

# ECOREGIONAL RESEARCH FOR DEVELOPMENT

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## ABBREVIATIONS

**ACED** Assessment of Current Erosion Damage  
**ARC-GCI** Agricultural Research Council-Grain Crop Institute  
(South Africa)

<b>CGIAR</b>	Consultative Group on International Agricultural Research
<b>CIMMYT</b>	Centro Internacional de Mejoramiento de Maíz y Trigo (International Wheat and Maize Improvement Center), Mexico
<b>CIP</b>	Centro Internacional de la Papa (International Potato Center), Peru
<b>CLRRRI</b>	Cuu Long Delta Rice Research Institute (Vietnam)
<b>CLUE</b>	Conversion of Land Use and its Effects
<b>GIS</b>	Geographical Information Systems
<b>ICIMOD</b>	International Centre for Integrated Mountain Development
<b>IDIAP</b>	Instituto de Investigación Agropecuaria de Panamá
<b>ILRI</b>	International Livestock Research Institute (Kenya)
<b>IMPACT</b>	Integrated Modeling Platform for Mixed Crop-Animal Systems
<b>IPM</b>	Integrated Pest Management
<b>IRRI</b>	International Rice Research Institute (Philippines)
<b>KARI</b>	Kenya Agricultural Research Institute
<b>LUPAS</b>	Land Use Planning and Analysis System
<b>MARDI</b>	Malaysian Agricultural Research and Development Institute
<b>MIDA</b>	Panama's Ministry of Agriculture and Development
<b>NUTMON</b>	Nutrient Modeling for Tropical Farming Systems
<b>SWAT</b>	Soil and Water Assessment Tool
<b>SYSNET</b>	Systems Research Network for Ecoregional Land Use Planning in Support of Natural Resource Management in Tropical Asia

## I. INTRODUCTION

The character of international agricultural research has changed profoundly in the last decades of the twentieth century. This can be well illustrated by developments within the Consultative Group on International Agricultural Research (CGIAR) as reviewed by [Rabbinge \(1997\)](#). The following successive phases may be distinguished since the 1960s: (1) crop improvement through better use of genetic material, with particular emphasis on wheat [CIMMYT, i.e., Centro Internacional de Mejoramiento de Maíz y Trigo (International Wheat and Maize Improvement Center), Mexico] and rice (IRRI, i.e., International Rice Research Institute, Philippines); (2) improved agronomic technologies, such as soil management, including soil fertility and tillage, irrigation,

and crop protection; (3) farming systems research tailored to farmers' socioeconomic needs; (4) awareness of environmental side effects of agricultural practices, particularly in fragile regions, such as land degradation, erosion, excessive leaching of agrochemicals, salinization and biodiversity loss, calling for improved resource management; and (5) a comprehensive systems' analysis focusing on basic, applied, and strategic research in a participatory mode and tailored toward ecoregions. Thus, supply-oriented research gave way to demand orientation. Technology push was replaced by technology pull and the linear knowledge model became obsolete and was replaced by a participatory cyclic knowledge model. Exclusive emphasis on crop research broadened to investigating production systems on farm and regional levels emphasizing sustainable development including socioeconomic and environmental considerations. Not only farmers became involved in research but also other land users and stakeholders as well as policymakers and planners, although addressing the latter category was and remains challenging.

The problems to be studied are highly complex and difficult. Computer simulation models, performing a comprehensive systems' analysis, appear to be indispensable research tools, as has been demonstrated in comparable econometric and exploratory studies of national planning bureaus. However, before the 1990s, methodologies for making a comprehensive systems' analysis of sustainable agricultural production systems were hardly available.

The need for a further support of comprehensive systems' analysis of the CGIAR agenda required new research and the development agencies of the Dutch and Swiss governments initiated, therefore, the Ecoregional Methodology Fund in 1995 as part of its development-oriented activities. Despite all rhetoric suggesting otherwise, most agricultural research activities in the tropics were still focused on plot, field, or farm level and were primarily addressed to farmers advising them on production issues. This was less relevant for decision makers and opinion leaders on regional, national, and international levels without a broader context.

