10

Tools to Support Strategic Decision Making

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Strategic decisions relate to the formulation of long-term policies or plans, either at farm, regional or national level. A perceived strength of models is that they can be used to provide information to support decisions especially in times of change when existing experience is no longer applicable or when new opportunities arise. The strength of modelling, in this context, is that impacts over a longer time frame can be simulated taking into account many complex factors in a way that would not be possible using conventional approaches. Models can be used to evaluate the longer-term implications of different agricultural practices or policies. By providing an estimate of the potential impacts of different options, outputs from model-based research can also provide a basis for decision making. In many cases, however, models are described in the literature in terms of their successful application by researchers, but the use of this information to support decision making in practice is seldom mentioned. There are, therefore, some overlaps between the applications reported here and those in the previous chapter on the use of models as tools in research.

10.1 Land-use Planning

Land-use decisions have to be made at all levels of the agriculture sector. Governments must know what policy instruments will bring about particular patterns of land use. For example, what would be the effect of making cheap credit available for agricultural inputs? At the farm level, land-use decisions must be taken to satisfy household criteria and

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goals such as income security and whether basic nutritional requirements can be satisfied while reducing risk, generating certain levels of cash or maximizing returns to capital investment (Thornton and Jones, 1997). In terms of decision support for land-use planning, agroecological zoning and land evaluation are also important steps in determining the agricultural potential of a region.

Reiterating the point made in Chapter 6, land evaluation is designed '. . . to guide decisions on land use in such a way that the resources of the environment are put to the most beneficial use for man, whilst at the same time conserving those resources for the future' (FAO, 1976). Agricultural problems of over-production in Western Europe and the United States pose quite different problems from those prevailing in many developing countries, where there is a desperate need to match food production with population growth. According to Beinroth *et al.* (1998), long-term sustainable development requires that we find effective ways to assess the potential of land-use patterns and predict impacts and performance under different policy or management options. Moreover, in developing countries, there is a particular need to identify data and tools for efficient, objective and comprehensible regional land-use planning to support multi-party negotiation and consensus building where there are potential natural resource conflicts. These methods should take into account basic information on soils, topography, climate, vegetation, as well as socio-economic variables such as relation to markets, skill of land users, level of social and economic development, etc. This section outlines some of the attempts that have been made to use models in these areas.

Crop models have been used in agroecological zoning in order to provide information on the potential for the introduction of new crops or cropping practices at a regional level. Jones and O'Toole (1987) used the ALMANAC crop growth model to illustrate how such models could be used to meet some of the objectives of agroecological characterization such as matching technology with resources and describing the impact of climate variability on crop yields. Angus (1989) analysed the long-term mean agroenvironment of the Philippines to estimate opportunities for multiple cropping of rain-fed rice using the POLYCROP model. Aggarwal and Penning de Vries (1989) used a simulation model to characterize agroclimatic zones in South-east Asia in terms of production potential for wheat, a non-traditional crop for the region and to identify regions that could be more productive in irrigated and/or rain-fed conditions. Aggarwal (1993) used WTGROWS, a model based on the Dutch MACROS model, and a geographic information system (GIS) to determine productivity of wheat at different locations in India as determined by climate and water availability. Penning de Vries (1990) describes how a model was used to evaluate the suitability of soybean in the Philippines, where it is a new crop. The yield was simulated for rain-fed and irrigated, upland and lowland sites over 20 years, and costs and benefits were analysed to give potential net profit.

In a study aimed at providing information to support policy decisions in Malawi, CERES-MAIZE was used to predict yields in two contrasting locations in the central region of Malawi. A regional analysis using the model linked with spatial databases showed variability in maize yields to be attributable to a combination of soil and weather effects. Nitrate leaching potential at the regional level was also shown (Thornton and Jones, 1997).

In another application, the International Potato Centre (CIP) used the LINTUL (Light INTerception and UTILisation) model for the agroecological characterization of global potato production to help target research at production problems in those regions were potato cultivation is most promising. In 1995, it was used by Penning de Vries *et al.* (1995) in a world food study in which potential and water-limited food production was estimated for the year 2040 for 15 major regions of the world. Similarly, Lal *et al.* (1993) used the BEANGRO model to carry out a regional productivity analysis of beans for three sites in western Puerto Rico. The analysis indicated that optimum cultivar selection, planting date and irrigation strategy varied from one site to another. In this, as in the majority of examples reviewed, there has been little or no attempt to assess the uptake and impact of this information.

