6 Can crop models contain economic factors?

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6.1 Introduction

Crop simulation is currently in the limelight: papers on modelling studies proliferate, conferences on agronomy and crop physiology devote significant sections to models, and simulation is the vehicle for extrapolation in impact studies. The reasons for this attention are easy to identify: models are getting better, more environmental data are becoming available, computers abound, and the number of scientists trained in systems-thinking is increasing.

The scientists who model crops are enthusiastic about this development, but prudent research leaders ask: can crop models contain economic factors? I will address this question in two ways: by extrapolating the evolution of crop models of de Wit's school, and by examining the nature of crops. I shall then consider how crop models can support decision-making and, finally, whether economic models should include crop models.

The socio-economic conditions in poor countries are often unfavourable for agricultural production. How socio-economic factors can be integrated with crop modelling studies is therefore a particularly relevant question to justify crop modelling in developing countries (e.g. Randhawa & Venkateswarlu, 1990).

Whereas models provide insight and information that can be used to improve management, they do not change things by themselves: something still has to be done. A relevant question, therefore, is whether crop models can provide information that can improve decision-making in regions where socio-economic constraints are dominant. The answer is 'yes': crop modelling can support farming indirectly by being a source from which guidelines, diagrams, and extension service advice can be derived, and by enabling explicit alternatives for agricultural development to be drawn up.

For the purpose of this chapter, I define a crop model as a dynamic model to simulate the behaviour of an agricultural crop, including soil and pests if necessary, and will restrict myself to arable crops. The crop environment consists of weather conditions, soil conditions and pest levels when these are not part of the model, and of crop management expressed as the choice of crop, planting date and physical inputs. A crop model has a narrower focus than a cropping systems model. I will use the term 'crop model' for models that are adequately evaluated and documented. Yet, it may be emphasized that careful testing and evaluation remain essential when models are applied to new situations.

6.2 Evolution of crop modelling

Crop modelling has been evolved in various parts of the world by several groups of researchers; I choose de Wit's school for illustration. One of the first dynamic crop simulators was developed by de Wit and co-workers (de Wit et al., 1970). The ELementary CROp Simulator contained a detailed canopy photosynthesis section, an elementary component on organ growth rates with the shoot-root equilibrium concept, and preliminary ideas about crop respiration. Improving the basic descriptions of processes in ELCROS led to the comprehensive BAsic CROp Simulator (de Wit et al., 1978). ELCROS, and BACROS to a smaller extent, contain little of traditional plant physiology, but are quantitive, whole-crop physiology models. Both models have their roots in sciences basic to crop physiology, as is shown by the field of the professional journals in which de Wit and his colleagues have published: biology, plant physiology, agrometeorology, agronomy, theoretical biology, ecology, soil physics, optics. To ensure scientific integrity and robustness, the 'explanatory' approach to crop modelling was followed: the nature and regulating mechanisms of basic processes are analysed, quantified and modelled (de Wit, 1982). The open structure of such models allows interactions with other disciplines.

A research project in a semi-arid region was the testing ground for coupling an ELCROS-type model to a water balance model by a root–water uptake interface (van Keulen, 1975). Crop physiology and soil physics have since been combined fruitfully in models in many studies, such as in the semi-arid (Stroosnijder, 1982) and semi-humid tropics (Penning de Vries et al., 1989).

Modelling nutrient dynamics in soils and crops started later. It developed more slowly, since the biological and soil chemical processes involved are difficult to measure and because soils are heterogeneous in complex manners. The 'three quadrant figure', a static model relating crop yield to applied and to absorbed nitrogen (de Wit, 1953; van Keulen, 1982), is still an important practical link between crop models and soil fertility. Comprehensive dynamic models were published recently on aspects of the dynamics of nutrients in soil and crop (van Keulen & Seligman, 1987; Leffelaar, 1987; de Willigen & van Noordwijk, 1987). It is expected that summary models will be derived from them in the near future for application on a wider scale.

Micrometeorology was associated with crop modelling from the outset, as evident in de Wit's early work (1958; 1965), which aimed at thoroughly understanding the transport processes involved (Goudriaan, 1977) so that canopy photosynthesis and transpiration could be simulated in a dynamic fashion. In addition, the insight obtained in stomatal regulation (Goudriaan & van Laar, 1978) is now used when simulating the impact of high ambient CO_2 levels (Goudriaan, 1986) and of air pollution (Kropff, 1987).