The Fund was charged to: *support the development of new methodological tools for research that is ecoregional in scope with the intention of promoting new approaches to natural resource management and rural development in ecoregions.*

This chapter summarizes and discusses what the Fund has accomplished and which future challenges remain. In doing so, the following items are discussed: (1) a sketch of the changing social and political environment in which the work has been done, ranging from the UN Millennium Development Goals (MDGs) to the strategy of the CGIAR Science Council and the Gleneagle summit, (2) the changing role of research vis a vis the policy cycle, (3) illustrations for the policy cycle from projects of the Fund, and (4) implications for research, including new forms of interaction, design of operational tools, and new forms of education and communication.

## II. CHANGING CONCEPTS OF DEVELOPMENT

In the early years of the Fund, the effectiveness of development cooperation was increasingly questioned by international donors. Even though substantial amounts of money were spent on a wide range of development projects, many very poor countries were unable to accelerate their development with the effect that the gap between rich and poor, North and South, continued to widen significantly. Corruption and ineffective governance next to poor planning led to waste and lack of promising results. In this period several studies by the World Bank were influential. For example, [Dollar \(1998\)](#) showed that aid was correlated with economic growth in poor countries but only under conditions of *good governance*, which was defined somewhat loosely as abiding by the rules of law, human rights, and democracy in a stable institutional framework. The suggestion was to restrict aid to countries with *good governance* and to require these countries to write *Poverty Reduction Strategy Papers* in which they specifically formulated their plans. This has worked well to a certain extent but the nagging question remained what to do about the many countries that did not meet the northern-imposed criteria for good governance? Increasingly, the feeling prevailed that no matter what, development processes in the world cannot be sustained when more than 800 million of its inhabitants are hungry and 1.2 billion earn less than one dollar a day. Poverty reduction seemed to be the key to a more or less harmonious pattern of global development.

Increased concern about the inadequacy of so many lofty plans that did not materialize, led in the year 2000 to the UN Millennium project which formulated 8 goals and 18 specific targets to combat world poverty ([www.unmillenniumproject.org](http://www.unmillenniumproject.org)). In 2005, 13 task forces reported on possible measures to be taken to reach the Millennium Goals. In the same year, the Fund was foreseen to end its activities. It would, of course, not be wise to ignore the Millennium Goals when evaluating the work of the Fund, goals which so clearly reflect an international consensus. Results will therefore also be reported in relation to the eight Millennium Goals. Of particular relevance are Goal 1 (eradicates extreme poverty and hunger), Goal 7 (ensures environmental sustainability), and Goal 8 (develops a global partnership for development). This selection indicates that the Fund and agricultural research in general can, of course, only cover part of what are seen as key problems of development. Still, as agriculture in most developing countries employs more than 80% of the people, emphasis on improving land productivity and land use can be seen as a core activity and as a logical starting point in trying to reach the Millennium goals. Aside from the task-force reports, the year 2005 also saw the results of the Gleneagle conference of the G8 where promised aid to Africa was doubled.

Within the CGIAR system, the Science Council has in this context defined five separate research priority areas for CGIAR, specified by 23 subpriorities ([www.sciencecouncil.cgiar.org](http://www.sciencecouncil.cgiar.org)):

1. Sustaining biodiversity
2. Producing more food at lower costs through genetic improvement
3. Creating wealth among the rural poor through high-value commodities and products
4. Combining poverty alleviation and sustainable management of water, land, and forest resources
5. Improving policies and facilitating institutional innovation to support sustainable reduction of poverty and hunger

Area (5) is particularly relevant for the ecoregional work where the primary focus is not on individual farmers but on policymakers, politicians, and planners and their plans as they affect farmers and other land users.

Illustrating the urgency of taking a fresh look at the role of research in development, the World Bank has launched a new assessment to look at the role of agricultural science, knowledge, and technology for development (IAASTD, 2005).

