The Tradeoff Analysis Project Phase 2: Scaling Up and Technology Transfer to Address Poverty, Food Security and Sustainability of the Agro-Environment

Problem Statement and Objectives

To achieve the goals of the SM-CRSP, i.e., to enhance farm and rural incomes in the near term without compromising their long-term productivity and sustainability, there is a compelling need to provide decision makers – from the farm and community level to the national and international policy levels – with accurate information about the economic and environmental consequences of their decisions.

This research addresses the need in developing countries to generate the farm and regional-level information demanded by decision makers to assess: the sustainability of existing technologies; the potential for adoption of economically and environmentally sustainable technologies; and the economic and environmental consequences of policy decisions for poverty, food security, and sustainability of the agro-environment.

The first phase of the Tradeoffs Project developed a *policy decision support system* based on tradeoff analysis of agricultural production systems, and applied that system to two watersheds in Ecuador and Peru. The first phase emphasized the development of the Tradeoff Analysis (TOA) method, and analytical tools to implement it (data, models and software for their integration). A significant product of the first phase was the Tradeoff Analysis Model©, computer software that integrates disciplinary data into standard geo-referenced formats, and provides a modular capability to link existing disciplinary simulation models to support the TOA method.

The TOA method is a *process* based on collaboration between stakeholders and multidisciplinary research teams. The process begins with identification of *sustainability indicators* for a production system deemed relevant by the stakeholders, the formulation of hypotheses about their interrelationships (*tradeoffs*), and the development of *technology and policy scenarios* to be assessed. The research team generates suitable data and parameterizes models to quantify sustainability indicators. These models are simulated and to assess how tradeoffs among sustainability indicators respond to technology or policy scenarios. This information is used by stakeholders and researchers to assess impacts and design strategies to improve the economic viability and sustainability of production systems. For further details, see Stoorvogel, Antle, Crissman, and Bowen (2001) and the various other reports and publications on TOA at *www.tradeoffs.montana.edu*.

In the first 5-year phase of this research project, the TOA method was implemented in Ecuador (in collaboration with the national agricultural research program, INIAP) and in Peru (in collaboration with the national soil conservation program, PRONAMACHS, and the national agricultural research program, INIA) to assess tradeoffs associated with pesticide leaching, water and tillage erosion, terracing, agro-forestry, and related soil management technologies. These applications provided the first tests of the TOA method and TOA Model software. Based on lessons learned from our first phase of work, as well as comments from the SM-

CRSP External Review and from the Phase 2 preproposal review, we propose the following activities in the next 5-year phase:

- Further develop and refine the existing TOA method and TOA Model software, through applications with collaborating institutions in the Andes, Central America, and Africa.
- Develop methods to scale-up the analysis possible with the TOA method from single agro-ecozones (e.g., watershed scale) to larger regional (sub-national or national) scales. Important components of the research will be:
    - methods to assess impacts of soil management technologies and related policies on poverty and food security at regional scales
    - methods to scale-up results from participatory research and assess transferability of soil management technologies across agro-ecozones.
- Development of protocols and materials to transfer the TOA method and the TOA Model software to existing and future user groups.

Identification of Objectives and Constraints

This project will address the following SM-CRSP objectives and corresponding constraints:

1. Develop methodologies to scale up technology adoption from participatory scales to national and regional scales. The project will develop a new approach to assess the transferability of soil management technologies. We will extend the statistical methods for ex post assessment developed in earlier research (Winters, Espinosa, and Crissman, 1998) by linking these methods to biophysical and socioeconomic data to identify agroecozones with characteristics associated with successful technology adoption in participatory research. We will also collaborate with scientists from the International Center for Tropical Agriculture (CIAT) who are developing related geo-statistical methods for scaling-up data and models. These methods will be applied to analysis of the technologies being developed in Ecuador, Peru, Honduras and Africa in participatory research programs.

3. Develop methodologies that enable households and institutions to assess and anticipate consequences of technology adoption. The TOA method is designed specifically to integrate biophysical and economic data and models, and to conduct scenario analysis of the economic and environmental tradeoffs associated with adoption of technologies. This information can then be communicated to decision makers at all levels, from the farm level to national policy makers. Phase 1 of the Tradeoffs Project demonstrated the effectiveness of this approach in the assessment of health impacts of technology adoption (pesticide use) in Ecuador, and assessment of soil erosion impacts and options in Ecuador and Peru. Our research in Phase 2 will investigate how the information generated by the TOA method can be integrated into the participatory research and training activities of CIP, CIAT and ILRI.