Interactions with the disciplines mentioned earlier benefited from the increase in physiological detail in models. Linking crop modelling with crop protection sciences benefits particularly from summarized comprehensive models, such as

SUCROS (van Keulen et al., 1982; Spitters et al., 1989). Deriving relations between infestation level and crop damage with such combination models appears to be effective (Rabbinge et al., 1989), and I expect many more such studies to be performed.

De Wit's baseline 'no experimentation without evaluation' and opportunities to apply crop modelling in developing countries provided a strong push towards the interaction of sciences and modelling (van Keulen et al., 1982; Penning de Vries & Djitèye, 1982; Alberda, 1984). Interactions also developed with other disciplines, including plant ecology (Spitters & Aerts, 1983), grassland management (Lantinga, 1985) and forestry (Mohren, 1987).

This glance at an evolution in two decades of crop simulation by de Wit, his collegues, students and visiting scientists demonstrates clearly that crop modelling interacts with an increasing number of disciplines. Is it a matter of time until crop models include socio-economics?

6.3 Crop modelling and economics

The number of disciplines associated with crop modelling is increasing, but concluding from that by extrapolation that 'economics' and 'sociology' are next on the list is not valid. Extrapolation does not recognize that crop-related modelling in the disciplines mentioned looks at crops in homogeneous fields where key processes have time coefficients in the order of hours to days. An economic system, such as an arable farm, deals with crops at significantly larger temporal and spatial scales: a farm may consist of several fields with different crops, and whereas interactions between farmers and crops occur only a few times during the season, they span periods of many years. Farmers cannot and should not be included in crop models as state variables. Why?

At any given moment, the rate of growth of a crop depends exclusively on the condition of the crop and on its physical, chemical and biological environment. Crops respond to concentrations of soil nutrients and to weather conditions, and pests reduce growth. But it matters not what process causes these environmental conditions to be at a particular level, or who controls them. (For instance, whether urea is expensive or not does not affect the crop response to it, and whether weeds are eliminated by women or chemicals does not matter either. There is a marginal and indirect effect, at the most, such as that on the availability of the applied nitrogen: more careful placement if expensive, and on damage to crop plants: less in handweeding.) Sociological and economic factors never interact directly with plant growth. Sowing, transplanting, thinning and harvesting, it may be argued, are activities by which farmers affect the crop directly. These activities are boundary conditions or prescribed rules in crop models, rather than dynamic, interactive processes. Hence: economic and sociological factors are no real part of crop models.

Moreover, crop models *should not* prescribe the behaviour of farmers. Prescription would take away their freedom to choose between alternatives, the development of which is one of the challenges to crop modelling. Modelling farmers would defeat the purpose of the exercise.

If crop models cannot include socio-economic factors, what relevance can be attributed to crop models (outside the area of agricultural research itself)?

6.4 Crop modelling and decision support

Farmers use a range of information for management: about the farm (soils, labour, equipment), about the state of the crops, the climate, soil fertility and pest problems, availability of irrigation water and fertilizer, about prices and markets (Figure 24), and for all these factors they consider both values and anticipated future values (PAGV, 1987). Some factors are fairly constant (land area available, land quality, machinery, crop characteristics), whereas others are variable (weather, pest level, future prices). Crop modelling can provide some of the information required for efficient farm management in the short and long run, and is particularly powerful with regard to variable factors. In the following paragraphs I shall show how crop modelling and socio-economics can interact to support farm management and agricultural development.

Decisions in farm management can be categorized as 'operational', 'tactical' and 'strategic'. Each of the categories relates to groups of processes with impacts over relatively similar scales of time and space. Operational decisions on arable farms relate to choices during a cropping season, e.g. about irrigation dates, intensity of fertilization, timing of insecticide spraying. Tactical decisions relate to choices made once per cropping season, such as species planted, date of sowing, yield targets. Strategic decisions have impacts during subsequent cropping seasons, such as those on investments in machinery, on improving fields and infrastructure, on education and training (Table 4).

6.4.1 Tactical decisions

Before the season starts, the farmer makes a production plan. He considers the available land, capital, tools and labour, seed stocks, climate and prices, and then decides on crops to be planted, how many hectares to plant, target yields, input levels and loans.