Are scientists prepared to make major contributions toward reaching the Millennium Goals or the objectives of the CGIAR priority areas? One cannot be sure. International agricultural research is now in a permanent discussion on its future course. There is a tendency to go back to the former linear knowledge model (mode-1) and pleas for more strategic research. There is, however, also clear interest to further develop the character of research emphasizing a more demand-driven approach using a participatory knowledge model (mode-2). This corresponds with a general trend in science where a focus on society and relevant policy issues is receiving increasing attention, emphasizing the need for interdisciplinary research and interactivity of researchers with various stakeholders (Ravetz and Funtowicz, 1999). Gibbons *et al.* (1994) speak about (mode-1) science which is academic, disciplinary, homogeneous, hierarchic, stable, and subject to academic quality control and accountability. “Mode-2” research, on the contrary, is application-oriented, transdisciplinary (also involving stakeholders), heterogeneous, nonhierarchic, and variable, while quality is measured on a wider set of criteria (Royal Netherlands Academy of Arts and Sciences, 2005) and accountability is to society as well. This broader focus is also clearly indicated in the strategic plan for the period 2006–2010 of the ICSU (International Council of Science, 2005). In their vision, they speak of: *where science is used for the benefit of all ... and where scientific knowledge is effectively linked to policymaking*. Their goal is to: *strengthen the international science for the benefit of society*. Also the recent reports of the InterAcademy Council (2004a,b) and the taskforce on Science, Technology, and Innovation

of the Millennium project emphasize the need for interdisciplinarity and interaction with stakeholders and policymakers.

Not only the international agencies were making plans. The Kenyan government, for example, published a Strategy for Revitalizing Agriculture in 2004 (Ministries of Agriculture and Livestock and Fisheries, 2004). The National Planning Commission of the Nepalese government published a Poverty Reduction Strategy Paper ([National Planning Commission, 2003](#)) and a South African report to the Office of the Executive Deputy President and the Inter-Ministerial Committee for Poverty and Inequality also addressed the need for development research ([Wilkens, 1998](#)).

The projects of the Ecoregional Methodology Fund clearly reflect the demand-driven approach, mentioned above, using a participatory knowledge model. Moreover, as the projects of the Fund have proceeded from 1996 onward, it became increasingly clear that the relation between the research community and its stakeholders, be it farmers, land users, or policymakers, was clearly changing. So rather than only defining tools and methods for ecoregional research (which was and is the prime objective of the Fund) major attention was also paid to the manner as to how these tools and methods are being used and can be used by whom and when. More broadly the question will be addressed in various case studies funded by the Ecoregional Methodology Fund, as to how environmental and agricultural sciences should adapt its procedures to the new challenges of the information age and to progressing globalization.

By addressing the regional level, the projects of the Fund fill a particular niche. The Millennium goals and many reports with a global scope address global issues in a by necessity generic manner. On the other hand, much agricultural research still focuses on the farm level and research at the intermediate regional level has so far been somewhat neglected. This level, defining specific local conditions, is particularly relevant for local stakeholders and national policymakers and they were the primary partners in the various projects of the Fund.

### **III. RESEARCH IN RELATION TO THE POLICY CYCLE**

The objectives for research under the auspices of the Fund focused on natural resource management and rural development. This strongly defines its character and not only implies emphasis on the regional and higher spatial levels, rather than on the field and farm level, but also requires nontraditional research. In the standard research procedure, a problem is defined and a hypothesis is formulated that has the potential of “solving” the problem.

Next, a research process is initiated that produces results within a given time and budget frame that, ideally, allows acceptance of the hypothesis and can be used to “solve” the problem. Consideration of natural resource management and rural development presents a rather different picture. Different stakeholders usually have quite contrasting ideas about management and development. There is not a single “truth”! Also, their perception of current and desirable conditions in future varies widely, as they are often inspired by ideological or commercial motivations. There is not a well-defined problem nor one single “magic” solution. The manner in which science should deal with such problems, which are characteristic for all problems of society and certainly not limited to dealing with natural resources, has been studied extensively in the last decades (Bouma, 2005; Castells, 2000; Funtowicz and Ravetz, 1993; Giddens, 1991; Ravetz and Funtowicz, 1999; Van Ittersum *et al.*, 2004; Wenger *et al.*, 2002).