4. Develop methodologies that provide farmers, government agencies and the general public with information needed to design policies that encourage adoption of production practices that are compatible with the long-term conservation of agricultural resources. The TOA method is specifically designed to assess the impacts of alternative policies on the economic and

environmental sustainability of agricultural production systems. In Phase 1 of the Tradeoff Project, the TOA method was adopted by the PRONOMACHCS program in Peru to assess the viability of its policy to subsidize investments in terracing as a means to combat soil erosion. In Phase 2, we will improve and apply the TOA method to support policy decision making through collaboration with PRONAMACHCS in Peru, with the national agricultural research program in Ecuador, with the CIAT Hillsides project and its partners in Honduras and Central America, and with the University of Florida-University of Hawaii-Cornell SM-CRSP carbon project in West Africa.

5. Accelerate technology transfer by applying existing methods to soil management products and practices. Application of the TOA method will provide decision makers with better information about where technology transfer is likely to be successful and where environmental impacts are likely to be positive or negative. Applications in the first 2-3 years of Phase 2 will include: soil fertility management, terracing and agroforestry technologies in Peru; technologies to increase productivity and sustainablility of crop-livestock systems in Ecuador, including methods to improve soil fertility and reduce tillage erosion; and technologies being developed by CIAT to reduce soil degradation and increase agricultural productivity in the fragile hillside soils of Central America, and methods to improve soil fertility and sequester soil carbon in West Africa. Applications elsewhere are anticipated in years 4-5, implemented by institutions adopting the TOA method.

6. Apply multidisciplinary methodology to facilitate decision making at different levels in the agroecosystem. The TOA method provides a common language of *sustainability indicators, tradeoffs, and scenarios* to be used by stakeholders (ranging from farmer and community organizations to national policy makers) and scientists. The TOA method is premised on collaboration between stakeholders and the scientific team conducting the tradeoff analysis. Communication is fostered through the use of this common language, and through the process of discussing and identifying the set of sustainability indicators and policy and technology scenarios to be incorporated into the tradeoff analysis. Research in Phase 2 will further apply the TOA method in the Andes, Central America, and Africa. These applications will involve a wide range of stakeholders, including farmer organizations in the study sites, agricultural research organizations, and local and national governmental and non-governmental organizations involved with agricultural development.

7. Develop practical methods to measure gains and losses of soil organic carbon over time in spatially variable soils. Research conducted by project PIs has demonstrated that critical aspects of soil C measurement for use in carbon sequestration projects – e.g., the spatial scale over which measurements need to made, and the required accuracy of the measurements – depends critically on the design of incentive mechanisms (policies or contracts) for soil C sequestration. Research in Phase 2 of the TOA project will further investigate these issues in relation to soil C sequestration projects designed to enhance adoption of improved soil management practices. In addition, Phase 2 of the TOA project will collaborate with ICASA (International Consortium for Agricultural Systems Applications) and the SM-CRSP project on soil C sequestration measurement and modeling, to link the recently developed DSSAT-Century soil C model with the TOA Model software. We will work with user groups to assess the impacts of soil management technologies (e.g., improved soil fertility management,

improved forages, tillage practices, terracing) and policies (e.g., input and output price subsidies, market infrastructure development) on soil C.

Project Strategy

The strategy of the proposed Phase 2 Tradeoffs Project is to build on the success of the Phase 1 project. According to the External Evaluation Panel's (1999) review of Phase 1,

"The Tradeoffs Model is uniquely suited for global replication. We see an opportunity to use the conceptual framework of the Tradeoffs Model to advance natural resources management research and development activities in multiple applications."

The reviewers of our Phase 2 pre-proposal advised us to carry out an additional set of applications to further develop the TOA method and TOA Model software, before undertaking its global dissemination. Accordingly, Phase 2 will involve further applications with existing collaborators in Ecuador and Peru, and new applications working with CIAT in Honduras and the International Livestock Research Institute (ILRI) in Africa. We will use these collaborations to further test the existing TOA method and TOA Model software, and to make further advances as described below. While these further applications are being implemented, we will continue to present the TOA method as a viable analytical process in regional and international fora.

A key lesson learned from collaborations in Phase 1 was that the various national and international organizations that are potential users of the information produced by applications of the TOA method have different capabilities to use the TOA method and TOA Model. Some organizations, such as international agricultural research centers, have the scientific capability to build the multidisciplinary teams of scientists needed to implement a study using the TOA method and software. Other organizations, such as national agricultural research institutes or soil conservation agencies, need the information produced by the TOA method but may not have the scientific capability to adapt the simulation models for new applications. Therefore, in Phase 2 we will pursue a two-pronged strategy for direct collaborations. First, for institutions with the capability to build scientific teams that can use the TOA method independently (such as Ecuador's national agricultural research institute INIAP, and CIAT and ILRI), we will design collaborations to build teams within those institutions. Second, for institutions such as PRONAMACHCS in Peru that cannot build an in-house scientific team to support the implementation of the TOA Model, we will develop collaborations to train staff in the TOA method, but the project's scientific team will provide the support needed to implement the TOA Model.