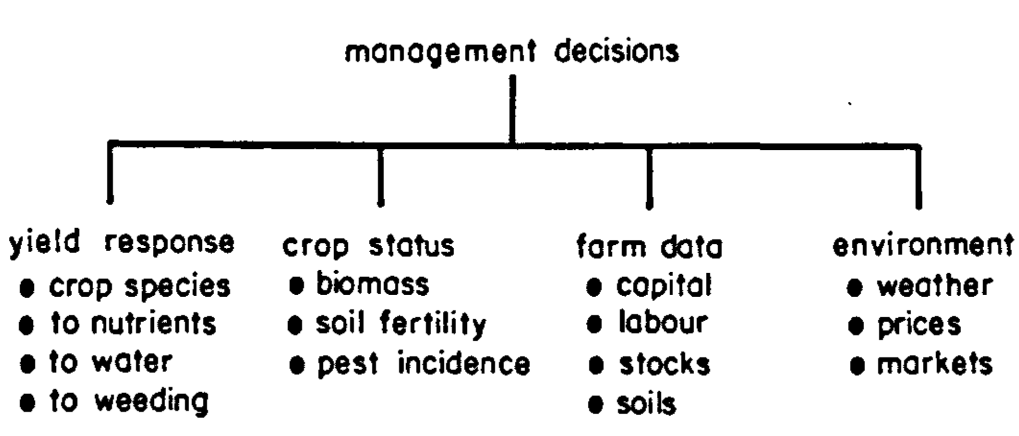

Figure 24. Types of information used for decision-making on farms.

Table 4. Levels of decision on arable farms.

	Impact on crop growth lasts	Typical decision
Operational	1–25 days	Weeding date
Tactical	5–50 weeks	Species sown
Strategic	0.5–10 years	Land improvement

How does crop modelling support tactical decisions? Modellers can generate guidelines in the form of rules, equations, tables, charts or maps, for aspects such as potential yield related to planting date, periods with increased risk of drought, and economic thresholds for pesticide application. Guidelines can be presented to farmers in various ways: as an aid to identify the crops that, on average, provide the highest yields, to set financially optimal target yields, and to calculate levels and timing of fertilizer and irrigation that correspond with the targets. Explicit and quantitative guidelines should be helpful when new opportunities arise (new crop types, irrigation facilities) or conditions deteriorate (lower prices, decreasing pest resistance) and farmers cannot rely on experience when making tactical decisions. This applies to developing countries where agriculture is evolving rapidly.

Using guidelines may be called 'indirect' support for decision-making. The guidelines are based on average weather, soil and crop data. Simulation for specific locations and situations may be called 'direct support'. This is still restricted to experimental stations, but it is moving towards intensively managed farms (Challa, Chapter 8). A few examples of support by modelling for tactical decision-making illustrate my point.

The first example relates to risk. Simulation of sorghum yields as a function of rainfall, soil type, crop duration and crop management provided charts of expected yield levels for first and second plantings at specific locations and sowing dates (Huda & Virmani, 1987). Long series of historical weather data were used, so that variability could be quantified as probabilities of attaining certain yield levels with specific planting dates. Guidelines can help farmers to consider risk in tactical decisions.

The second example is a survey of potentials for soya bean production, a new crop in the Philippines. A crop model was adapted to and evaluated for soya bean in rice-based cropping systems (Penning de Vries et al., 1990). It simulates yields for four situations: rainfed and irrigated upland, rainfed lowland and saturated soil moisture culture (Lawn et al., 1986). By simulating year-round monthly sowing for sequences of 20 years with different weather patterns, the relations between yield level and sowing date that have a 75%, 50% and 25% chance of being exceeded are established (Figure 25). Analysis of cost (labour, inputs, land) and benefits (harvested pods, increased soil nitrogen) gives the potential net profit (Figure 26). Even when rice remains the first crop planted, there is a window of