In some cases, crop models and GISs have been combined to assess the agricultural potential of a given region or to consider the impact of different options. The use of the Agricultural and Environmental Geographic Information System (AEGIS) for assessing the agricultural potential of land previously used for sugarcane production in Puerto Rico (Beinroth *et al.*, 1998) has already been discussed in Chapter 6. The results showed that tomato double cropped with a cereal would increase profits for land use and would probably decrease risks of erosion and N leaching, compared with a number of alternative cropping systems (Hansen *et al.*, 1998). However, it is unclear as to the extent to which socio-economic factors were considered in this conclusion. Moreover, there is no mention of the involvement of local planners in the work nor of whether it had any impact on agricultural practice.

Stoorvogel (1995) proposes the integration of different models and tools as an effective way to analyse different land-use scenarios and thus inform agricultural policies and economic incentives for sustainable agricultural production. He suggests that the limitations in one model can be compensated for by others, making this an ideal methodology for multidisciplinary research and the integration of socio-economic and agro-ecological data. The method was tested by analysing different land use scenarios for the Neguev settlement in the tropical lowlands of Costa Rica. Crop growth simulation models and expert systems were used for the description of alternative land-use systems. This was linked to a GIS with land use being optimized using a linear programming model. The simulation was used to look at the effects of: (i) changes in capital availability;

(ii) restrictions on biocide use; and (iii) effect of nutrient depletion on farm income, although Stoorvogel makes the point that an infinite number of scenarios could have been analysed.

10.2 Planning for Climate Change

Recently, due to concern over the potential impacts of the build up of greenhouse gases in the atmosphere, the issue of climate change has moved to the forefront of the global scientific agenda. Simulation models are the only way that the impacts of a variety of potential scenarios can be explored. Such simulations can be used to investigate the effect that climate change will have on agriculture. By considering alternative scenarios, decision makers or planners are in a better position to plan future strategies based on the most likely outcome. This may be extremely important to planners in the developing countries which will be the most vulnerable to the effects of global warming.

Some examples of the use of crop models in this area have already been discussed in Chapter 7. The following cases are some further examples which have all involved the use of the Decision Support System for Agrotechnology Transfer (DSSAT) suite of crop models, which have gained widespread acceptance within the research community. The outputs do provide information that could potentially support decisions on agricultural strategy. However, there is no mention as to whether the results have been used in policy consideration or whether they are merely of scientific interest.

In Bulgaria, climate vulnerability assessments for agronomic systems have been initiated (Alexandrov, 1997). DSSAT version 2.1 was used to predict that an increase of between 5 and 10°C would lead to a decrease in the yield of maize and winter wheat.

- In the Philippines, DSSAT was used in combination with results from four general circulation models (GCMs) to assess the impact of climate change on rice and maize crops (Buan *et al.*, 1996). The results showed both increase and decrease in rice yields according to the variety, while maize yields consistently decreased. This was partly due to increased flooding that would be brought about by an increase of 10% in rainfall. The model was unable to simulate the affects of high winds that would result from typhoons.
- In Java, Indonesia, there is concern that rice self-sufficiency, maintained since 1984, may be threatened by climate change. Three models, including DSSAT, were used to simulate climate change so as to aid policy makers in planning for the effects of recurring droughts and other possible changes. The simulations suggested that changes from 2010 to 2050 could drastically reduce rice yields because of an increased incidence of drought (Amien *et al.*, 1996).

- In Argentina, DSSAT was used to evaluate the potential impact of climate change on the productivity of maize, soybean and wheat, three crops making major contributions to the national economy. According to the results, a generalized increase in soybean and decrease in maize would occur. Regional impacts were varied for wheat, which was likely to increase in the west and east but decrease in the north (Magrin *et al.*, 1997).
- A combination model (CERES-RICE coupled with BLASTSIM) was used in conjunction with weather generators from DSSAT to study the effects of global climate change on rice leaf blast epidemics in five Asian countries. The simulation allowed for analysis of distribution of the disease and estimated yield losses over a 30-year period. The simulated climate change had a significant effect on disease development, although this varied according to the agroecological zone (Luo *et al.*, 1995).