There is already a remarkable level of interest in the TOA method and related quantitative approaches to integrated natural resource management (INRM). The Consultative Group for International Agricultural Research (CGIAR) has an INRM working group focused on research methods development. There are also systemwide programs of the CGIAR such as the Global Mountain Program and the Systemwide Livestock Program that utilize integrated modeling approaches to agricultural and environmental problems. The integrated analysis done with a

modeling focus that is the basis of the TOA Model also is a core interest of the International Consortium for Agricultural Systems Analysis (ICASA). The Tradeoffs Project research team is and will be actively participating in these scientific networking fora.

The target sites for applications of the TOA method are located in regions of widespread and extreme poverty. The rural agricultural regions of the central and northern Andes, the hillside agriculture zones of Central America, and marginal agricultural areas of West Africa are home to many millions of poor rural families that desperately need to intensify their farming practices while sustaining and enhancing the future productivity potential of fragile environments. The mixed crop-livestock agriculture practiced by these farmers is typical of most small-holder farming, and the environmental problems of hillside agriculture and the sub-Sharan region are of immediate concern to the SM-CRSP.

Work Plan

Methodological Developments (Objectives 1, 3, and 4)

This component of the project will provide for: (1) further improvements in disciplinary data and models, including development of minimum data sets and simplified models, and methods to assess the effects of minimum data sets, simplified models, and up scaling on the accuracy of the information produced by the TOA method; (2) further development of linkages between crop, livestock, environmental, and economic models; (3) addressing the fundamental challenge of scaling-up site-specific data and models used in agricultural systems analysis from the field and farm scale to higher (i.e., regional and national) scales; (4) further developments in the TOA Model software.

1. *Improvements in disciplinary data and models.*

Biophysical Data and Models. Extension of research conducted in Phase 1, including:

- *Disaggregating soils and climate data.* In Phase 1 a cost-effective methodology for obtaining high-resolution soils data for model inputs was developed for the specific conditions of Ecuador, and was also applied in the Cajamarca site in Peru (Van Soest, 1998; Overmars, 1999). In Phase 2 we plan to standardize this methodology and further apply it and test it in other locations in Ecuador, Peru, Honduras, and Africa.
- *The development of data standards for the environmental process models.* The TOA Model software is based on the concept of modularity giving the software its generic character. As a result of the data standards developed by ICASA for data input and output for crop growth simulation models (Hunt and White, 2000), and the implementation of these standards in a large number of simulation models, it is possible to use any of these models with the TOA Model software. However, such standards have not been developed for environmental process models. One challenge of environmental models is that they are more varied in their data inputs and types of outputs. Our goal is to begin the process of developing ICASA-style standards for the environmental process models that we are using with the TOA Model, including leaching and erosion models. We will use our participation in the scientific networking fora mentioned above to introduce and promote this concept.

- *Procedures for the calibration and validation of crop growth simulation models (in collaboration with ICASA and other SM-CRSP projects that use crop models).* New applications of the TOA method require the use of crop growth simulation models from the suite of models in Decision Support System for Agricultural Technology Transfer (DSSAT; Jones et al., 1998). However, standard procedures for the calibration and validation of these models as they are applied to new sites are lacking. Our goal is to develop and document a set of cost effective procedures for calibrating and validating crop models.

Economic Data and Models. Extensions of topics investigated in Phase 1, and new topics, including:

- *Methods to parameterize economic models using minimum data sets and secondary data.* The applications of the TOA Model thus far have been based on the collection of field-scale and farm-scale data using dynamic surveys (surveys conducted through periodic collection of data from respondents). Such data are accurate but also costly and time-consuming to obtain. As part of our work to increase the efficiency of implementing the TOA method, one goal will be to use data collected in Phase 1 to assess the quality of analysis produced with less detailed secondary data. Research conducted as part of Phase 1, as well as research conducted by related projects of the PIs will be utilized here (Antle et al., 2000a).
- *Methods to analyze dynamic processes associated with land degradation and with investments in soil conservation technologies.* Land degradation introduces a dynamic aspect to the analysis of a production system that has implications for the design of economic models (Antle and Stoorvogel, 2001). Various soil conservation technologies have been developed such as terracing and agroforestry. Adoption of these technologies requires an investment in the near term that returns benefits over many years. Our research during Phase 2 will extend the work done in Phase 1 to further develop the capability of the economic models used in the TOA Model to address the dynamic interactions among crop and livestock productivity, land quality, and economic decision making.
- *Models to analyze soil carbon sequestration.* To support our collaboration with the FHC carbon sequestration project in the SM-CRSP, we will incorporate recent developments in economic analysis of soil carbon sequestration into the economic models used in the TOA model (Antle et al 2000c, 2000d, Antle and McCarl 2001). This will involve modifying the economic simulation models to input soil C rates from the DSSAT-Century model, and to incorporate this information into the land use and management decisions simulated in these models.
- *Development of data standards for economic models following the ICASA approach for crop models.* Research in Phase 1 developed a set of generic econometric production models for use in the econometric-process simulation model developed for the TOA Model. In Phase 2, our goal is to further standardize input and output data for these models, following the approach used by ICASA for crop models.