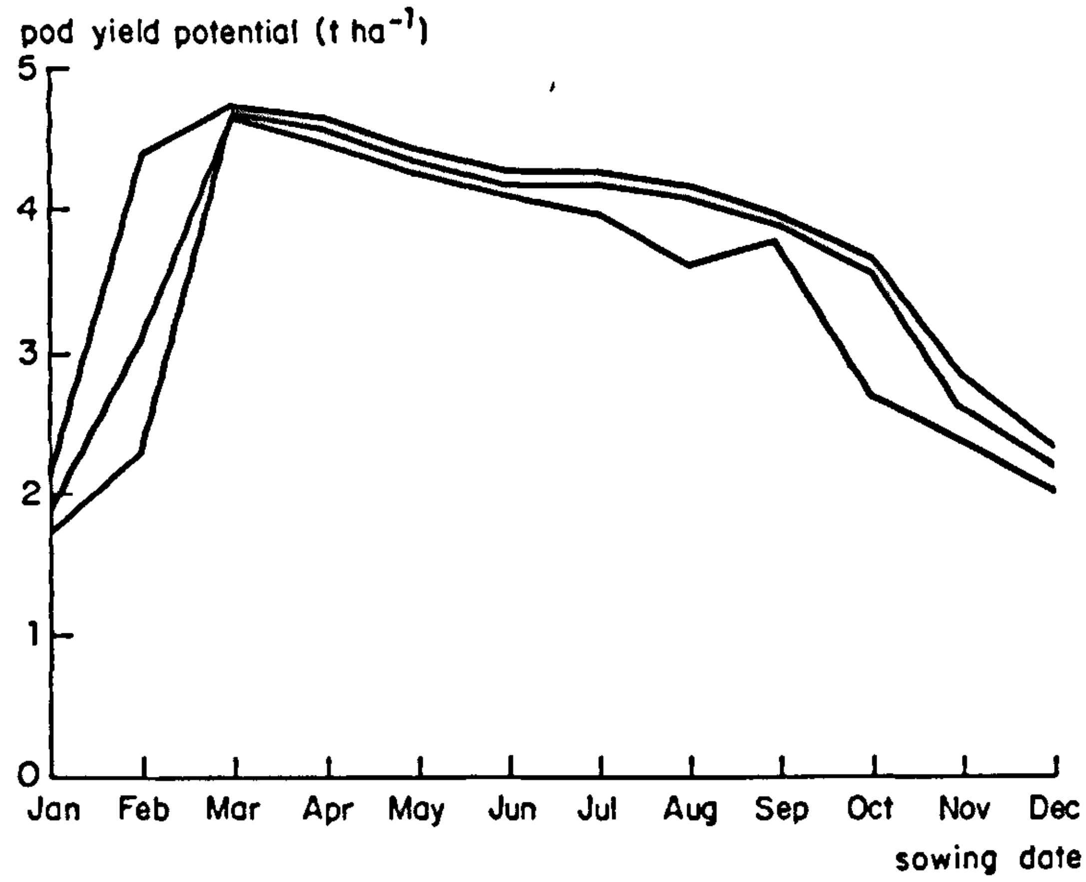

Figure 25. The simulated potential yield of soya bean on rainfed upland in Baguio, the Philippines, as a function of sowing date. The lines represent yield levels with a 25% (upper line), 50% (middle line) and 75% (lower line) chance in any year of being exceeded. The seasonality is due to temperature and precipitation fluctuations. Source: Penning de Vries et al., 1990.