There is no question as to the relevance of science in this confusing context: “true” information and an objective evaluation of issues raised are essential in discussions where emotions can run high and where particular interest groups may unduly dominate and monopolize discussions. The general concept of sustainable development is most useful in this context: whatever is being proposed as a way to deal with a given problem, it should balance economic, social, and environmental interests in a manner, acceptable to all or, at least, to a majority of those involved. Defining a series of options that might solve a problem, rather than a single “magic” solution, has turned out to be a profitable way of dealing with the question of solving problems of natural resource management or rural development. Next, a selection has to be made by policymakers in dialogue with stakeholders, from all options presented. This approach is, of course, not new. Scenario analyses have been made by many agencies in the past (e.g., the SHELL oil company in the eighties). As time went by in this project, we have increasingly returned to this approach of defining sustainable options for land use and natural resource management whereby emphasis was paid to defining *story lines* to make such options more accessible to various users. The Fund contributed to two important elements: (1) Options were geographically defined and visualized by using Geographic Information Systems (GIS). Rather than producing generic tables with data, illustrating effects of different land-use options, we focused on defining what might happen *where* and *when*. This turned out to be particularly interesting for policymakers, planners, and stakeholders alike as it offered opportunities to introduce spatial differentiation when fine-tuning policy measures. (2) Interaction with stakeholders received much emphasis during the entire policy circle, and not only during parts of it. We try to be involved during the entire policy cycle, which includes the following:

1. The *signaling* phase in which problems are identified, preferably based on a characterization of current conditions.
2. The *design* phase in which options for possible corrective action are defined based on research using existing and newly acquired information.
3. The *decision* phase in which a selection is made by policymakers of options being presented. Here, negotiation processes play an important role.
4. The *implementation* phase in which the selected option is being realized.
5. The *evaluation* phase in which the entire process is analyzed in terms of a learning experience. This may have to include new monitoring activities to document achievements.

Rather than have a short period of interaction between researchers and stakeholders at some point during the research process (usually during the *design* phase), we intended to introduce a long, joint-learning process in our projects for the five phases mentioned above, in which tacit knowledge and experience of stakeholders played an important role next to scientific data and information being injected into the debate by scientists. Such data and information are quite different in the various phases: (1) Scientists have a particularly important role in the *signaling* phase: all ideas should be welcomed but some degree of screening may be needed. This is also the phase where scientists are called on to introduce long-term visions and where there is time for having dreams. (2) When *designing* different options to solve a given problem, scientists have a major responsibility to make sure that for any option, a primary focus on sustainable development is being maintained. In other words, economic, social, and environmental aspects should always be considered for any option. This is essential for making realistic trade-offs later between contrasting demands. Action groups, NGOs, and policy-makers with particular political signatures often emphasize only one of the three basic aspects of sustainability when defining their favorite option. Scientists, who are neutral, in principle, in terms of their personal preferences, have an important function in keeping track of the overall context of any given problem. (3) Scientists have no role in *decision* making. They can, however, facilitate the political negotiation process by providing additional information or clarification at the right time and place. (4) Problems always occur when a given plan has to be *implemented*. Again, scientists have a limited role here to make sure that implementation stays on track by making sure that the original objectives are not forgotten and mistakes or errors are promptly communicated to and openly discussed with the members of the team. The time of interesting, new ideas is over when implementing a plan that has been widely discussed and agreed upon. Of course, conditions can change, but suggestions for continued change of plans may also be suspected

and may reflect hidden agenda's of particular participants. More general, it is in the interest of science that at least some shining examples are generated of well executed and successful plans that have followed the policy cycle and that illustrate what science can accomplish. The role of scientists is now often terminated after the decision phase and this is unfortunate because a lot can be learned from *implementation* and making this part of an overall *evaluation* process is attractive as part of a learning process that can make research more effective in future.

The schematized policy cycle, as presented here, suggests a rigid sequence of successive phases. This is, of course, not realistic as the various phases may interact while the sequence may occasionally change over time. The cycle is, however, a good metaphor to illustrate different functions that have to be distinguished no matter what in the overall decision-making process: thinking about what should or might be done, defining possible options to solve problems, wondering about who decides what, deciding about implementation plans, and learning from evaluating the processes involved.

When dealing with natural resource management and rural development, effective contact and interaction between governmental agencies, users of the land, and other stakeholders are crucial. If land users are not involved when governmental agencies define new land-use policies or desired forms of management and corresponding rules and regulations, those users are unlikely to implement measures as they are seen as having been imposed from above. On the other hand, policymakers cannot only base their designs, rules, and regulations exclusively on opinions of the land users because broader issues that are beyond scope and expertise of the land users may be important from a national or international policy point of view and have therefore to be taken into account, however unpopular they may be at the time. This is the particular responsibility of policymakers and they have to find ways by which this can be communicated convincingly to the land users. Interaction between land users and policymakers is therefore crucial and here scientists can make unique contributions as *mediators* and *facilitators* while at the same time continuously feeding scientific information into the debate. This is, in our view, more fruitful than scientists having exclusive contacts with either land users or policymakers which is often seen in practice.

