Tradeoff Assessment as a Quantitative Approach to Agricultural/Environmental Policy Analysis

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Introduction

This chapter discusses tradeoff assessment as an organizing concept for a quantitative approach to ecoregional research and agricultural/environmental policy analysis. Motivating this approach is the view that quantifying tradeoffs is an essential ingredient in setting research priorities and in designing and implementing the criteria of sustainable agriculture in agricultural research programs, as described in detail in Crissman, Antle and Capalbo (1998). This chapter also provides an introduction to a modeling system (the Tradeoff Model) being developed as a decision support tool for agricultural and environmental policy analysis and policy decision-making (Stoorvogel, Antle, Crissman, and Bowen, 2000). This modeling system is designed specifically to integrate disciplinary data and models at the field scale, and aggregate economic and environmental outcomes to a scale relevant to policy analysis, in order to quantify tradeoffs between competing economic and environmental policy objectives.

The ultimate goal of the research programs supporting the development of the Tradeoff Model is to construct a flexible tool that can be used to integrate disciplinary data and models to provide information about agricultural production systems needed by policy decisionmakers. The goal is to develop a tool that can be used by a team of disciplinary researchers and adapted to fit any production system. The modeling system described here is a prototype of this type of policy decision support system. It is designed to represent a specific production system – the potato/pasture system typical of the equatorial Andes. The objective of ongoing research is to develop methods for generalizing the structure of the system and for simplifying the model components to the degree possible while maintaining the degree of accuracy needed for policy analysis.

Tradeoff assessment provides an organizing principle and conceptual model for the design and organization of multi-disciplinary research projects to quantify and assess competing objectives in agricultural production systems. This process is illustrated in Figure 1. Input from the general public ("stakeholders"), policy makers, and scientists is used to identify the critical dimensions of social concern, *i.e.*, criteria for assessment of the sustainability of the system. Based on these criteria, hypotheses are formulated as tradeoffs between possibly competing objectives, such as higher agricultural production and improved environmental quality. Not all outcomes need to be tradeoffs; win-win cases also can be accommodated.

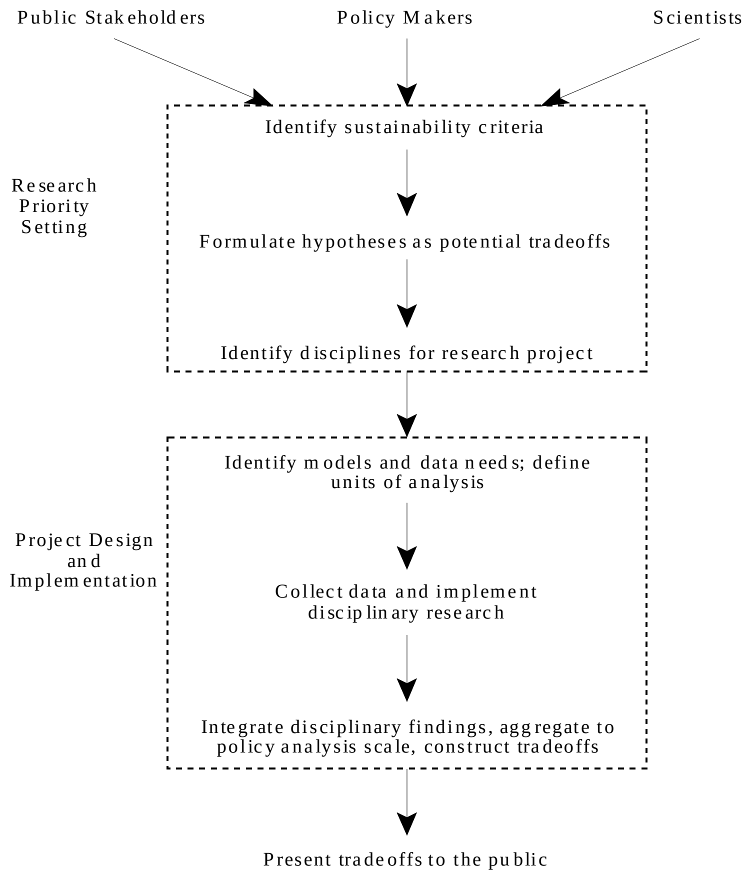

Figure 1. Tradeoffs research design and implementation process (Crissman, Antle, and Capalbo, 1998)

Once the key tradeoffs are identified, research team leaders can proceed with project design and implementation, and can identify the appropriate scientific disciplines to further design and implement the research needed to quantify these tradeoffs. The next step, critical to quantifying tradeoffs, is the identification of disciplinary models and data needed to quantify each sustainability indicator. A key aspect of this stage of the research design is to identify the data needs for each of the disciplinary components of the analysis, and how the model outputs can be effectively linked for the construction of tradeoffs. As we discuss further below, a key element at this stage is for all of the disciplines to agree upon basic spatial and temporal units of analysis: Will analysis be conducted at the field scale or watershed scale? Will time steps be daily, weekly, monthly, or yearly? Will all disciplinary components of the analysis operate at the same spatial and temporal scales, and if not, how will differences between scales be reconciled? Once these fundamental issues in research design have been resolved; data collection and disciplinary research can proceed. Upon completion of the disciplinary components of research, the respective data and models can be linked to test hypotheses about tradeoffs, and the findings can be presented to policy makers and the general public.