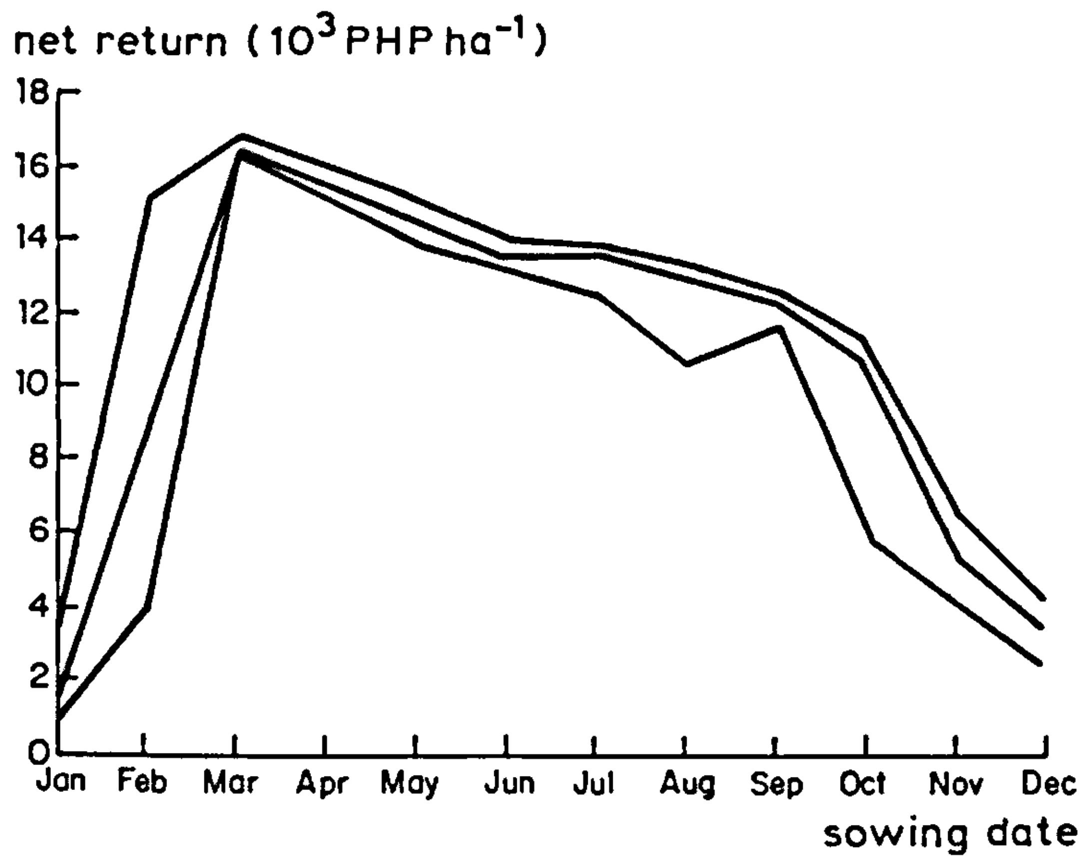

Figure 26. The simulated potential net profit of soya bean production (in 1000 PHP ha^{-1}) that corresponds with 80% of the values of Figure 25 (20 PHP is approximately 1 USD). The lines represent profit levels with a 25% (upper line), 50% (middle line) and 75% (lower line) chance in any year of being exceeded. Source: Penning de Vries et al., 1990.

two months to grow soya bean profitably at this location on deep soils. On shallow soils, however, the window lasts only a few weeks (not shown). From such charts, farmers and agro-industries can draw conclusions with respect to planting date, turn-around time, crop duration. If the potential result is positive after comparison with the potential for alternative crops, research can focus on specific soya bean problems and develop improved technologies.

The third example is an advisory model for farms (Dowle et al., 1988). It simulates annual grass production as a function of latitude, average rainfall and method of grassland exploitation. The output is grass production and growth of sheep and cattle, both in weight and financial value. The model is intended to help farmers in the U.K. to set their annual production plans by trying alternative schedules and choosing the one that fits best.

6.4.2 *Strategic decisions*

Crop models similar to those for tactical decisions can help to prepare strategic decisions. But they are now being used to investigate a wider range of options (different crops, production levels, etc.) over longer time periods and for future conditions that are more distant and less certain. Year-to-year variability is an aspect, particularly with unreliable rainfall. Different scenarios of developments in the production environment can be considered in simulation studies for devising a strategy for successive farm production plans and major investments. Since the future environment is less certain, intuition plays a larger role than in the case of tactical decisions. Dynamic models on sustainability and environmental issues, such as on soil fertility (Wolf et al., 1987) and soil erosion (Haith et al., 1984) may also contribute information for strategic decisions.

At a regional scale, crop simulation, economics and sociological considerations can complement each other to make explicit the realistic alternatives for crop production in a certain area, with crop modelling providing many of the essential input/output relations. Linear programming is used for choosing between the alternative opportunities. Flinn et al. (1980) concluded that their economic multiple goal linear programming model for farms needed results from crop production studies to become more practical.

My first concrete example refers to crop models used by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT, 1985). Among others, IBSNAT uses 'systems analysis and soil, crop and weather models to predict the performance of crops and management systems'. Collaborators are encouraged to collect basic data and evaluation data in standard formats. The crop models include aspects of the soil water balance and fertility. The authors state that their models allow predictions of crop potential and performance at locations where the crop has not yet been grown. Whereas this statement may be overly optimistic for the current state of these programmes, in the hands of skilled users crop models increase the number of options for cropping that can be assessed.

