		(mm)	(mm)	(m)	(%)
1	RBE	50	150	60	4
2	RBE	50	150	180	12
3	RBE	100	300	120	8
4	RBE	150	450	60	4
5	RBE	150	450	180	12
6	BE	100	300	120	2
7	BE	100	300	360	6
8	BE	150	450	240	4
9	BE	200	600	120	2
10	BE	200	600	360	6

[a] RBE = Red Brown Earth BE = Black Earth

Table 3. Management systems evaluated in simulation model.

Management System	Management Practices
1	a_1 b_2 c_2 d_3
2	a_2 b_2 c_2 d_3
3	a_1 b_1 c_2 d_3
4	a_1 b_3 c_2 d_3
5	a_1 b_2 c_1 d_3
6	a_1 b_2 c_3 d_3
7	a_1 b_2 c_2 d_1
8	a_1 b_2 c_2 d_2
9	a_2 b_3 c_3 d_3
10	a_1 b_1 c_1 d_1
11	a_2 b_2 c_2 d_2

Key to Management Practices

a stubble management
- a_1 stubble left
- a_2 stubble removed

b length of fallow
- b_1 2 months
- b_2 4 months
- b_3 6 months

c frequency of cultivation during fallow
- c_1 1 cultivation
- c_2 3 cultivations
- c_3 5 cultivations

d mechanical control practices
- d_1 terracing
- d_2 contour cultivation
- d_3 up and down slope (vertical) cultivation

It was apparent from the simulation output that, for all environments, management systems combining stubble burning with vertical cultivation (i.e. systems 2 and 9) produced marked reductions in net revenue and increases in soil loss relative to the results for other systems. These effects became apparent after relatively short (5 to 10 years) periods of time. It was assumed that contour cultivation alone was not effective in reducing soil loss for some combinations of slope length and degree of slope. Thus, for environments 2, 3, 5, 7, 8 and 10, the net revenue streams for management systems 8 and 11 were identical to those for systems 1 and 2, respectively.

A broad conclusion that may be reached from the results shown in Tables 4 and 5 is that the best systems for all environments tend to be those employing relatively low rates of use of soil resources. This conclusion held even for relatively high discount rates. However, the best system was not always that which minimizes soil loss (system 10), even for a zero discount rate. The break-even costs for minimizing soil loss, shown in Tables 4 and 5, are the cumulative net revenue, at each discount rate, for the selected system less that for system 10.

The adjusted break-even costs must also take account of the productive state of the soil resources at the end of the planning period. Thus, the standard formular for net present value was modified to take this fact into account. This adjustment resulted in management system 10 becoming the best system for environments 3 and 9 at zero discount rates. Other than that, the adjustments had little effect on break-even cost for minimizing soil loss.

Table 4. Break even costs for minimizing soil loss on red-brown earths.

Environment	Minimum Soil Loss	Discount Rate	Management System Selected	Soil Loss	Cumulative Net Revenue	Break-even Costs for Minimizing Soil Loss	Adjusted Break-even Cost
	(mm)	(%)		(mm)	($/ha)	($/ha)	($/ha)
1	14	0	10	14	693	0	0
		6	8	21	214	6	4
		10	8	21	139	12	12
		25	8	21	60	16	16
2	57	0	10	57	413	0	0
		6	10	57	127	0	0
		10	3	191	79	4	3
		25	3	191	49	32	32
3	29	0	3	101	1285	30	0
		6	3	101	452	67	64
		10	3	101	301	64	64
		25	3	101	135	50	50
4	13	0	10	13	2221	0	0
		6	8	14	718	12	11
		10	8	14	460	15	15
		25	8	14	193	16	16
5	50	0	10	50	1802	0	0
		6	3	250	612	41	32
		10	3	250	414	58	57
		25	3	250	186	54	54

Although an infinite adjusted break-even cost was associated with environment 10 at zero discount rate it could be expected that the differences between the net revenue streams for systems 1, 8 and 10 would not remain constant in perpetuity, and that system 10 would eventually prevail.

Table 5 Break-even costs for minimizing soil loss on Black earths

Environment	Minimum Soil Loss	Discount Rate	Management System Selected	Soil Loss	Cumulative Net Revenue	Break-even Costs for Minimizing Soil Loss	Adjusted Break-even Cost
	(mm)	(%)		(mm)	($/ha)	($/ha)	($/ha)
6	10	0	10	10	2216	0	0
		6	8	15	709	5	3
		10	3	24	455	10	10
		25	3	24	192	13	13
7	18	0	10	18	1847	0	0
		6	3	136	629	54	46
		10	3	136	420	64	63
		25	3	136	186	55	55
8	14	0	10	14	2888	0	0
		6	5	54	917	2	0
		10	5	54	587	14	13
		25	5	54	242	18	18
9	10	0	8	13	3246	45	0
		6	8	13	1040	26	26
		10	8	13	658	23	23
		25	8	13	267	17	17
10	17	0	1,8	122	3037	309	
		6	1,8	122	1004	153	153
		10	1,8	122	643	118	118
		25	1,8	122	265	71	71

As would be anticipated, management systems employing low (or near enough to zero) rates of use of soil resources were the best systems for all environments if production was considered in perpetuity and a zero rate of time preference was assumed. However, while these conditions meet the requirements of the "true" conservationist, many farm operators, and Governments, may for quite legitimate reasons, adopt non-zero discount rates.