A number of challenges face researchers in implementing this type of research. First, despite the widespread acceptance of the goal of sustainable agricultural systems, a scientific consensus is lacking on how the economic, environmental, and public health impacts of agricultural technologies can be quantified and assessed. Analysis of these complex, interrelated issues raises difficult theoretical and methodological problems for researchers. Environmental, agricultural, and health characteristics of farmers, farmland, and farming technologies vary over space and time.

Second, a key methodological challenge is the choice of the unit of analysis including the spatial and temporal scales. Research in the biological and physical sciences typically deals with a unit of analysis—whether it is at the cellular, plant, animal, or field level—that is different from the farm or sector levels relevant to policy analysis. Policy analysis typically is concerned with large units, usually defined in relation to a geographic or political region that contains a population of the units addressed by biological and physical sciences. The aggregation problem, *i.e.*, the problem of combining heterogeneous small units into a larger unit for policy analysis, must be addressed by all researchers if their data and results are to be useful for policy analysis. While emphasis has been placed on the problem of spatial aggregation in the geo-statistics literature, similar problems arise in the time dimension.

Third, the problems that concern the public involve issues addressed by various fields of science and thus require a multi-disciplinary approach. Overcoming disciplinary biases and establishing effective inter-disciplinary communication is a continuing challenge for a research team. The fact that the various scientific disciplines use different units of analysis frequently means that the data and methods developed for disciplinary research are of limited value for policy research. Disciplinary research typically operates in a format dictated by disciplinary orientation and generates data intended to satisfy disciplinary objectives. This disciplinary orientation of research leads to a situation in which various pieces of the scientific puzzle are investigated without regard to the fitting together of those pieces into the larger picture that is required for policy analysis. Thus, the disciplinary component of research intended to support the assessment of tradeoffs must be planned at the beginning of the research effort to produce methods and data that are required for disciplinary analysis, but that can also be utilized across disciplines to assess tradeoffs. The planning, in advance, of *coordinated disciplinary research* is one of the key benefits of the tradeoff assessment methodology that is being proposed here.

Fourth is the problem of spatial variability. Tradeoffs associated with agricultural production systems can be defined across several dimensions at a point in time, and can also be defined in one or more dimensions over time. In evaluating the long-term sustainability of a production system, economic and environmental indicators can be used to quantify the productivity and other attributes of a system over time. These indicators may include measures of phenomena such as economic returns, soil erosion, chemical leaching, nitrate movement through soil profiles, and the organic content in the soil. Measuring tradeoffs in these dimensions requires site-specific data and models. Because the environmental impacts of different production systems are generally site-specific, one production system may not have the same impacts in all environmental dimensions at all sites. Thus, any attempt to rank production systems according to sustainability criteria needs to account for spatial variability in economic, environmental, and health outcomes.

The larger the spatial or temporal scale, the more complex becomes the process of quantifying tradeoffs for analysis of agricultural sustainability. Analysis at the regional or national scale is even more difficult than analysis at smaller scales, such as a watershed. Attempts to develop quantitative indicators of the sustainability of the U.S. farming sector, or the farming sectors of member countries of the Organization for Economic Cooperation and Development (OECD), have relied on aggregate data about production, input use, and resource degradation (U.S. Department of Agriculture, 1994; OECD, 1994). These data do not provide a scientifically defensible foundation for policy analysis because production cannot be linked to environmental and health impacts on a site-specific basis. In contrast, the approach followed in the development of the Tradeoff Model is to link the site-specific management decisions of producers with environmental and health impacts. By conducting the analysis at a statistically representative set of sites, the site-specific outcomes can be aggregated to represent the relevant human and physical populations and can be used to assess tradeoffs at whatever scale is deemed relevant for policy analysis.

Economists know that when the economic decisions of individual economic agents – e.g., farmers – are aggregated to a larger spatial unit, these economic agents interact through markets. Prices which are exogenous to the individual agent may become endogenous (i.e., determined by market equilibrium processes). It is important to emphasize that the Tradeoff Model framework is designed to represent the economic and associated environmental outcomes of individual economic agents' decisions, but it is not designed to determine market equilibria. Conceptually, the tradeoff relationships derived by aggregating individual agents' decisions can be viewed as a multidimensional representation of a production possibilities frontier which includes both market and non-market outcomes (Antle, Capalbo and Crissman, 1998). Thus, the points along the tradeoff curve define combinations of economic and environmental outcomes that may be associated with different relative output prices, just as the points along a production possibilities frontier define the combinations of outputs that are associated with different relative output prices. However, as is well known from the theory of general equilibrium, a production-possibilities frontier does not define an equilibrium by itself. Rather, the production possiblites frontier must be combined with the demand side of the economy to determine at which point along the production-possiblities frontier a particular equilibrium will occur. Similarly, the analyst may use a market model to determine equilibrium prices, and these prices may in turn be used to identify which point along an economic-environment tradeoff curve is associated with that equilibrium.

