

Tradeoff analysis as a quantitative approach to agricultural/environmental policy analysis

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Abstract

The Tradeoff Analysis Model is a modeling system being developed as a decision support tool for agricultural and environmental policy analysis and policy decision-making. This modeling system is designed to integrate disciplinary data and models at the field scale, then aggregate the economic and environmental outcomes to a scale relevant to policy analysis to quantify tradeoffs between economic and environmental policy objectives. The modeling system is utilized in a participatory process designed to place stakeholders, decision-makers, and scientists in contact. 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. This report briefly describes the conceptual basis for the tradeoff analysis, the data needed to implement the system, the disciplinary model components, and the operation of the model integration software that is called the Tradeoff Analysis Model. The ultimate goal of the research programs supporting the development of the Tradeoff Analysis 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 decision-makers. This tool is meant to be used by a team of 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 accuracy needed for policy analysis.

INTRODUCTION

This paper discusses tradeoff analysis as an organizing concept for a quantitative approach to integrated natural resource management research and agricultural and 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 (Crissman et al. 1998). This chapter also provides an introduction to a modeling system (Tradeoff Analysis Model) being developed as a decision support tool for agricultural and environmental policy analysis and policy decision-making (Stoorvogel et al. 2000). The modeling system is

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designed to integrate disciplinary data and models at the field scale, then aggregate the economic and environmental outcomes to a scale relevant for policy analysis so that tradeoffs between competing economic and environmental policy objectives can be quantified. The modeling system and data to support its development are based on research at two case study sites in Ecuador and Peru.

The ultimate goal of the research programs supporting the development of the Tradeoff Analysis Model is to construct a flexible software tool that can be used to integrate disciplinary data and models to provide information about agricultural production systems needed by policy decision-makers. The software system is intended to be used by a team of disciplinary researchers who will be able to adapt it to fit any production system. The modeling system described here is a prototype of this type of policy decision support system. For now it is designed to represent a specific production system - the potato/pasture (dairy) 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 accuracy needed for policy analysis.

Tradeoff analysis provides an organizing principal and conceptual model for the participatory 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 (stake-holders), 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 can be accommodated as well.

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. It is at this point in the tradeoff analysis process that the Tradeoff Analysis Model is used. Finally, the findings can be presented to policy makers and the general public.

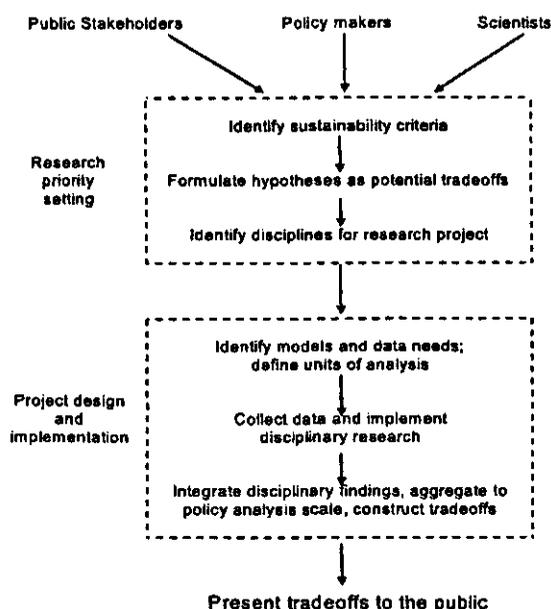


Figure 1. Research design and implementation process for tradeoff analysis (Crissman et al. 1998).

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. Environmental, agricultural and health characteristics of farmers, farmland, and farming technologies vary over space and time. Analysis of these complex, interrelated issues raises

difficult theoretical and methodological problems for researchers.

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. These regions contain populations of the units addressed by biological and physical sciences. If their data and results are to be useful for policy analysis, all researchers must address the aggregation problem, i.e., how to combine heterogeneous small units into a larger unit for policy analysis. While emphasis has been placed on the problem of spatial aggregation in the literature on geostatistics, there are also similar problems 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 analysis 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, for example, measures of economic returns, soil erosion, chemical leaching, nitrate movement through soil profiles, and the organic matter 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 Analysis Model is to link the site-specific management decisions of producers with environmental and health impacts. By conducting the analysis at statistically representative sets of sites, the site-specific outcomes can be aggregated to represent the relevant human and physical populations, and tradeoffs assessed at whatever scale 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 that are exogenous to the individual agent may become endogenous (i.e., determined by market equilibrium processes). It is important to emphasize that the Tradeoff Analysis 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 equilibrium. 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 et al. 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. Nevertheless, as is well known from the theory of general equilibrium, a production-possibilities frontier does not define equilibrium by itself. Rather, the production-possibilities frontier must be combined with the demand side of the economy to determine at which point along the production-possibilities 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 Analysis 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 transferable 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 Analysis 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 multi-attribute decision models, and without attempting to value impacts in monetary terms for benefit-cost analysis. Rather, the approach is to provide private and public decision makers with estimates of impacts, while the determination of subjective values is left to the individual decision maker and to the political process.