2. Further development of linkages between crop models, livestock models, environmental models, and economic models.

In the current version of the TOA Model, crop and livestock models are used to estimate site-specific inherent productivity. The estimates of inherent productivity are then passed to the economic models and used to help predict spatial variation in management. We refer to this

type of model linkage as loose coupling of disciplinary models (Antle et al., 2000e). For some purposes, a closer coupling may be needed:

- To account for dynamic linkages between bio-physical processes such as crop growth or pests and management decisions such as fertilizer and pesticide use, and the dynamics of land degradation processes.
- To account for spatial inter-relationships between land units (referred to recently in the literature as spatial externalities) caused by processes such as erosion and runoff.
- To link economic models to integrated crop-livestock models being developed in the Ecoregional Fund project at ILRI.

Research on the integration of biophysical and economic models is being funded at Montana State University by the USEPA (Antle et al., 2000b). These developments as well as additional developments by Tradeoffs Project PIs will be incorporated into the TOA Model framework in Phase 2.

3. Methods for Scaling Up TOA and Incorporation of Indicators for Poverty and Food Security.

The application of tools for regional land use analysis is significantly constrained by the availability of reliable data. The TOA method also faces significant data needs to capture accurately the spatial variation in productivity caused by a high degree of spatial heterogeneity. Nevertheless, to make the TOA method widely applicable without large investments in data collection, we need to assess the effects of data aggregation and up-scaling of data and models, and we need to develop methods that can work reasonably well with less detailed data to the degree possible. It is therefore extremely important to define minimum data sets, develop cost-effective methods to obtain those data, adapt the methodology to fit better with available data sets, and develop methods to scale-up analysis.

Research conducted in Phase 1 established that when spatial heterogeneity is high, as it typically is in the environments of tropical hillside agriculture, estimates of the productivity impacts of resource degradation may be seriously downward biased if sufficiently disaggregate data are not used (Antle and Stoorvogel, 2001). In ongoing research by the project PI and collaborators funded by NSF (Antle, Capalbo, Mooney, and Paustian, 2001a), methods for assessing the benefits and costs of conducting analysis at alternative spatial scales are being developed in relation to the degree of spatial heterogeneity of the data. Related research on up-scaling data for quantitative analysis has been conducted by CIAT scientists (CIAT, 2000). These developments will be used to assess the loss of accuracy in the TOA Model associated with model simplification, aggregation and up-scaling. Based on these results, recommendations for minimum data needed for application of models used in the TOA Model will be developed to guide users.

In Phase 1, the sustainability indicators that were used were current and future agricultural production, pesticide leaching, human health risk, and soil erosion. To increase the usefulness of the TOA method for regional and national policy analysis of poverty and food security, work in Phase 2 will expand the sustainability indicator set to include broader social measures of well-being, including measures of income, income risk, income distribution, and food security. This work is closely related to the methodological developments discussed above, but

also goes beyond them in several critical respects. As noted earlier, a key challenge is to link the TOA method with broader data and tools that can support analysis not just of agricultural production, but analysis of farm households and of rural populations (both farm and non-farm rural households).

- *Incorporation of household decision making into the farm-level economic models*. A first step that can be taken within the existing modeling framework is to broaden the economic models beyond agricultural production to incorporate other household decisions and constraints. The existing body of literature on household production models could be utilized, but existing models have high data demands (e.g., see the various studies in Heerink, van Keulen, and Kuiper, 2001). The econometric-process simulation model methodology developed by the PI (Antle and Capalbo, 2001) is well suited to incorporate the effects of key household constraints on production decisions, such as family labor availability and financial constraints, without requiring the large amount of data needed to estimate complete structural household models.
- *Linkage of TOA Model software to census and other social and economic data.* Various census and other social and economic data are available in most regions of the world. Such data can be incorporated into the TOA Model software to facilitate spatial analysis of impacts of policy interventions on poverty, food security, and income distribution.
- *Linkage of TOA Model to data available at differing spatial scales and across large geographic regions.* Remotely-sensed data on topography, land cover, and land use, as well as socioeconomic data from population and agricultural censuses, are available for large geographic regions. We will link our research on up-scaling to these kinds of data in order to extrapolate the TOA method findings to regions that have similar biophysical and socioeconomic characteristics.