In [Section IV](#), projects of the Fund will be discussed, following the various phases mentioned above. We will describe examples according to the policy cycle, allowing us to illustrate the quite different circumstances that we have encountered in all four continents where projects have been executed. As stated above, only a main story line will be presented here. Detailed reports are presented on the project website ([www.ecoregionalfund.com](http://www.ecoregionalfund.com)).

## IV. EXAMPLES FROM THE PROJECTS OF THE FUND

### A. DEVELOPING THE KENYAN HIGHLANDS

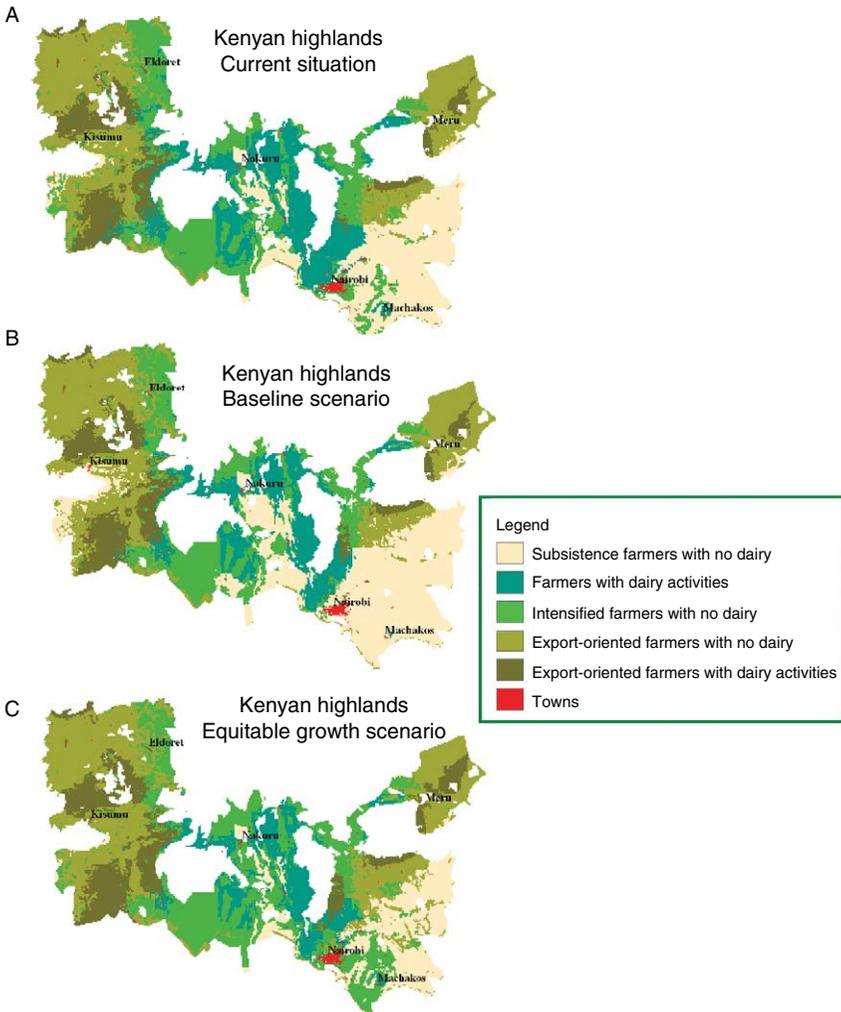
Hunger and poverty in sub-Saharan Africa have received huge media attention in the 1980s. More recently, they have been emphasized in the formulation of the millennium goals. Although attention was focused on dramatic soil degradation processes—like water erosion and salinization—and extensive droughts, increasingly soil fertility decline was mentioned as one of the key drivers behind the stagnating agricultural production in this part of the world. After studying the low levels of fertilizer use and the declining productivity, FAO commissioned a study to quantify soil nutrient balances for sub-Sahara Africa in 1989. The results showed that soil nutrient losses were significant especially in East Africa with annual per hectare losses exceeding 40 kg N, 7 kg P, and 20 kg K (Stoorvogel and Smaling, 1990; Stoorvogel *et al.*, 1993). It became clear that soil fertility decline may be just as important as some of the other factors of soil degradation. More detailed studies that followed the initial study confirmed the earlier results at more detailed scale levels (De Jager *et al.*, 1998; Smaling *et al.*, 1993). The signal function of these studies was clear, but at the same time the studies did not provide a solution to the problem. Key question that remained was how to deal with the problem? Where do we start and how to intervene? Since the early study, soil nutrient depletion has gained international attention and is often considered to be one of the key causes for stagnating or declining productivity. It is therefore not surprising that it is emphasized in Kenya's Strategy for Revitalizing Agriculture of 2004. The document provides us, among others, with two possible directions how to intervene: (1) stimulates nutrient inputs through mineral fertilizer and (2) promotes efficient livestock production systems. The document is, however, not very specific as to how this can be implemented.