10.3 Crop Forecasting

Crop forecasting operates on a much shorter time scale than that used to predict the effects of climate change on crop production or disease incidence. Large area yield forecasting prior to harvest is of interest to government agencies, commodity firms and producers. Crop forecasting can provide an important tool for agricultural planning in both developed and developing countries. Crop forecasting packages have many potential benefits. They enable policy makers to plan for food security and determine import/export plans and prices, and they enable farmers to plan their marketing strategies and provide a basis on which to make decisions about crop management practices such as fertilizer top dressing, irrigation and fertilizer application (Horie *et al.*, 1992). The decision-making capacity of farmers and resource planners would be improved if they had some means of quantifying risk associated with particular strategies (Bannayan and Crout, 1999). So far, the most widely used methods for operational yield forecasting are based on empirical, statistical or sampling techniques. An evaluation of the relative advantages and disadvantages of different systems however, shows that a combination of remote sensing and crop modelling may provide the most effective method (Horie *et al.*, 1992).

Some such packages are still being developed but appear to have potential. For example, Bannayan and Crout (1999) used the SUCROS model to experiment with real-time yield forecasting of winter wheat in the UK. The results showed that the model was able to forecast final biomass and grain yield with less than 10% error.

In developing countries, there is potential for developing early-warning systems using crop forecasting methodology. Early warning of a poor harvest in highly variable environments can allow policy makers the time they need to take appropriate action to ensure food security in vulnerable areas. Thornton *et al.* (1997) describe how the CERES-MILLET model was used in conjunction with a GIS and remote sensing to estimate millet production in contrasting seasons for 30 provinces of Burkina Faso. They found that provincial yields simulated halfway through the growing season were generally within 15% of their final values. They considered the methodology to have considerable potential for providing timely estimates of regional production of the major food crops in sub-Saharan Africa. However, as far as we know, no operational early warning system has so far been produced.

A methodology was developed using the CERES-MAIZE model to assess drought impacts on maize at an early stage in the season. The index was intended to provide an objective measure that policy makers could use to declare areas as drought-stricken and then implement subsidy schemes on a fair basis (du Pisani, 1987). Although the results proved positive, there is no mention of implementation.

An attempt was made by Abawi (1993) to use long-range weather forecasts based on the Southern Oscillation Index (SOI) linked to a crop harvesting model to predict long-term risks associated with earlier harvesting of wheat in Australia. Since long-range weather forecasts are generally not reliable, Horie (1992) suggests that the ideal crop forecast system should accurately assess current crop status and predict future status and yield under the 'most probable' weather. The most probable weather may be 'normal' climate in a given location with allowances for some deviations. An example of such a model is the SIMRIW dynamic crop-weather model combined with a weather information system. Horie (1992) used this model in Japan and predicted that such models would have an increasingly important role in regional rice yield forecasting in that country. However, successful implementation of the model relied upon the fact that, in Japan, meteorological data such as air temperature, sunshine hours, precipitation and wind-speed had been recorded in 860 sites since 1974. Few, if any, such intensive networks of meteorological stations are available in developing countries.

In Europe, many attempts have been used to use models to forecast yields. For example, the Monitoring Agriculture with Remote Sensing (MARS) project involved the use of crop models for long-term yield predictions in Europe. WOFOST, a general purpose crop simulation model (van Diepen *et al.*, 1988), was integrated with a GIS to produce a crop growth monitoring system for operational yield forecasting in the European Union (EU) (Bouman *et al.*, 1996). However, according to John Taylor (Cranfield University, Silsoe, 2000, personal communication), remote sensing techniques and simpler regression models provide an alternative methodology that can be equally as effective as the use of agrometeorology models. In the 1990s, WOFOST was also used as part of the policy study 'Ground for Choices' to explore regional yield potentials in the EU under different management intensities (NSCGP, 1992). The process involved optimizing land use and production systems under four contrasting economic scenarios, and is discussed in more detail in Chapter 6.

Seligman (1990) states however, that crop models have had poor results as yield predictors, and, despite much research, the more advanced versions of such models are not yet being implemented for commercial use.

10.4 Irrigation Planning

Water for agriculture is coming under increasing pressure from alternative industrial and domestic end-users, so an understanding of the likely future demand for water is needed to develop strategies for water management. Planning for long-term irrigation needs is of great importance in areas of water shortage, where water supply is a potential cause of conflict and trade-offs must be considered between different potential uses and users.