Fifth is the problem of valuation. The Tradeoff Model is motivated in part by the political demands for sustainable agricultural production technologies. Production technologies inevitably exhibit various economic and environmental attributes. Ranking technologies according to multiple criteria requires a method of converting these criteria to a common unit of analysis. One approach is to utilize multi-attribute decision models. These models optimize choices across multiple attributes by assigning weights to the alternative outcomes. This raises the question of what weights to use – a problem that has no objective solution. In benefit-cost analysis the solution to the weighting problem is to convert all impacts to monetary terms and to use this information. However, despite decades of research on valuation of environmental and health outcomes by environmental and health economists, a scientific consensus on monetary valuation methods is lacking. Data for valuation of most environmental and health impacts are not readily available, particularly in developing countries, and research in the field of environmental economics has shown that valuations from one place or context may not be transferrable to another place or context. Even when monetary valuations are feasible, their acceptance by the public or by policy decision makers is often questionable (*e.g.*, in the United States, Federal government agencies may not accept results from contingent valuation studies, see Belzer 1999). The philosophy underlying the Tradeoff Model is that a more useful approach to informing the policy decision making process is to establish a sound scientific basis for quantifying tradeoffs that exist with alternative production systems, without assigning arbitrary weights as in multiattribute decision models, and without attempting to value impacts in monetary terms for benefit-cost analysis. Rather, the approach is to provide private and public and private decision makers with estimates of impacts, and the determination of subjective values is left to the individual decision maker and to the political process.

Tradeoffs and the Analysis of Sustainable Production Systems

The concept of tradeoffs between present and future outcomes of an agricultural production system can be used to quantify the concept of sustainability and provide quantitative measures of the sustainability of an agricultural production system.

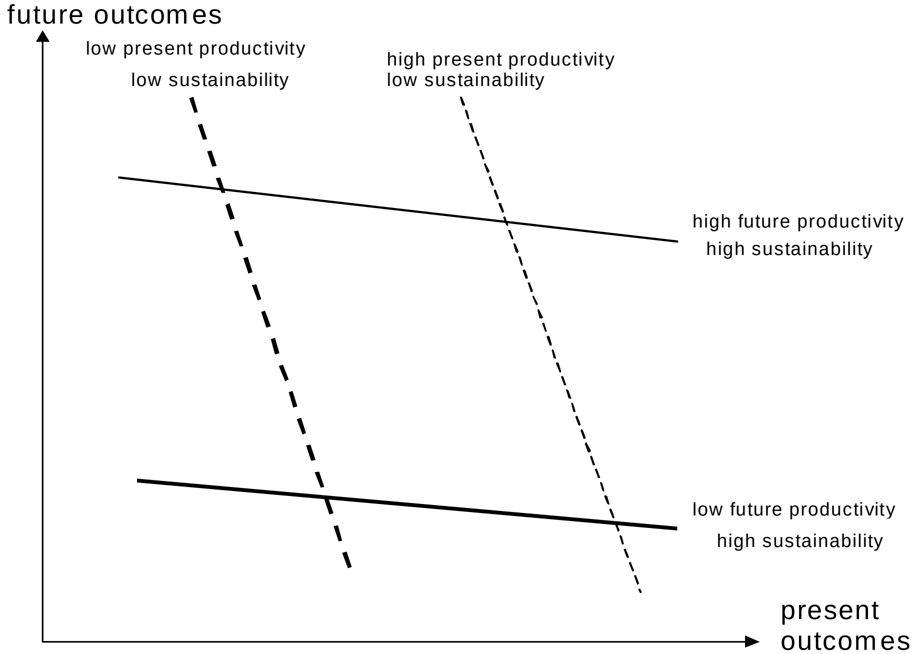

Figure 2: Tradeoff between present and future outcomes with low and high levels of productivity and sustainability.

Figure 2 presents tradeoff curves between present and future outcomes of a production system that illustrate how tradeoffs can be used to quantify sustainability. The degree of sustainability of a system is defined as the inverse of the absolute elasticity of the tradeoff curve between present and future outcomes (Antle and Stoorvogel, 1999). Thus, a steeply-sloped curve in Figure 2 represents a relatively low degree of sustainability, meaning that for a given production technology and resource endowment, any changes that induce higher levels of current production lead to a rapid reduction in future production potential. Similarly, a relatively flat tradeoff curve represents a system with a relatively high degree of sustainability, as increases in current production have relatively little impact on future production potential. Figure 2 also shows that production systems can differ in the level of present or future productivity. Systems that are exhibit either low or high levels of productivity also may exhibit either low or high degrees of sustainability.

The example in Figure 2 shows tradeoffs between present and future outcomes. The axes also can represent outcomes in the same time period, e.g., the tradeoffs between present economic welfare, environmental quality and human health associated with the potato/pasture system studied in Crissman, Antle and Capalbo (1998).