4. Further Developments in TOA Model Software

With the adaptations of biophysical and economic data and models, continued improvements in the TOA Model software are anticipated. In addition, the software will undergo modifications and improvements through interactions between the project's research team and users of the software. Anticipated improvements include adaptations of the software to incorporate the methodological developments from this phase of work. Additionally, we intend to develop online documentation and a web page for interaction between project PIs and users.

Applications of the TOA Method (Objectives 5 and 6)

The target groups for our work are farmer and community organizations, as well as sub-national, national and international governmental and non-governmental organizations that have a responsibility to make decisions that impact the development and adoption of soil management technologies. The principal groups and locations for the first 2-3 years of the Phase 2 work are described below. During years 3-5 of the project, our plan is to disseminate the TOA method more widely, working through the regional and global networks of the international agricultural research centers.

- **INIAP (National Agricultural Research Institute), Ecuador.** Building on the long-standing and successful collaboration between CIP and INIAP researchers, our goal is to support

the development of a research team within INIAP with the capability to apply the TOA method and tools to support decision making by the Ministry of Agriculture in Ecuador. We will collaborate with two funded research projects that have adopted the TOA method:

- *Eco-soils: Investigation for the ecological management and productivity of soils in the Ecuadorian Andean Eco-region*. This is a CIP-INIAP-IFDC-University of Guelph collaboration financed by the Competitive Grants for Research fund of the Agricultural Services Modernization Program (PROMSA) of the Ecuadorian Government. This project sought collaboration with the Tradeoffs Project to assess technology scenarios including the utilization of improved soil cover for erosion prevention, and improved soil organic matter management through soil amendments and use of cover crops.
- *Strengthening research capacity for productivity improvement and sustainability of mixed livestock-crop systems in the Andean eco-region*. This is a CIP-IFDC-ILRI-INIAP collaboration financed by the Strategic Alliance fund of PROMSA. This project sought collaboration with the Tradeoffs Project to examine scenarios of sustainability of mixed crop-livestock systems in four sites in the Ecuadorian Andes. These scenarios include rotations of pasture with different crops and increases in animal carrying capacity.

- **PRONAMACHCS (National Watershed Management and Soil Conservation Program), Peru**. PRONAMACHCS is a national institution that became a user of the TOA method in Phase 1 of the Tradeoffs Project, but lacks the in-house scientific capability to adapt the TOA Model to new applications. During the last year of our Phase 1 work, we are using the TOA method to conduct an assessment of the conservation technologies (e.g., terracing and agroforestry) being promoted by PRONAMACHCS in the Cajamarca region of Peru in collaboration with PRONAMACHCS staff. As a part of that collaboration, we are training PRONAMACHCS staff in the use of the TOA method and TOA Model. Our goal in Phase 2 is to extend this collaboration to evaluate the PRONAMACHCS conservation technologies in other regions of Peru, and to further develop the capability of PRONAMACHCS staff to use the TOA method. We also intend to work with PRONAMACHCS to investigate the potential for a soil carbon sequestration program in Peru, and if the potential is high, we intend to work with PRONAMACHCS to develop a pilot soil carbon sequestration program.

- **CIAT, Project on Community Management of Natural Resources in Hillside Agroecosystems of Latin America.** The Tradeoff Analysis project was invited by the SM-CRSP Phase 2 Preproposal Reviewers to develop a collaboration with the CIAT Hillsides project in Honduras. In January 2001, two Tradeoffs Project PIs (Antle and Stoorvogel) visited CIAT headquarters in Cali and the CIAT Hillsides project reference site in Honduras. Based on this visit and discussions with CIAT leadership, we are proposing in Phase 2 to initiate a new collaboration with the CIAT Hillsides project. The objectives of this collaboration are as follows:
  - *Develop a multidisciplinary research team in Honduras with the capability to use the TOA method to support research and policy decision making associated with the CIAT Hillsides project*. The CIAT Hillsides project is working at a watershed-scale

reference site in the Yoro region of north-central Honduras. At this reference site, CIAT is developing technologies and agroenterprise strategies to address the problems of resource degradation and poverty. TOA will be used by the research team to assess the potential for CIAT technologies to increase incomes and reverse the widespread degradation of the fragile hillside soils, under various economic and policy scenarios. The research team will also work with the CIAT Hillsides project to communicate this information to regional and national stakeholder organizations (including NGOs and national government agencies) to support more informed decision making by these organizations.

- *Collaborate with CIAT scientists in further development of scaling-up methods for the TOA method*. The Tradeoffs Project PIs will collaborate with the CIAT-TOA team and other CIAT scientists on the methodological developments outlined above.
- *Collaborate with research organizations and development organizations in Honduras and other Central American countries and disseminate the TOA method*. Miguel Ayarza, director of the CIAT Hillsides project in Honduras, recently organized the Integrated Soils Management (MIS) consortium. This consortium consists of 18 Central American and South American research organizations, universities, and NGOs working on integrated management of fragile soils throughout Central America. MIS is one of four consortia that comprise the CGIAR systemwide program on Soil, Water and Nutrient Management. The CIAT-TOA team will work through the MIS consortium to disseminate the results of the CIAT-TOA work and to identify other target groups for dissemination of the TOA method.