Although technical solutions at the field level may contribute, it is clear that solutions to this wide scale problem need also to be addressed at higher scale levels. Three different projects supported by the Fund dealt with three different issues: (1) Where do we expect major changes in agricultural land use under different policy scenarios or so-called story lines? (2) What changes in agriculture can we expect under different policy scenarios or technological innovations? and (3) Are the modeled changes realistic options if we evaluate them at the farm level in combination with the specific constraints and objectives of the farmer? Here we will provide an overview on the approaches that have been followed to answer each of these questions. The analysis was focused on the smallholder mixed crop-livestock producers in the Kenyan highlands.

## 1. Detecting Hot Spots for Change

The Trajectory of Change (TOC) program (see: [www.trajectories.org](http://www.trajectories.org)), coordinated by the International Livestock Research Institute, Kenya (ILRI) focused on the determination of hot spots for change. Where do we expect that major changes in land use will take place? The project followed a two-step approach. Intensive stakeholder consultation resulted in the development of various story lines for agricultural development in the Kenyan Highlands. These story lines were next translated into various scenarios representing pathways for development in terms of population density, education, extension services, and specific policy interventions. Two examples are the baseline scenario and the scenario of equitable growth. The baseline scenario mimics the policy, government, and investment environment that has characterized Kenyan agriculture during the 1980s and 1990s. Key features include poorly functioning public institutions for supporting agriculture and market development; market barriers internally and externally, and poor market infrastructure; a policy environment that stifles innovation in both rural and urban economies. The equitable growth scenario mimics the plans put forth in the government's Economic Recovery Strategy. Key features include well-functioning public institutions for supporting agriculture and market development; reduced market barriers and improved infrastructure, both internally and externally; and a policy environment that facilitates innovation in both rural and urban economies. These two scenarios represent different pathways for development. Under the baseline scenario about 20% of land use in the area is likely to change between 2004 and 2024. Of this change, 9% of the farming systems are projected to turn into less intensified farming systems and 80% of the farming systems will turn into more intensified farming systems of which 53% will shift into export-oriented farming. Under the equitable growth scenario 25% of the area is likely to change in the same period. Only 5% of the farming systems are now projected to turn into less intensified farming systems, and most of the others are likely to change into more intensified systems of which 66% will change into export-oriented farming.

The TOC project used the Conversion of Land Use and its Effects (CLUE) model (Verburg *et al.*, 2001) to subsequently analyze where these changes in farming systems are likely to take place. The CLUE model was applied to the Kenyan highlands showing actual land-use patterns and changing patterns that might result from the different scenarios. The CLUE model can do this because it defines critical "drivers" of land-use change which can be used to answer the central question: "what might happen if?" Thus, "hot spots" and "cold spots" of change could be identified for the various scenarios. Figure 1 shows three maps indicating which areas are likely to be subject to change under the two scenarios. A good



**Figure 1** Projected land-use change in the Kenyan highlands with the CLUE model: (A) current situation, (B) baseline scenario, and (C) equitable growth scenario.

example of a hot spot is the Machakos district (southeastern corner of the study area). Under the Baseline scenario many intensified farmers are going back to subsistence farming whereas under the equitable growth scenario many farmers that are currently subsistence will intensify their farming system. In other parts of the Kenyan highlands changes are less pronounced.