Tradeoff Assessment and the Eco-Regional Approach to Sustainability Research

Making sustainability operational within the context of international agricultural research calls for new approaches to research priority setting, problem identification, and organization. Several new research initiatives are adopting an eco-regional approach to integrate information at various levels of aggregation (Rabbinge, 1995). The International Potato Center (CIP) and its fellow institutes in the Consultative Group for International Agricultural Research (CGIAR) adopted an eco-regional approach as a means to operationalize the concept of sustainability. The CGIAR identifies eco-regions as agro-ecological zones and defines the role of the eco-regional approach as follows:

The main role of the eco-regional approach is to contribute to the goal of increasing sustainability of agricultural production by providing: first, a process that identifies the right research content due to its holistic and forward looking perspective which contrasts with traditional disciplinary and commodity approaches to research. Second, a mechanism for partnership, among relevant actors with complementary functions, that contributes to achieving their common and individual institutional goals through applied and strategic research on the foundations of sustainable production systems. Third, a mechanism that develops, tests, and supports effective research paradigms for the sustainable improvement of productivity (CGIAR, 1993, p. 4).

The eco-regional approach places emphasis on modeling production systems and their environmental impacts at a small scale, such as the field scale or watershed, and on how those small-scale impacts affect systems at larger scales or higher levels of aggregation. The approach is primarily a systems approach that emphasizes the importance of economic decision-making models to capture changing priorities in farm households and communities. Other tools important to the eco-regional approach include geographic information systems and crop, livestock, and soils models (Bouma *et al.*, 1995). It must be emphasized that these tools build upon the methods and data provided by the traditional experimental approach of agricultural research that is the hallmark of the CGIAR research system (CGIAR, 1995). The Tradeoff Model provides a methodology for the implementation of research within the eco-regional paradigm.

A recent review of the ecoregional approach comissioned by the Technical Advisory Committee of the Consultative Group on International Agriculturel Research finds continuing strong support for the ecoregional approach to sustainability research (Henzell et al, 1999).

General Framework for Tradeoff Analysis

The conceptual framework for disciplinary integration and policy analysis is illustrated in Figure 3. A unique aspect of this conceptual model for tradeoff analysis is the location of farmer decision making in the figurative center of the analysis. Above the box indicating farmer decision making are those attributes of the system in which the farmer operates that condition the decisions he or she makes. Immediately below are the boxes that register the consequences of those decisions. Moving from top to bottom, the framework captures the logical sequence of how policy affects farming decisions that result in micro-level impacts, and how those impacts can be measured and aggregated to units useful for policy analysis. At the center of the analysis is an economic model of farmer decision making. By incorporating the decision-making process of the land manager, the model provides the link from economic, physical, and technological factors affecting farmer behavior, to the environmental outcomes that are affected by their management decisions.

The upper part of Figure 3 shows that prevailing policies and market prices, technologies, farmer characteristics, and the physical attributes of land affect farmers' management decisions in terms of both land use and input use - the extensive and intensive margin decisions. Physical relationships between the environmental attributes of the land in production and management practices then jointly determine the agricultural output, environmental impacts, and health impacts associated with a particular unit of land in production.

Farm-level decision models show that each unit of land that is in production has management and environmental characteristics which in turn are functions of prices, policies, technology, and other farm-specific variables. As indicated in the lower part of Figure 3, the probability distributions of technology, farmer, and environmental characteristics in the region induce a joint distribution of management practices, environmental characteristics, and health outcomes for each land unit in production, as a function of prices and policy parameters. This joint probability distribution provides a statistically valid representation of the outputs, inputs, environmental impacts, and health impacts for the population. Therefore these individual outcomes can be "added up" to produce an aggregate distribution of impacts. These aggregate outcomes - measured in terms of agricultural output, environmental quality indicators, and health indicators - are used to construct tradeoffs for policy analysis. Information about market equilibrium prices can be input into the tradeoff analysis. If monetary values can be assigned to all impacts, then a benefit-cost analysis of policy alternatives can be conducted. However, since monetary values are not usually available, the more useful approach is to present information about tradeoffs directly to policy decision makers.

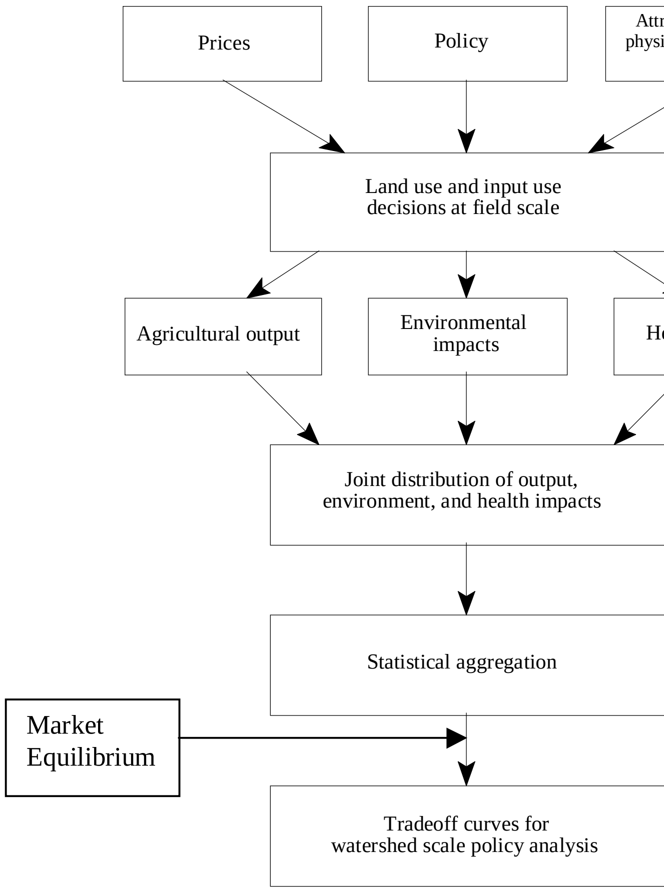

Figure 3. Conceptual Framework for Disciplinary Integration and Policy Analysis (Crissman, Antle, and Capalbo, 1998)