- International Livestock Research Institute. PI Crissman will relocate from Quito to Nairobi in June 2001. He will assume leadership to develop an application of the TOA method in collaboration with Philip Thornton at ILRI and the Florida-Hawaii-Cornell SM-CRSP carbon project. Crissman will collaborate with Thornton in the design of data collection in the FHC project and will train African collaborators in the use of TOA and the TOA Model. Our goal is to incorporate the DSSAT-Century and ILRI crop-livestock models into the TOA Model framework, and to use the TOA method in a manner that parallels the work with the CIAT Hillsides project in Honduras. We hope that these first applications of the TOA method in Africa will create interest among other potential user groups in Africa.

Dissemination of the TOA Method and Training of User Groups

A significant component of the work in years 4 and 5 of the project will be the production of scientific and popular publications derived from the methods developments and applications in years 1-3. In addition, a book-length manuscript composed of chapters written by the participants in the project will be a major product of years 4 and 5. This manuscript will be submitted to a commercial publisher.

Another major component of years 4 and 5 will be the development of training materials and workshops for dissemination of the TOA method and tools to other user groups. This activity

will respond to the SM-CRSP External Review recommendation that the TOA be applied globally. Our goal is to work through the various networks of research organizations and development organizations. For example, in January 2001 Jetse Stoorvogel presented the TOA method and TOA Model in a regional training course on policy and institutional reform for sustainable rural development organized by the World Bank Institute in India. A similar training course is being organized by Stoorvogel (to be held February 2001) for the Graduate School of Production Ecology at Wageningen University and the Ecoregional Research Fund. We anticipate that continued involvement in these types of activities will generate a demand for the TOA products during the later years of this project.

The project will also develop a support site on the world-wide web for users of the TOA method and software. We are aware of other programs that have developed successful web sites for this purpose and plan to learn from those experiences in developing our web site.

Collaborative Relationships

Collaboration within the SM-CRSP. The Tradeoffs Phase 2 project will collaborate with two other proposed projects for Phase 2:

- **The University of Florida-University of Hawaii-Cornell University Carbon Project.** The goal of this collaboration is to incorporate the DSSAT-Century model developed by Jim Jones and collaborators into the suite of models that can be implemented within our Tradeoff Analysis Model software, and modify the economic models within the TOA framework so that they can be used for analysis of soil C sequestration. We will then implement this DSSAT-Century-TOA modeling system in a series of case studies:

    - We plan to implement a first pilot project for soil C sequestration as an extension of our analysis of terracing and agroforestry programs in Cajamarca, Peru. We plan to support the parameterization the DSSAT-Century model for the principal crops in the Cajamarca site (potatoes, grains, beans and peas, dairy) and link it to the Tradeoff Analysis Model. We will also use this modeling setup to incorporate a soil C analysis into our application of Tradeoff Analysis in Honduras.

    - We plan to collaborate with Philip Thornton at ILRI (who is also a collaborator in the FHC project) to include application of the DSSAT-Century-TOA modeling system to one or more of the sites in West Africa where the FHC carbon project will be working. Charles Crissman, working for CIP but based at ILRI in Nairobi, will lead our collaboration with Thornton. He will advise Thornton on data design to support application of the TOA modeling to the West African sites, and will assist with training of African collaborators in the use of the TOA approach and software.

- **The North Carolina State NuMass Project.** Our plan is to facilitate the dissemination of the NuMass decision support system in the Andean region, working with CIP's Papa

Andina regional project in Ecuador, Peru and Bolivia, and with the MOSAndes consortium that Walter Bowen has helped create and lead. This collaboration would also provide the impetus for exploring possible synergies and linkages between the NuMass decision support system and the Tradeoff Analysis approach and software. Some specific points of collaboration will be: training user groups how to use NuMaSS; validating nutrient diagnosis and NuMass recommendations; and using the TOA Model to assess the economic and environmental implications of the NuMass recommendations in Ecuador, Honduras and Peru.

International Potato Center (CIP). The well-established relationship with the natural resource management program at CIP will continue, based at CIP's Quito facility. CIP staff involved will include Charles Crissman in Nairobi, Walter Bowen at CIP-Quito, Roberto Quiroz at CIP-Lima, and a jointly funded economist position based at CIP-Quito. The person in this jointly funded position will have responsibilities for research, project management, collaboration with established user groups, and dissemination of TOA to new users.