A second example is MIDAS, a Model of an Integrated Dryland Agricultural System (Kingwell & Pannell, 1987), a whole-farm mathematical programming model of the agricultural system of Western Australia's eastern wheatbelt. The purpose of MIDAS 'is to provide a model to answer, from the perspective of the whole farm system, questions posed by researchers and extension workers. The model needs to account for the whole farm objective of profit maximization, the many alternative but feasible uses of farm resources, financial and resource constraints, and biological and other farm relationships'. A crop model was used to establish some of the input/output relations. A wise footnote is that 'to be effective, the model needs not only to be accurate but also to be seen by end users to be accurate, relevant and complementary to models stored in their minds', such as their concepts of the socio-economic system in which they live.

For a third example, I choose recent work done by de Wit and his colleagues. They developed and applied a particular form of finding optimal solutions for land use planning (de Wit et al., 1988; van Keulen, Chapter 15). Both the temporal and the spatial horizon are wider than individual farms. The approach encompasses an extensive use of input/output relations obtained by simulation and aims at quantifying concrete alternatives for agricultural land use, both in diversity and intensity, for agricultural planners and researchers. Using Interactive Multiple Goal Linear Programming, their program determines the best mix of activities to reach one of several main goals, while secondary goals are met at a minimum acceptable level. In a study in Egypt, these goals were employment, income and extent of pastoral land use (Table 5). Optimizing successively for these goals yielded alternative options for agricultural development. The cost of meeting one goal can then be expressed in terms of reaching fewer the other goals. The possibilities, limitations, and acceptance of this promising technique need to be ascertained.

Table 5. Upper and lower limits for three goal variables in a region of Egypt over a 15-year period.

Goal maximized	Values of goal variables		
	consumable income (USD 10^6)	employment (10^2 person-year)	traditional systems (10^3 ha)
After one set of iterations			
cons. income	197	135	112
employment	50	192	100
trad. systems	50	58	742
After two set of iterations			
cons. income	144	113	600
employment	90	131	600
Final result			
cons. income	135	125	600

Source: de Wit et al., 1988

6.4.3 *Operational decisions*

Farmers use agronomic information for day-to-day planning when production plans have to be adjusted to unusual weather, outbreak of pests, break-down of machinery or other disturbances. To redress the situation, farmers irrigate, fertilize, spray, or hire equipment. Agronomic information that permits farmers to choose the best alternative in terms of yield, resource use efficiency and profit must be presented in a comprehensive form and consists of guidelines (i.e. rules, equations, charts, tables). Such guidelines are usually summaries of crop responses derived from field trials, but they can also be obtained by simulating crop growth under different environments and management inputs.

Deriving guidelines for operational decisions is not yet common, but it seems that crop modelling has a large potential for this use, particularly for countries with rapid changes in agriculture and with too few experimental stations to address all local differences. Calibration can to a limited extent (if done by experts) replace parts of models that are still weak.

Expert systems that support operational decisions on farms are being developed, in which the expert knowledge consists of facts, guidelines and even dynamic simulation models (J.R. Lambert, personal communication). They could become part of expert systems for advising and training farmers and the extension service (Heong, 1990).

One example of indirect use is the advice on irrigation in different climatic zones (Doorenbos & Kassam, 1979); the guidelines were derived with a crop–soil model. CROPWAT (FAO, 1988), a successor to this study, is a crop model to compute irrigation requirements for specific situations. It can be used on personal computers by farm managers.

Another example is the comprehensive formula for calculating grass production on grazed land (Lantinga, 1985), which was derived by simulation. It is used to determine the optimal cattle stocking rate.

Real-time indirect decision support, using up-to-date or forecasted weather instead of average data, could become an interesting form of application of crop models. It would permit general guidelines to be adjusted to current weather conditions, and be of particular value for regional advice on crop protection and irrigation. Zadoks & Rabbinge (1989) indicate that in the Netherlands modelling supports protection of field crops by supplying computer-generated guidelines shown on TV or provided by telephone service. The dissemination by mass media (radio, newspaper) of general guidelines and of adjustments related to actual weather may become practical in developing countries (S.K. Sinha, personal communication). Optimizing nitrogen fertilization with crop models, however, has not yet been successful (van Keulen, personal communication).