The scale of analysis

A diagram introduced in a soil science context by Hoosbeek and Bryant (1992) is useful to illustrate the research procedure followed in the Tradeoff Model analysis (Figure 4). They utilize two perpendicular axes to represent combinations of research procedures. Ome represents the range from qualitative to quantitative procedures and the other from empirical to mechanistic procedures. The vertical axis represents a scale hierarchy, where the plot level (the individual soil) occupies the central position (i level). Higher levels are indicated as i+, while lower levels are i-. The scale in Figure 4 ranges from molecular interaction (i-4) to the world level (i+6).

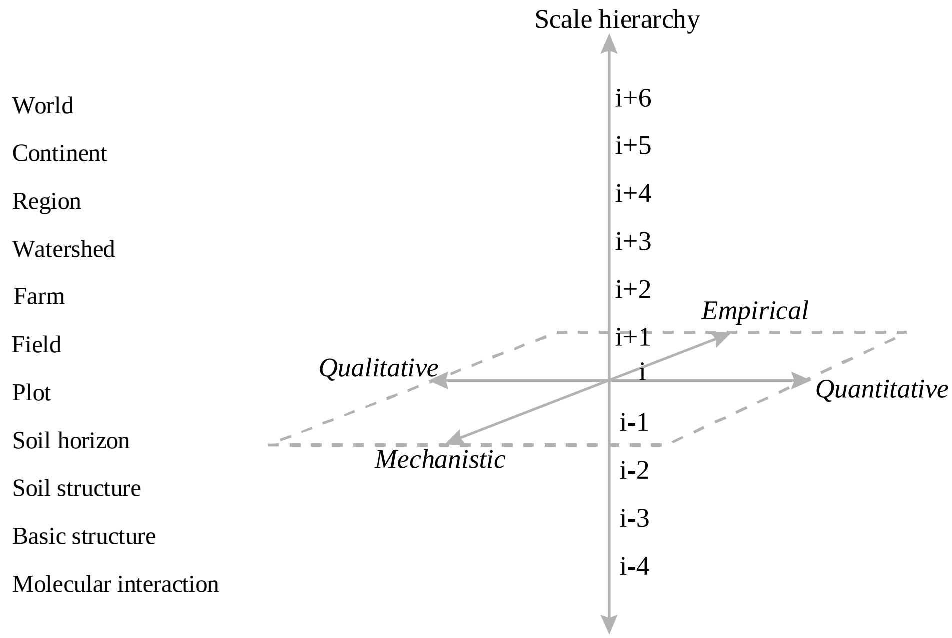

Figure 4. Classification scheme for research procedures (Hoosbeek and Bryant, 1992)

Different research approaches can be described with this construct of research procedures and placed within the plane obtained at each scale level (Bouma, 1998):

K1: Application of user expertise (qualitative, empirical)
K2: Expert knowledge (qualitative, mechanistic)
K3: Use of simple comprehensive methods, including modeling (quantitative, empirical)
K4: Complex, mechanistic methods, including modeling (quantitative, mechanistic)
K5: Detailed methods, including modeling, which focus on one aspect only, often with a disciplinary character (quantitative, mechanistic)

Within the tradeoff methodology, we work on different scale levels and use different research approaches. The lines in Figure 5 represent the so-called "research chain" that corresponds to the Tradeoff Model. The Tradeoff Model demonstrates how the problem is analysed using different research procedures at different scales. The problem definition of the Tradeoff Model is at the regional level and is defined by using expert knowledge (**K2**). For example, what will be the effect of an alternative technology on the tradeoff between development and pesticide leaching? Since decisions are taken at the farm/field level, the problem is re-defined (still in rather qualitative terms) at the field level: How will pesticide use be affected by an increase in economic performance of the cropping system? In a next step, a quantitative, empirical economic simulation model (**K3**) is used to simulate decision making for that field. Crop production and environmental processes such as pesticide leaching are modeled for a specific point within a field. If soil variability occurs within a field it is necessary to carry out simulation runs for different locations withn the field. While simulating crop growth and pesticide leaching at the point level we use quantitative, mechanistic simulation models (**K5**). During the simulation of these bio-physical processes it is necessary to consider processes of nutrient uptake by roots, mineralization of organic matter, and adsorption/desorption of pesticides, processes that occurr at the plot level and molecular interaction scales. The quantitative results are aggregated to the field level and finally the results of the simulation for many fields are aggregated to the regional scale in the form of tradeoff curves (**K3**).