THE ANALYSIS OF SUSTAINABLE PRODUCTION SYSTEMS USING TRADEOFFS

The concept of tradeoffs between present and future outcomes of an agricultural production system can be used to analyze the concept of sustainability and provide quantitative measures of the sustainability of an agricultural production system. Figure 2 presents tradeoff curves between present and future outcomes of a production system that illustrate how tradeoffs can be used to quantify sustainability.

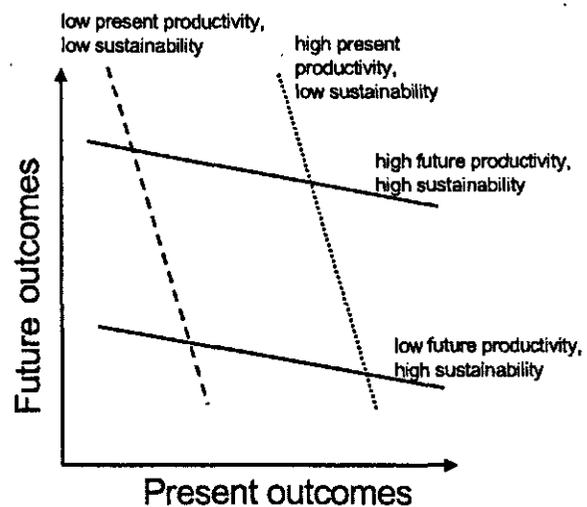


Figure 2. Tradeoffs between present and future outcomes at both low and high levels of productivity and sustainability.

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 exhibit either low or high levels of productivity may also 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 et al. (1998).

TRADEOFF ANALYSIS 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 ecoregions 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; and 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 Analysis Model provides a methodology for the implementation of research within the eco-regional paradigm.

A recent review of the eco-regional approach commissioned by the Technical Advisory Committee of the Consultative Group on International Agricultural Research finds continuing strong support for the eco-regional 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 that indicates 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.

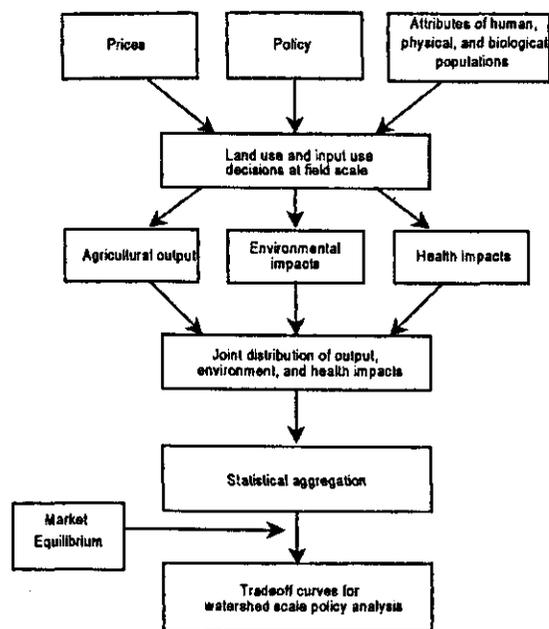


Figure 3. Conceptual framework for disciplinary integration and policy analysis (Crissman et al. 1998).

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.

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 Analysis Model (Figure 4). They utilize two perpendicular axes to represent combinations of research procedures. One 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 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).

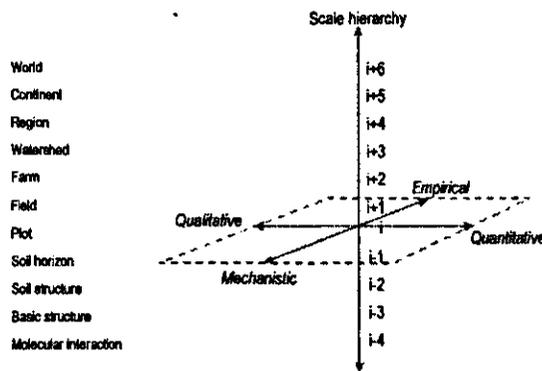


Figure 4. Classification scheme for research procedures (Hoosbeek and Bryant, 1992).

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 focuses on one aspect only, often with a disciplinary character (quantitative, mechanistic)

Tradeoff analysis allows us to work at different scale levels using different research approaches. The lines in Figure 5 represent the so-called "research chain" that corresponds to the Tradeoff Analysis Model. The Tradeoff Analysis Model demonstrates how the problem is analyzed using different research procedures at different scales. The problem definition of the Tradeoff Analysis 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?

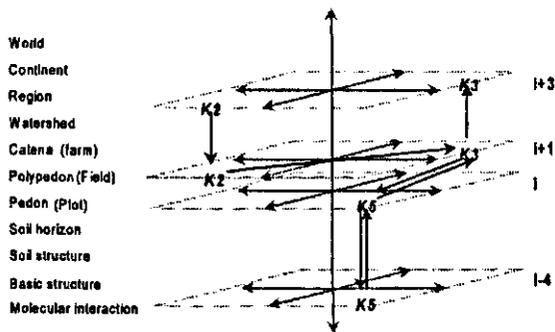


Figure 5. An illustration of a research chain representing the sequence of research activities at different scale hierarchies for the Tradeoff Analysis Model.