International Fertilizer Development Center (IFDC). Walter Bowen has a joint posting with CIP and IFDC. His presence on the Tradeoffs Project team provides a linkage to this center of expertise in soil fertility management.

International Center for Tropical Agriculture (CIAT). CIAT will support the TOA project's collaboration with its Hillsides project in Honduras and Central America through a significant commit of time of a senior scientist, support staff, vehicles, and joint support of an economist position similar to the arrangement with CIP. CIAT will catalyze the interaction of project staff with the systemwide Soil Water Nutrient Management program in both Central America and Africa.

International Livestock Research Center. Philip Thornton at ILRI has agreed to collaborate with the project as described above.

The Ecoregional Fund. In Phase 1, the Ecoregional Research Fund supported various project activities related to methodological developments in collaboration with the Tradeoffs Project. The Fund has expressed interest in co-financing further development and application of the TOA method. However, the Fund could not make a commitment at the time this proposal was submitted.

INIAP (National Agricultural Research Institute), Ecuador. Victor Barrera, Head of the Department for Technology Validation and Transfer of INIAP in Ecuador, a collaborator in Phase 1, will be the leader of the TOA team that will be developed during Phase 2. He is also co-PI (with Walter Bowen) of the INIAP projects using TOA described above.

PRONAMACHCS (National Watershed Management and Soil Conservation Program), Peru. The group of PRONAMACHCS staff that were trained in use of the TOA method in 2001 will provide the core group of collaborators in Phase 2.

MOSAndes (Consortium for Soil Management in the Andes). MOSAndes, a consortium representing a total of 51 investigators from six countries, has funding from the Ibero-Americano Program on Science and Technology for Development (CYTED) to facilitate scientific exchanges and regional workshops for a four-year period beginning January 2001. Walter Bowen helped found this consortium which will be collaborating with the the Tradeoffs Project in Phase 2.

SANREM and IPM CRSPs. We expect to continue to collaborate with the IPM CRSP in Ecuador. We expect that a collaboration with the SAMREM CRSP activities related to soil carbon sequestration will be initiated in 2001 after this proposal is submitted.

USAID Missions. The Honduras mission has expressed interest in SM-CRSP support for impact assessment, and we plan to pursue this opportunity to support USAID. We will continue to disseminate our findings through the USAID missions in the other countries where we are working.

Other Potential Collaborators. As noted earlier, collaboration will be sought with other institutions that are members of the Consortium for Integrated Soil Management in Central America, and with other governmental and non-governmental organizations in Africa. The Ministry of Agriculture in Panama has expressed interest in collaboration with the TOA project to assess environmental impacts of the Panama Canal watershed. Other potential collaborations we are exploring include EMBRAPA in Brazil, and CIP research programs in the Altiplano region of Bolivia. We expect other collaborations to develop from our networking activities detailed above.

Products to be Delivered

All written reports and presentations from project meetings and scientific conferences will continue to be made available on the project's web site at www.tradeoffs.montana.edu.

1. Project reports and publications that describe the methodological innovations described above, including a book-length manuscript summarizing the project's work.
2. Reports and publications documenting the use of the TOA method in the Andes, Central America, Africa, and other regions where adoption may occur during Phase 2. These reports will include summaries of policy analysis conducted using applications of TOA.
3. The TOA Model software and documentation developed during Phase 2.
4. The suite of biophysical and economic models that operate with the TOA Model software.

Results and Impacts

The impacts of Phase 2 of the Tradeoffs Project will come through successful application of the TOA method by user groups in various countries and institutions. It is difficult to quantify the impact of improved decision making. We will document impact by identifying the numbers of individuals trained, the institutions that adopt the TOA method, and by documenting

changes in technologies or policies that are associated with adoption of the TOA method as a decision making aid.

This project also will have measurable impact on the state of science used to understand and predict the behavior of complex agricultural systems at farm and regional scales. These impacts will be measured through the conventional means of publications in peer-reviewed journals, presentations at scientific conferences and other scientific communication and dissemination methods.

Another measure of impact and success of the project is the ability to attract additional funding to leverage the SM-CRSP funding. The Phase 1 Tradeoffs Project was highly successful in leveraging SM-CRSP funding with grants from the Ecoregional Research Fund, IDRC, and other programs (as documented in Phase 1 annual reports). The PIs intend to continue to leverage SM-CRSP funds aggressively during Phase 2 as opportunities arise.

References

Antle, J.M. and S.M. Capalbo (2001). "Econometric-Process Models for Integrated Assessment of Agricultural Production Systems." *American Journal of Agricultural Economics*, in press, May. Available at www.climate.montana.edu.

Antle, J.M. and B.A. McCarl (2001). "Economic Analysis of Soil Carbon Sequestration in Agriculture." T. Tietenberg and H. Folmer, editors. *International Yearbook of Environmental and Resource Economics*, Vol. 6, Edward Elgar.