The procedures that were followed in the TOC project were very attractive to get the message out. First, the results were visualized using the linkage

with a GIS model allowing users to see the spatial patterns in the outcomes. Second, the story lines were jointly defined with the various stakeholders. Recognition of story lines and the user-friendly visualization allow for effective communication to the various stakeholders. On the other hand, we have to realize that the farming systems as they have been defined in the analysis are not static and even farming systems staying in the same category will undergo changes. The consequences of the two story lines on, for example, soil degradation and poverty alleviation require, therefore, more detailed studies.

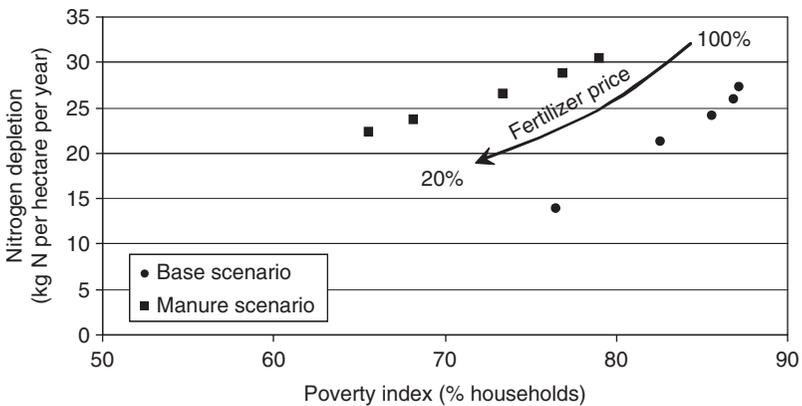
## 2. Trade-offs in Agricultural Development

The CLUE model results show that under the two story lines Machakos is expected to undergo significant land-use changes. The Machakos district is famous for land-use changes through the publication of Tiffen *et al.* (1994): “More People, Less Erosion.” They present Machakos as the miracle case where, despite increasing population density, soil erosion has been stopped through massive introduction of terraces. Today the future of Machakos agriculture is less bright as soil fertility decline seriously threatens the sustainability of the systems; a reason for some researchers to revisit the study by Tiffen *et al.* (Siedenburg, 2006). The CLUE analysis in the TOC program indicates the Machakos study area as a hot spot for land-use change where under the various scenarios farming systems are likely to develop into producing export cash crops with limited dairy activities. Interesting enough, there has already been a significant expansion of zero-grazing units in the area; although many farmers lost their dairy cattle during the recent drought. The Machakos district is well studied in the past. In the last decade various surveys have been carried out to describe farm management and to assess the dynamics in soil fertility (De Jager *et al.*, 1998, 2001).

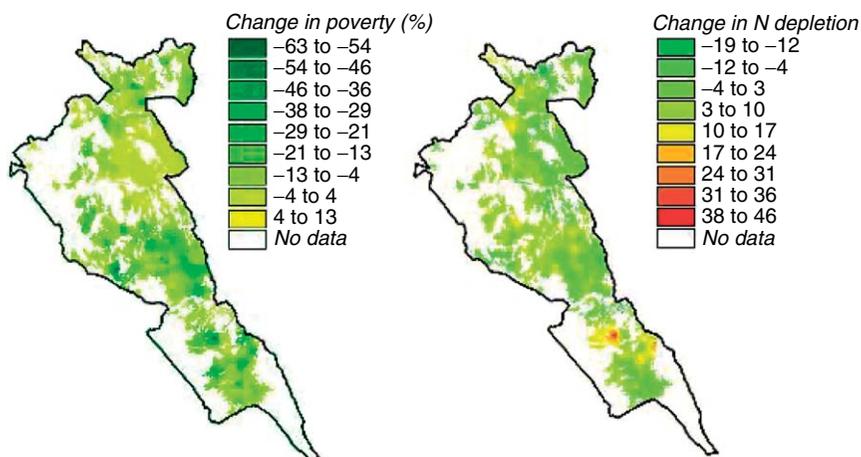
The Trade-off Analysis (TOA) project funded by the Fund in combination with the Soil Management Collaborative Research Support Program of US-AID and headed by Wageningen University and Montana State University took up the challenge to carry out an integrated assessment of the farming systems in Machakos using available survey data from the various Nutrient Modeling for Tropical Farming Systems (NUTMON) studies. Through econometric estimation techniques the land-use decision process of the farmers was modeled where land-use decisions are a function of expected productivities, price distributions, and resource availability. The TOA system (Stoorvogel *et al.*, 2004a,b) uses these models for a quantitative assessment of various interventions in terms of mutual “trade-offs” between economic, social, and environmental indicators. The analysis allows for an *ex ante* evaluation of technology and policy interventions.