Knox *et al*. (1997) calculated the annual irrigation needs for England and Wales using the Irrigation Water Requirements (IWR; Hess, 1996) model, to help the UK Environment Agency in their long-term water management strategies. The IWR model estimates the daily soil water balance for a selected crop and soil type. For each year of the available weather records, the model outputs data on the crop water use, any irrigation applied and the proportional yield loss due to any water stress. The same approach could be applied in developing countries provided sufficient data are available (J. Knox, Cranfield University, Silsoe, 2000, personal communication). Similarly, Hook (1994) used the CERES-MAIZE, SOYGRO and CROPGRO models, in combination with water use models, to predict yield and irrigation demand in Georgia (USA) for drought years using data from the 15 driest years on record. The demand was assessed relative to the mix of crops grown in the region. This has potential in regions where water resources are limited, making it important to plan the permitted area of irrigated crops and water demand for years of drought. It can be used for strategic planning for irrigation water withdrawals at a regional or watershed level. The approach has since been developed further to provide a practical tool for Environment Agency Abstraction Licensing Officers to be able to validate licence applications from farmers. This has been taken up nationally with operational training support from Cranfield University (J. Knox, 2000, personal communication).

Models have also been designed to deal with the question of irrigation management at a farm level, helping farmers and their advisors to link the strategic and tactical aspects of on-farm water management. For example, as already mentioned in Chapter 4, MacRobert and Savage (1998) describe the development in Zimbabwe of an interactive version of CERES-WHEAT, which searches for the optimum intra-seasonal irrigation regime to maximize the total gross margin for a particular soil, cultural and weather scenario, within the constraints of land and water availability. This optimum regime can then be used by the farmer to plan irrigation management strategies. They illustrate the use of the package by evaluating deficit irrigation techniques which aim to maximize the gross margins (per unit of water rather than land) in large-scale farms in Zimbabwe, where land availability exceeds irrigation water resources.

Passioura (1996) gives an example of the strategic use of the OZCOT cotton model which has been calibrated for a given restricted irrigation area, and can be used to decide what area of cotton should be grown in dry years when irrigation water is restricted. For example, if only half of the water supply is available, the model can give advice on whether it is better to grow, say, only half the normal area of cotton at normal irrigation, or to grow the normal area at half the level of irrigation (Dudley and Hearn, 1993).

LORA is a decision support system developed in France to help farmers and their advisers develop a cropping plan for both the irrigated and non-irrigated areas of their farm (Deunier *et al.*, 1996). The model considers which crops should be irrigated and what their water requirements are. The objective is to obtain the best economic return, taking into account the risks due to climate variability and uncertainty regarding production prices. The model produces an irrigation schedule for each crop and a management choice for each climate scenario. The user can also test his/her own irrigated and non-irrigated cropping plan which the model then evaluates over all climate scenarios and seeks optimal management methods. LORA has been available in France since 1990, and has been modified to take into account changes in the European Union's Common Agricultural Policy (CAP). It is used in three areas: (i) providing direct help in decision making for farmers via their advisers; (ii) studying irrigated systems at a regional level; and (iii) providing training in water management at a farm level for advisers.

10.5 Assessing the Benefit of Proposed New Technologies

Since farmers in developing countries tend to be risk-adverse, they may be unwilling to adopt new, more sustainable, practices when they are uncertain of the immediacy, likelihood or scale of the resulting benefits. Moreover, field data on the impacts of new practices or technologies may give misleading results if the long-term variations of factors, such as weather, are not taken into account. The modelling of proposed changes to the system can provide a longer term view of the potential effects of new practices, and can enable the user to see the probability of the outputs from field experiments being representative in the long term.

Soil and water conservation practices provide a typical example of proposed measures for increased sustainability that are potentially risky for farmers, since they often require high levels of investment in the short term, but provide uncertain benefits in the long term. The examples below, some of which have already been discussed in Chapter 5, show how models can be used to help farmers justify the adoption of new or improved technologies by enabling them to identify the probability of positive yield responses and how they can help to validate the results of field research. It is however, interesting to note that there is little mention as to whether the outputs of this research have been shared either with farmers or extension workers.