'Real-time' crop modelling can help in yield forecasting for operational decisions by government organizations. The Department of Agriculture in the Philippines, for instance, uses a modelling project to predict the rice yield before the harvest (F. Lansigan, personal communication). In the future, dynamic crop models may support operational decisions on farms in well monitored and controlled situations by simulating crop and soil processes with time steps of hours or less. Challa (Chapter 8) elaborates this for glasshouse crops and Seligman (Chapter 14) for a cotton irrigation model. Such models demand much field-specific data and real-time information on variable conditions of crop and environment. However, it may be that summary models, derived for specific objectives, are all we need, even for these conditions.

6.5 Economics and crop modelling

Let me finally reverse the question raised by the research leader in the introduction (Section 6.1) and ask: have crop models a place inside dynamic agro-economic models? I will argue that the answer is 'yes', and present two examples. In economic models that simulate water consumption, crop growth could be simulated dynamically. Calibration of certain parameters, derived from specific experiments or observations, is probably often necessary to ensure that realistic results are obtained. The crop model should be a summary model, containing only the most significant processes and components, to prevent the total model from becoming biased in the attention it pays to certain aspects and in its data requirements. Unfortunately, summary crop models are still weak in dealing with soil fertility and pest damage.

One model simulates day-to-day water distribution to and use on fields at different distances from channels in a diversion irrigation system in the Philippines (Rosegrant, 1985). The background to this study is the concern for the efficiency of irrigation systems, and the hypothesis that 'improved management of water distribution could improve both the total benefits from the system and the distribution of benefits'. The model consists of three parts: water distribution among irrigation channels, a farm level water balance model, and a farm decision component. Simulation of water balances for several years provided an average number of stress days in the fields. Rice yield per field is obtained with a regression equation, and net income is derived from yield and associated inputs. The equation is based on more than 3000 trial results and contains 11 variables, including the number of stress days. The model simulates two alternative irrigation schedules: continuous supply to all fields (head fields get more water than tail fields) and rotational irrigation (in turn, every field gets a full supply). Rosegrant concludes that income distribution would be more equal for the rotational pattern, but that the total production remains almost the same. The study is being extended to other parts of Southeast Asia (IFPRI, 1988).

A key relation is the response of yield to irrigation. Our crop–soil model (Penning de Vries et al., 1989), calibrated to attain at the full-irrigation yield levels (mimicking nutrient shortage and pests), produced curves somewhat different from Rosegrant's (Figure 27). This is at least partly due to the nature of the curves (average, versus a particular case). The simulated unirrigated dry season yield could be low because a water table may have been set too deep (1 m in the dry