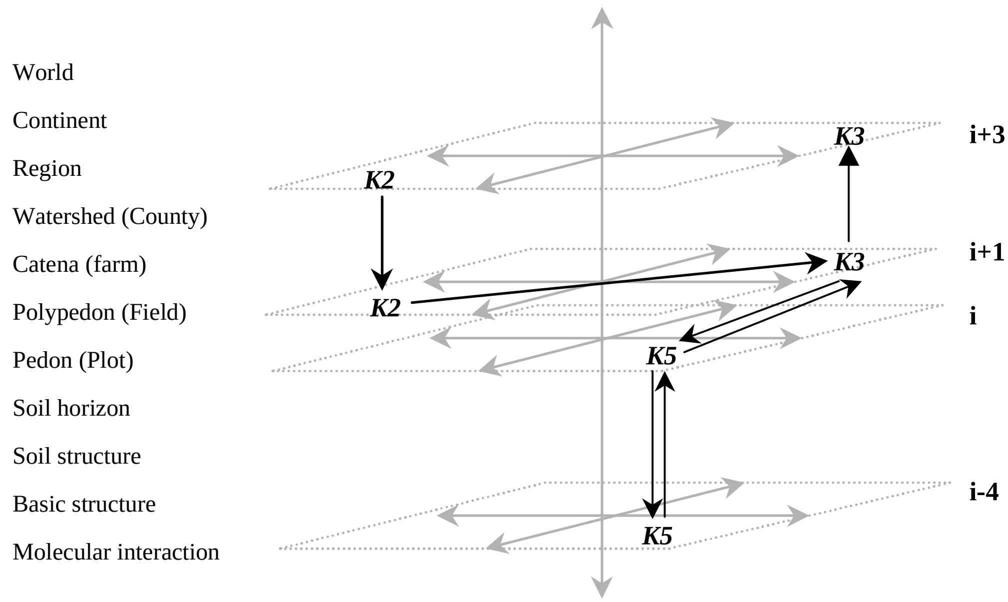

Figure 5. An illustration of a research chain representing the sequence of research activities at different scale hierarchies for the tradeoff model

Figure 5 showed that the tradeoff model works at four different scale levels: the regional level (i+4), the field level (i+1), the plot level (i), and lower levels for components of the bio-physical models (i-4). Scenarios and boundary conditions are defined at the regional level. The final results of the tradeoff analysis will also have to be presented at this level. Land allocation and land management decisions are taken at the field level. Hence, simulation of these decisions takes place at the field level. The crop models and most environmental process models work at the plot level. It is crucial that the different components of the tradeoff model can communicate. This means that data will have to be disaggregated (*i.e.*, to move down in the scale hierarchy) or aggregated (*i.e.*, to move up in the scale hierarchy). Disaggregation of data is used at two points in the analysis as dictated by the type of data and the way data have been collected.

In the case of soil data, in the existing case study sites an exploratory soil survey is available covering the whole study area. Typically one would use this soil survey, describe representative soil profiles for the different mapping units, and use those profiles for subsequent analyses. However, this would imply that any soil variability within the mapping units is discarded. Since this variability is considered to be large in the Andean highlands, alternative procedures have been developed. The exploratory soil survey is disaggregated using detailed information available from a digital elevation model. Relation between soil variability and parameters describing the topography of the terrain (derived from a digital elevation model) are used. This procedure requires additional field observations but provides the detailed information that is necessary.

Again, in the case study sites detailed economic information exists. Field-scale economic data originate from a dynamic survey of farmers' land use and management practices. In the Ecuador study of Crissman, Antle and Capalbo (1998), a representative sample of the fields in the study area were surveyed during a two-year period. Although the sample was relatively large it does not provide a spatial coverage of the region. To extrapolate these data, statistical distributions of selected economic parameters are estimated. These sample distributions are then sampled in simulations designed to represent the economic populations in the region.

For some variables a combination of both procedures is used. In the case of field size, we observe large differences within the region. A single distribution for the entire study area does not describe accurately the variation in field size. Instead we sub-divided the region into zones with similar patterns in field sizes. On the basis of the survey data, we determined the distribution in field size for each zone.

The simulation of crop production, crop selection and management, and pesticide fate takes place at the field level. Where there is a large topographic variation within an individual field, several model runs are necessary to calculate crop production and pesticide fate. A set of simulations is executed for all fields under a specified set of economic conditions (the so-called tradeoff points), for different repetitions (to capture the stochastic character of different input parameters). The results for each tradeoff point are aggregated to the watershed level. A plot of a number of tradeoff points defines a tradeoff curve.

Tradeoff Model Structure and Software

Figure 6 presents the structure of the Tradeoff Model. The model can be broken down into components that are discussed in corresponding sections of this report:

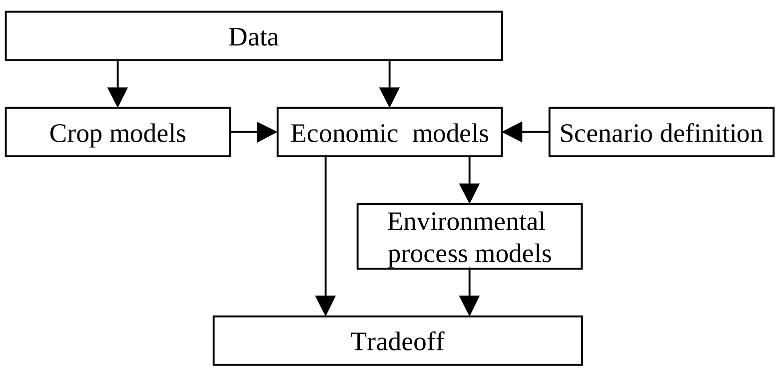

Figure 6: The general setup of the tradeoff model.