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 within the field. While simulating crop growth and pesticide leaching at the point level we use quantitative, mechanistic simulation models (K5). Such

models take into account processes such as nutrient uptake by roots, mineralization of organic matter, and adsorption/desorption of pesticides, which are processes that occur at both the plot 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).

As indicated in Figure 5, the Tradeoff Analysis 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 biophysical 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 Analysis Model 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, an exploratory soil survey is available covering the whole study area in the existing case study sites (Ecuador and Peru). Typically one would use this soil survey, describe representative soil profiles for the different mapping units, and use these 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. Relations 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 at less cost.

Again, detailed economic information exists for the case study sites. Field-scale economic data originate from a dynamic survey of farmers' land use and management practices. In the Ecuador study of Crissman et al. (1998), a representative sample of the fields in the study area was 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 were estimated. These sample distributions were 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 observed large differences within the region. A single distribution for the entire study area does not describe accurately the variation in field size. Instead we subdivided 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 at different points. 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 then defines a tradeoff curve.

Tradeoff Analysis Model Structure and Software

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

Data

The model begins with two types of data. Soil and climate data are organized in a GIS format and they are used as inputs to the biophysical 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. 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

Crop models are used to estimate the spatial and temporal variation in inherent productivity of the land that is determined by variations in soil and climate. 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.

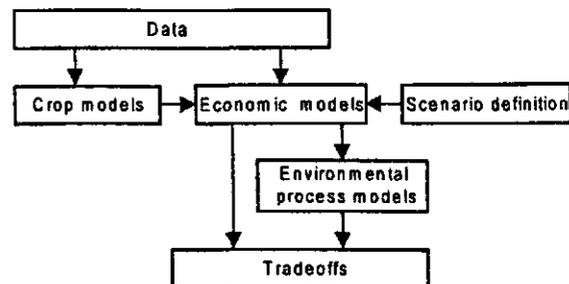


Figure 6. The general structure of the Tradeoff Analysis Model.

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 production) and environmental outcomes from the environmental process models (e.g. pesticide loading to the environment, soil erosion) are aggregated. The different price 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 Analysis 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.

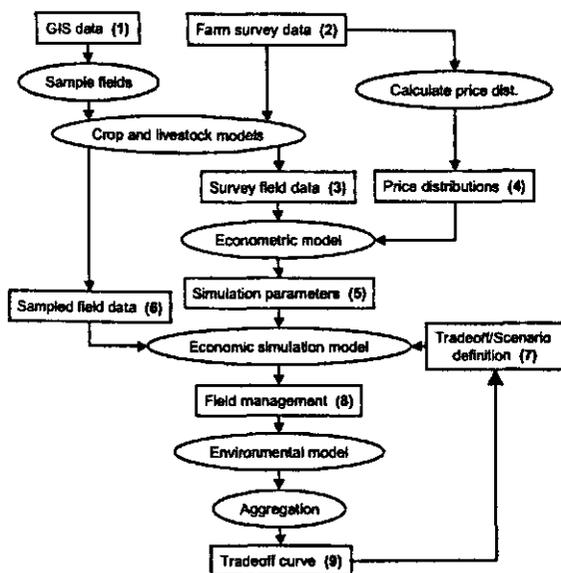


Figure 7. Structure of the Tradeoff Analysis Model

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 in Ecuador 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 works with different input and output files. The main shell has been programmed in Borland Delphi Version 4.0⁵. 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 programmed in SAS⁶, and for the simulation of pesticide fate, a modified version of LEACHP is used (Wagenet and Hutson, 1989). The Tradeoff Analysis Model shell moves the necessary input and output data among the different models and provides a format for the coordination of different scenario runs.

A typical session of the Tradeoff Analysis 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 numbered boxes in Figure 7.

- Establish the appropriate 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 distribution (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 biophysical constraints (e.g., by soil type or by altitude). In the present model, 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, soil type 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).

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At this point the economic simulation model is parameterized 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 scenario 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 while holding other parameters constant. Here, we generate trade-offs 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, i.e., 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 these respective files. The SAS batch file with the economic simulation model is updated and run. Like with all the other external models, the tradeoff shell reads the model results.
- The economic simulation model simulates crop selection and field management decisions for a particular field and the specified economic conditions (the tradeoff points) (8). The output of this model is, together with the biophysical 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 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 Analysis Model therefore contains 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 Analysis Model provides a tool to quantify economic, environmental and health tradeoffs. Crissman et al. (1998) describes in detail the first phase of the project in Carchi, Ecuador and the considerations during the development of the model. Initially, the calculation of tradeoffs was a rather cumbersome activity due to the large number of models involved. Hence, the Tradeoff Analysis Model shell described in this report was developed to facilitate the construction of tradeoff curves and the communication between models and data. 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 make introduction of new models extremely easy. However, data standards for environmental process models and economic models are still lacking. Future development of the Tradeoff Analysis 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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