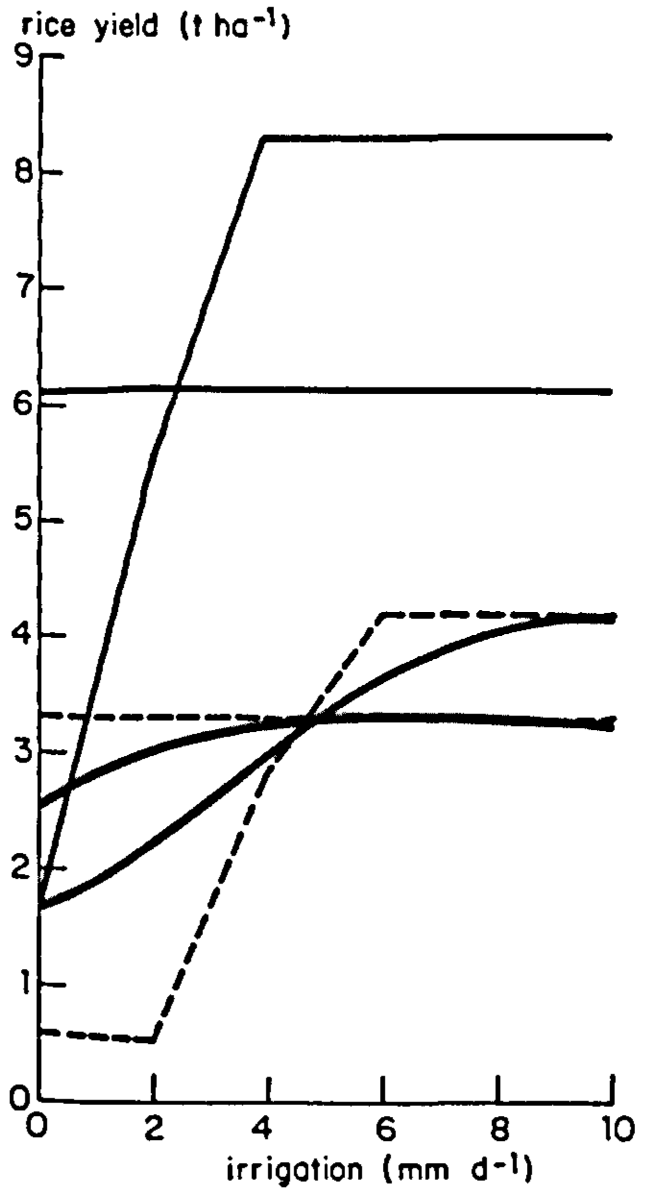

Figure 27. Response curves of rice yield to water supply in an irrigation system in the Philippines. Bold lines are from Rosegrant (1985); the light (rainfed potential) and broken lines (calibrated) were computed with MACROS modules (Penning de Vries et al., 1989); for each pair of lines, the line with the highest unirrigated yield refers to the wet season.

season) and our model is sensitive to this. Simulation shows that response curves reach higher values and that their shape can change with high inputs (Figure 27).

Adding an explanatory crop model to this economic model would lead to a more flexible tool for analysis. This would then avoid simulating water balances independently of crop growth and relating yield to the average stress pattern rather than simulating it in response to varying levels. Such changes would probably modify the outcome. A combined model can be used for other rice varieties, crop species, soils and weather and water table patterns. For crop production in situations with nutrient shortage, specific field trials are needed for calibration.

The second model simulates day-to-day water use on small rice farms in tank irrigation systems (Palanisami & Flinn, 1988). Irrigation water is the runoff from a catchment area, collected in a large, communal tank. This system is widespread in southern India. The authors examined 'tank irrigation system performance using productivity increases and income equity as performance criteria under existing and improved physical and management strategies, and to evaluate the financial viability of alternative improvement strategies to help guide future investments in tank improvement'. The model simulates the water balance of fields at different positions along irrigation channels and access to pumped groundwater. The crop part is represented by a regression equation of final yield versus number of stress days, developed by Palanisami & Flinn (1988):

$$Y_t = a_t - b_t SD_t \qquad (t = 1,2,3) \qquad \text{Equation 17}$$

where Y_t represents the rice yield in t ha^{-1}; a_t the base yield, given no stress days; SD_t the number of stress days observed; b_t the estimated reduction per day of stress; and 1,2,3 are the successive periods of differing sensivity.

In Equation 17, sensivity to stress depends on crop age. Net income per field is derived from the financial value of outputs and inputs.

As a result of calibration, the equation and constants summarize the specific condition in one tank adequately. However, the equation is only valid in one location because values of its constants depend, among other things on crop duration, fertilization level and water table depth. Other equations will be more suitable in other conditions. Moreover, the equation applies only to rice production, even though it is important to consider other crops that require less water in a part of India where rainfall is scarce and the price of water may go up. In fact, by using this model it is almost implied that one must choose from a narrower range of options than really exists.

6.6 Conclusions

Economic and sociological factors can be used to set boundary conditions, management rules and to develop objectives for using crop models, but they cannot play a dynamic role in them.

However, crop simulation can supply agronomic information that can be used jointly with economic information and other data, to arrive at management decision. With respect to developing countries, it seems that crop modelling can provide support at a tactical level of farm management to decisions about the annual farm production plan, at the strategic level for long-range planning by quantifying consequences of alternative options, and at the operational level by preparing guidelines for day-to-day actions. It seems to me that there are already many opportunities for deriving guidelines for specific crops, soils and weather patterns, in spite of the infancy of applied crop modelling and of environmental data bases.

Combining dynamic agro-economic models with dynamic crop models can improve results, raise the number of alternatives for management or planning assessed, expand the area to which the new model is applicable (soil, climate, crop varieties), and broaden the range of agronomic options studied (crops, fertilization). There is a challenge in combining crop and economic models.

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