Data. The model begins with two types of data. Soils and climate data are organized in a GIS format and they are used as inputs to the bio-physical models. These data are utilized in two ways. First, soils and climate data are matched to farm survey data at the field scale to estimate econometric production models (see Section 5). Second, the geographical data are used to draw a random sample of fields from the population of fields in the study area. This sample of fields is used to represent, in statistical terms, the spatial variation in soils, climate and field size in the study area. This sample is then used as the basis for simulation of the crop, economic, and environmental models.

Crop Models. The crop (and potentially livestock) models discussed in section 4 are used to estimate the spatial and temporal variation in inherent productivity of the land that is driven by soils and climate variations. These measures of inherent productivity are inputs into the economic models to explain variation in management decisions of farmers.

Economic Models. Econometric production models are estimated, using the farm survey data and the inherent productivity indexes derived from the crop models. Parameters for distributions of prices and other exogenous variables in the production models are estimated using the survey data. These parameters are input into the economic simulation model, with the indexes of inherent productivity from the crop models.

Environmental Process Models. The management decisions from the economic simulation model (*e.g.*, land use, pesticide applications) are input to environmental process models to estimate impacts on soil quality, pesticide fate, and other environmental processes of interest.

Scenario Definition, Model Execution, and Analysis of Tradeoffs. For each policy or technology scenario of interest to policy decision makers, the simulation model is executed for a series of price settings. Economic outcomes from the economic simulation model (*e.g.*, value of crop and livestock production) and environmental outcomes from the environmental process models (*e.g*, pesticide loadings to the environment, soil erosion) are aggregated. The different prices settings induce changes in management which in turn induce tradeoffs between economic and environmental outcomes. These outcomes are aggregated to the spatial scale deemed appropriate for policy analysis (*e.g.*, to the watershed or regional level).

Structure and Organization of the Software

Figure 7 presents the overall structure of the Tradeoff Model software. This "model" is in fact a tool for integration of disciplinary data and site-specific simulation of disciplinary models, and for statistical aggregation of model results and construction of aggregate policy tradeoffs. To explain how the model integration software works, we walk through an example that illustrates each of its components. In this example, the data and models from the Carchi region are used to investigate tradeoffs between agricultural output, pesticide leaching, and human health impacts of pesticide use. In the example, we show how the tradeoff shell looks and explain the different input and output files. The main shell has been programed in Borland Delphi Version 4.0[1]. However, as mentioned before, the shell mainly functions as an integrator of different tools and models. For example, crop growth simulation is carried out by models from the DSSAT suite of models (Jones *et al.*, 1998), economic simulation models have been programed in SAS[2], and for the simulation of pesticide fate, a modified version of LEACHP is used (Wagenet and Hutson, 1989). The Tradeoff Model shell moves the necessary input and output among the different models and provides a format for the coordination of different scenario runs.

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[2] *Copyright ©1999 SAS Institute Inc.*