For the non-zero rates assumed, the use of terrace systems (7, 10) is questionable for most situations. On the other hand, the best systems involved shorter periods of summer fallow than are commonly used in the study area. Chemical cultivation appeared in the selected systems for environment 8 (Black Earths), otherwise the best systems for Red-Brown Earths and Black Earths were similar. The benefits, in terms of moisture conservation, of heavy cultivation for weed control during the fallow period (system 6) appeared to be outweighed by the costs incurred through loss of soil structure. Contour cultivation, in the absence of other mechanical control practices, appeared in the best management systems for several environments.

SOIL CONSERVATION MODELS FOR THE LOWLAND HUMID TROPICS?

The model discussed above was developed for a sub-tropical region characterised by large (approximately 400 hectare) highly mechanised farms. In this region wheat is grown as a monoculture on land slopes seldom exceeding eight percent. Such farming systems are in stark contrast to the agricultural technology employed in the majority of the lowland humid tropics of West Africa. Here most farms are small (less than 2 ha.), labor intensive with systems of inter and relay cropping; shifting cultivation is used to restore soil structure and fertility.

Obviously the simulation model cannot be transferred without drastic modification, even if the data were available, from the large holder of the sub-tropics to the small holder of the humid tropics. However, the model may without structural change, be applicable to assess the economic and soil loss consequences of large scale, sole crop, mechanised farms being developed by Governments and private enterprise in the high forest and derived savannah zones of West Africa. The problem of course, of using the model, even for these "commercial farms" in the L.H.T. is the paucity of relevant crop, weather and economic data.

Yet, these data constraints are becoming less of a bottleneck. The work for example, of Roose [1967] and Lal [1975] among others, to relate the erodability of a storm to crop and soil conditions in West Africa is providing the class of information required for predictive crop-erosion models to be developed. Further, advances made in statistical generation of weather data from limited weather records [e.g. Phillips, 1971] may result in the lack of long term weather records not being a major impediment to the computer testing of various soil management strategies.

The type of erosion control practices appropriate to larger farms may be completely irrelevant for the smallfarmer who is likely to continue intercropping and shifting cultivation for several decades. Conservation systems for the smallholder will probably need to rely on the selection of crop, mulching, weed control and cultivation practices, and the timing of these operations for their success as opposed to the use of structural erosion control measures. The need to cater for a large number of crops, cropping systems, forms of cultivation and crop residue management will undoubtedly make the required bio-economic models more complex than the one reported, in addition to making it costly and time consuming to assemble the empirical data.

When developing a crop-soil erosion simulator for tropical systems, two assumptions not bio-physical in nature, reasonable in the sub-tropical model are questionable for the small farmer system. First, in the model reported, the present value of the net income stream was the choice criteria for selecting the most preferred soil management practice. The nature of the smallfarmers preferences may suggest an alternative choice criterion (e.g. that which ensures stability of food production over time; minimises labor or capital expenditure subject to a threshold level of output, etc.), to be more appropriate. Second, given the constraints faced by the smallfarmer -- those of liquidity, scarcity of labor and often land, suggests that the nature of the erosion technology tested should be neither capital nor labor intensive. This fact may be particularly important as it appears that many smallfarmers do not regard erosion as one of their major farming problems [Williams et al. 1975].

In summary, both conceptual and data problems exist when developing simulation models of soil conservation systems for the smallfarmer. This does not infer that the time is not ripe for soil scientists, agronomists and economists to pool their expertise to develop such models. Simulation models may be constructed from data collected from a variety of sources, hence progress can be rapid this feature represents one of the chief advantages of simulation methods [Angus *et al*. 1974], especially for regions which do not have a long history of agricultural research. Often these are the same regions for which the pressures on agriculture are greatest. In such regions the continual demand for new and more successful crop production systems can make life very difficult for agricultural researchers relying on field and laboratory methods. The increasing availability of computer systems should enable these researchers to complement more traditional research methods with simulation procedures. This approach offers the possibilities of:

a. increasing the number of new cropping systems that may be examined for a given bundle of research resources.

b. reducing the time taken to obtain information on system performance under varying economic and weather conditions.

c. markedly reducing the time and research resources required to examine the long-run bio-economic effects of systems aimed at soil conservation and

d. providing the basis for more purposive field and laboratory research.

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