Stephens and Hess (1999) used the PARCH model to assess the long-term benefits of runoff control or water-harvesting techniques on maize yield in the Machakos district of Kenya. Using the model with weather data for 30 years enabled the relative effect of different levels of water conservation to be evaluated in terms of their likelihood of success. The results highlighted the pitfalls of traditional experimental approaches in areas with highly variable rainfall. In another study, Freebairn *et al*. (1991) used the PERFECT model to compare, on one hand, a farming system using contour banks, stubble mulching and storage of runoff water for later use, with a second system using bare fallow and no conservation structures in terms of the effect on mean annual runoff, sediment loss and wheat yield. In this study, runoff and sediment loss were greatly reduced, and wheat yield was increased by 14%. Similarly, the Erosion Productivity Impact Calculator (EPIC) model has been used to evaluate erosion consequences of cropping practices and tillage (Williams *et al*., 1984).

Modelling can also help decision making on the optimum design of soil water conservation practices. For example, Stroosnijder and Kiepe (1997) used the DUET model to evaluate various types and frequencies of conservation tillage, aimed at better infiltration of water into the soil, on the growth of millet in the Sahel. They also used a model called SHIELD to determine optimum row spacing in contour hedgerows. However, it is not reported if the results from this work were disseminated to the farmers.

10.6 Planning Optimum Farm Management Strategies in Collaboration with Extension Services and Farmers

In the last 10 years, there has been a realization that models may have a useful role to play in planning strategic farm management with extension workers and farmers. This approach is relatively new, and is still being actively developed (Seligman, 1990). However there are already a few examples of its application both in developing countries as part of internationally funded development projects and in a more commercial context in developed countries.

Two examples come from Australia. As early as 1987, Kingwell and Pannell (cited in Seligman, 1990) describe how the MIDAS model, which is based on simple biological relationships, was being used experimentally for planning optimum farm management strategies in collaboration with extension services. FARMSCAPE (Farmers, Advisers and Researchers Monitoring Simulation, Communication and Performance Evaluation) provides a more recent example of the experimental use of a combination of hard and soft systems methodologies to support farmers (McCown *et al.*, 1998, cited in Newman *et al.*, 2000). The FARMSCAPE approach, used for a dry-land crop production management system, was an alternative to traditional DSSs since it combined simulation (hard system) with participatory interactions with the farmers and advisers. It was hoped that the farmer would gain the benefit of recommendations and also learn in the process. The simulator provided the opportunity to compare options for the forthcoming season and was used by the farmer, researcher and adviser as part of a discussion focused on farm planning. An evaluation of the process showed that, when taken in context, the simulation helped participants to gain insight into the way their production system functioned, and increased their experience in tactical decision making (Newman *et al.*, 2000).

In a developing country context, an example comes from the Hindu Kush Himalayas, in which ten Asian countries participated in a project which used field scale modelling for decision support in participatory watershed management. The project involved training and workshops, and was so well received by the participants that China translated the manuals into Chinese and set up its own training course (Rajan Muttiah, Texas, 2000, personal communication). A similar process was described by Beinroth (1998), already discussed in Chapter 6, of using AEGIS to assess the feasibility of small irrigation projects for watersheds in the Colombian Andes as part of an interactive irrigation planning exercise. The model could be used to explore trade-offs between domestic water requirements, irrigation demand and downstream use, and be able to support the process of consensus building during community discussions by enabling new positions to be simulated and evaluated in an iterative manner.

In Zimbabwe, the Agricultural Production Systems Simulator (APSIM) model is currently being applied in an Australian-funded 'risk management' project to help farmers, policy makers, extension agents and researchers improve their understanding of the trade-offs between different crop and cropland management strategies under scenarios of climatic risk (P. Grace, CIMMYT, Mexico, 2000, personal communication). APSIM was chosen because of its ability to deal with complex interactions between climate, soil fertility, and crop and residue management. Rather than focusing on an optimal strategy, the scenario analysis focused on practices that would be feasible and productive in a context where farmers are managing multiple fields under tight labour and capital resource constraints. The modelling aspect was important since it would not have been possible to undertake such analysis either on-farm or at a research station in a reasonable time frame. The project was designed to open up new perspectives in a training setting. It demonstrated how simulation models can help in thinking about the options open to resource-constrained smallholders combined with dialogue with farmers and extension workers. The participants' awareness of model limitations was helpful since they were aware of the need to 'reality check' the outputs of the models, and to consider in particular the implications of constraints not captured in the models. Although there were deficiencies in terms of modelling household constraints, the study was able to highlight the challenges faced by smallholders when investing in fertilizer inputs and it provided pointers for future on-farm research directions.