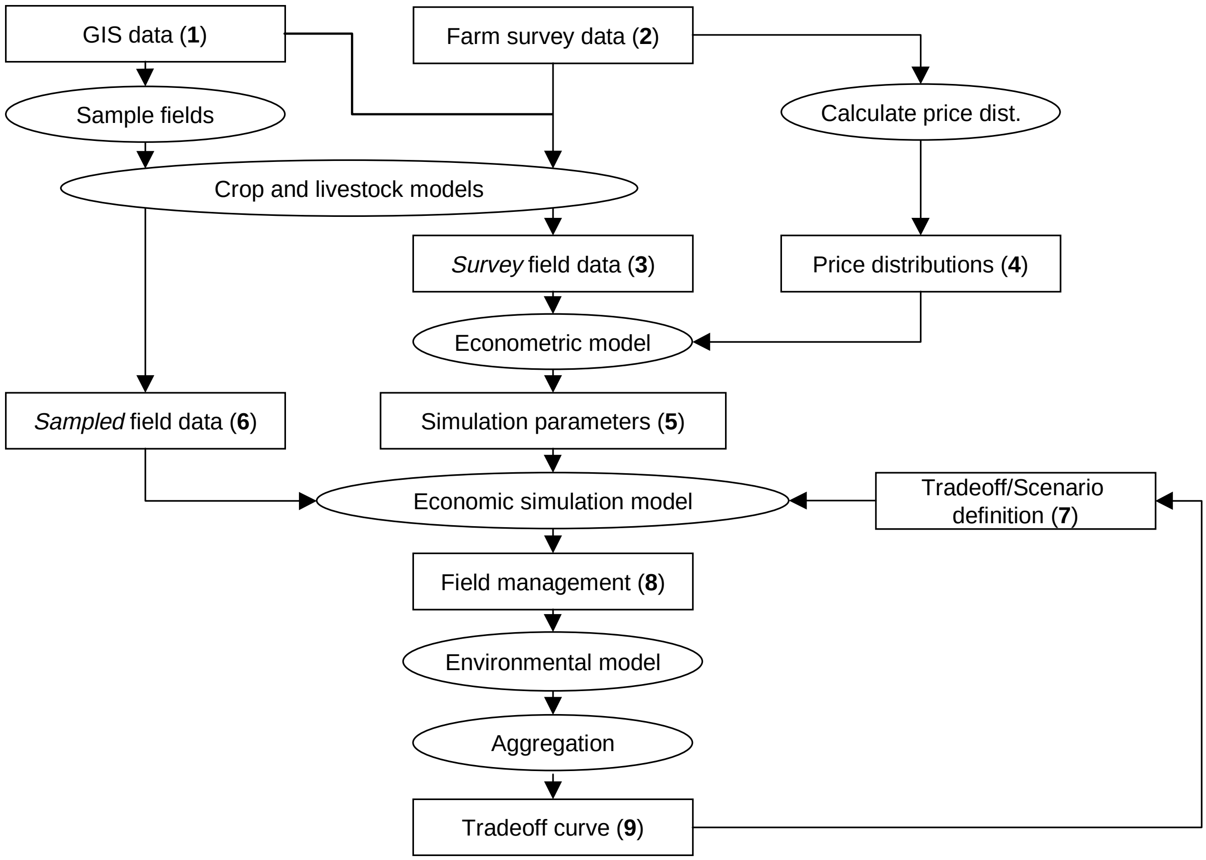

Figure 8 Structure of the Tradeoff model

A typical session of the Tradeoff model can be sub-divided into two parts. First, a number of operations need to be made only once to derive the proper model parameters. Second, a number of operations need to be done for each scenario run. The steps to create the model parameters are listed below. The numbers in parenthesis refer to the numered boxes in Figure 7:

- Establish the apropriate GIS (1) and farm survey database (2).
- Run the livestock and crop growth simulation models to calculate the inherent productivity of those fields. The inherent productivity is the expected productivity with average management and without problems of pests and diseases. After running the crop and livestock models the survey field data (3) are complete.
- Calculate price distributions (4) on the basis of the farm survey data.
- Estimate the simulation parameters (5) using the survey field data and the price distributions.
- Draw a set of *sample* fields from the GIS data. One can limit the set of sample fields by giving certain bio-physical constraints (in terms of *e.g.* soil type and altitude). In the present model setup pairs of X- and Y-coordinates are drawn randomly. The properties of the location are derived from the GIS databases and it is checked whether they fulfil certain criteria such as altitude or location in a watershed. If so, the point is used, if not a new pair of coordinates is drawn. On the basis of the different distributions in field sizes, the field size is drawn.
- Calculate the inherent productivity for the sample fields with the crop or livestock model and finalize the sampled field database (6).

At this point the economic simulation model is parametrized and we have a set of sample fields with the required characteristics. We are now ready to carry out the simulation runs to determine one tradeoff curve. Each scenarion will yield a scatter of simulation points that can be summarized into a trade curve. Each scenario run involves several steps:

- A tradeoff curve is defined as the set of outcomes generated by varying one parameter and hold other parameters constant. Here we generate tradeoffs by letting price parameters vary within a specified range under the assumption that expected productivity is monotonic in these price parameters. The tradeoff points (7) need to be defined, *i.e.* how are we going to shift the price distributions. Each tradeoff point is defined by a shift in the respective input and output prices: price of fungicide, carbofuran, other insecticides, dairy products and potatoes.
- The Scenario definition (7) includes a number of parameters that can be changed to simulate the effect of the introduction of new technologies, changes in input use efficiency, etc.
- All the previous results: the simulation parameters for the economic simulation models(5), the *sample* field database (6), and the Tradeoff/Scenario definition (7), are stored in separate files. To run the economic simulation model, one needs to define the filenames of the respective files. The SAS batch file with the economic simulation model is updated and run. Like with all the other external models, the model results are read by the tradeoff shell.
- The economic simulation model simulates crop selection and field management decisions for a particular field and given specific economic conditions (the tradeoff points) (8). The output of this model is, together with the bio-physical data of the fields, the input for the environmental impact model(s). These models are run after that the appropriate data files have been selected.
- Given the fact that several simulation runs will be carried out for the different fields under different economic conditions, the number of runs is large and results are therefore difficult to interpret. The tradeoff model is therefore capable to create a batch file for SAS that takes care of the user-specified aggregation (9).
- Finally, the results of alternative scenarios can be viewed in simple graphs.

Conclusions

The tradeoff model provides a tool to quantify economic, environmental and health tradeoffs. Crissman, Antle and Capalbo (1998) describe in detail the first phase of the project in Carchi, Ecuador and the considerations during the development of the model. Calculating tradeoffs was a rather cumbersome activity due to the large number of models involved. As a result the shell described in this report was developed to facilitate the operation of the tradeoff model. Although one might argue that the disciplinary models should be integrated into one large model, we believe that a modular approach is more useful. New applications of the methodology will require different models. The modular approach allows us to adapt the modeling framework to utilize other models. In the case of the crop growth simulation models, the data standards being used in DSSAT makes introduction of new models extremely easy. However, data standards for environmental process models and economic models are still lacking. Future developments of the tradeoff model will focus on data standards and how the model can be more generic so that it can be readily adapted to other applications.

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