Antle, J. and J.J. Stoorvogel (2001). "Integrating Site-Specific Biophysical and Economic Models to Assess Trade-offs in Sustainable Land Use and Soil Quality." N. Heerink, H. van Keulen, and M. Kuiper, eds., *Economic Policy and Sustainable Land Use: Recent Advances in Quantitative Analysis for Developing Countries*. New York: Physica-Verlag. pp. 169-184.

Antle, J.M., S.M. Capalbo, S. Mooney, and K. Paustian (2000a). "Economically Optimal Spatial Scale for Integrated Assessment of Agricultural Production Systems." Research proposal funded by the NSF Models and Methods for Integrated Assessment Program, June 2000-June 2002. Summary available at www.climate.montana.edu.

Antle, J.M., S.M. Capalbo, S. Mooney, E. Elliott, and K. Paustian (2000b). "Close Coupling of Ecosystem and Economic Models: Adaptation of Central U.S. Agriculture to Climate Change." Research proposal funded by USEPA program on Assessing the Consequences of Interactions between Human Activities and a Changing Climate, October 2000-September 2003. Summary available at www.climate.montana.edu.

Antle, J.M., S.M. Capalbo, S. Mooney, E. Elliott, and K. Paustian (2000c). "Economic Analysis of Soil C Sequestration in Agriculture: An Integrated Assessment Approach."

Journal of Agricultural and Resource Economics (submitted). Available at www.climate.montana.edu.

Antle, J.M., S.M. Capalbo, S. Mooney, E. Elliott, and K. Paustian (2000d). "Spatial Heterogeneity and the Design of Policies for Soil Carbon Sequestration." *Journal of Environmental Economics and Management* (revision submitted). Available at www.climate.montana.edu.

Antle, J.M., S.M. Capalbo, E.T. Elliott, H.W. Hunt, S. Mooney, and K.H. Paustian (2000e). "Research Needs for Understanding and Predicting the Behavior of Managed Ecosystems: Lessons from the Study of Agroecosystems." September. Under review for publication in *Ecosystems*. Available at www.climate.montana.edu.

CIAT (2000). *Project PE-3: Community Management of Natural Resources in Hillside Agroecosystems of Latin America*. Annual Report, October.

External Evaluation Panel (1999). *SM-CRSP Trip Report, Nov. 3-9, 1999, The TOA Model, John M. Antle, PI.* Revised November 15, 1999.

Heerink, N., H. van Keulen, and M. Kuiper, eds. (2001). *Economic Policy and Sustainable Land Use: Recent Advances in Quantitative Analysis for Developing Countries*. New York: Physica-Verlag.

Heerink, N., A. Kuyvenhoven, and M.S. van Wijk (2001). "Economic Policy Reforms and Sustainable Land Use in Developing Countries: Issues and Approaches." Heerink, van Keulen, and Kuiper, eds., *Economic Policy and Sustainable Land Use: Recent Advances in Quantitative Analysis for Developing Countries*. New York: Physica-Verlag. pp. 1-20.

Hunt L.A. and J. White (2000). "Agronomic Data: Advances in Documentation and Protocols for Exchange and Use." In Proceedings - Third International Symposium on Systems Approaches for Agricultural Development [CD-ROM computer file]. International Potato Center (CIP), Lima, Peru.

Jones, J.W., G. Tsuji, G. Hoogenboom, L.A. Hunt, P.K. Thornton, P.W. Wilkens, D.T. Imamura, W.T. Bowen, and U. Singh (1998). "Decision Support System for Agrotechnology Transfer: DSSAT v3".. G.Y. Tsuji, G. Hoogenboom, and P.K.Thornton, eds., *Understanding Options for Agricultural Production*. Dordrecht, The Netherlands: Kluwer Academic Publishers. pp. 157-178.

Overmars, K.P. (1999). "Developing a Method for Downscaling Soil Information from Regional to Catena Level." M.S. Thesis. Laboratory of Soil Science and Geology: Wageningen University.

Stoorvogel, J.J., J.M. Antle, C.C. Crissman, and W. Bowen (2001). *The Tradeoff Model: A Policy Decision Support System for Agriculture*. Quantitative Advances in Systems Analysis, Wageningen University, (in press).

Van Soest, F. (1998). A Method for Downscaling Soil Information from Regional to Catena Level. M.S. Thesis. Laboratory of Soil Science and Geology: Wageningen University.

Winters, P., P. Espinosa, and C.C. Crissman (1998). Resource Management in the Ecuadorian Andes: An Evaluation of CARE's PROMUSTA Program. International Potato Center Social Science Department Working Paper No. 1998-2. International Potato Center, Lima, Peru. 60 p.