Although a plethora of different scenarios can be presented, we will have a more detailed look at the effect of the two interventions proposed in Kenya's strategy to reduce poverty through improved soil nutrient management. First of all, they propose the reduction of fertilizer prices. Currently, farm gate prices of fertilizer are far above the world market prices due to transaction costs (import tariffs, transportation costs, and retailer). These high prices are commonly perceived to be one of the key reasons behind low fertilizer use by farmers (De Jager *et al.*, 2001; Salasya, 2005). Fertilizer prices can be reduced through various interventions including the development of efficient marketing chains or packaging smaller quantities. A second example is the intensification of the livestock production which should improve the nutrient efficiency through better recycling of nutrients on the farm. This can be done through, for example, improved zero-grazing units on farms and an increase in manure use. Figure 2 shows the main effects of these two scenarios on the two key indicators for the Machakos district: soil nitrogen depletion and poverty, that is, the number of people below the poverty line of US\$1 per person per day.

The reduction of fertilizer prices clearly is a win-win situation (although at the cost of the investments needed to reduce these prices!). Both the poverty index as well as the nitrogen depletion rate are going down. On the other hand, we see that increasing manure production negatively influences the soil nitrogen balance. This may seem rather counterintuitive. The reason for this change are the underlying processes that link manure availability and manure use to the production of maize. In other words, if we stimulate manure use, we will also stimulate the cultivation of maize. Maize is one of the more depleting



**Figure 2** The relationship between soil nitrogen depletion and poverty under different fertilizer price regimes and the effect of improved manure management for Machakos district as analyzed by the TOA system.



**Figure 3** Changes in soil nutrient depletion (in  $\text{kg ha}^{-1} \text{ year}^{-1}$ ) and poverty index (% people under the poverty line of US\$1 per person per year) in the Machakos district as a result of improved manure management.

crops and, as a result, an increase in maize results in a more negative soil nutrient balance.

Machakos district is a highly variable region with a wide range in different agroecological conditions. As a result one can wonder whether these conclusions are actually valid throughout Machakos district. The maps presented in Fig. 3 show the impact of the manure scenario on the poverty index and the soil nutrient balance (under the observed fertilizer price regime). The maps show that the impact of the scenario is also highly variable within the district and this underlines the need for the georeferenced analysis and presentation of the scenario results.

### 3. Verifying the Feasibility

The Kenyan Highlands story is completed by the Integrated Modeling Platform for Mixed Crop-Animal Systems (IMPACT) model (Herrero *et al.*, 2005) that models individual farming systems. CLUE simulations tell us where agricultural land use is going to change and model simulations make selections among various discrete farming systems, each with a dynamic character. In a more detailed analysis we see the TOA system modeling the various management decisions at the farm level. By modeling the various decisions at the farm level one can wonder whether the simulated system is realistic and whether all the boundary conditions in terms of, for example, feed availability are met. It is therefore extremely useful to take the assumptions for the various simulation

runs as well as the simulation results to an analysis at the farm level. The IMPACT model is used to check whether the various options for farming systems by CLUE are realistic. At the same time IMPACT is used to check whether results of the TOA can be applied to farming systems in the area and if not, how they can be modified.

In [Sections IV.A.1 and IV.A.2](#), we looked at the potential changes in farming systems in the African highlands. We identified the Machakos region as one in which we can expect significant changes. Two alternative scenarios were subsequently analyzed representing commonly believed perceptions that fertilizer prices have to be lowered for farmers to make adequate use of this essential input and more intensive livestock management is required to streamline nutrient flows within the farm through effective nutrient recycling. The farming systems in Machakos are highly complex with numerous crops grown on a single field, among them, fodder crops, and with significant interactions between the various farm components, that is, the cropped fields, livestock, zero-grazing units, stocks, and the household. The IMPACT model enabled us to analyze these complex interactions and to put the model results in perspective. Increased fertilizer use may not resolve the soil nutrient balance directly but the increased production of crop residues that may be fed to the animals (leading to increased manure production) or incorporated in the soil may support a more sustainable use of the soil resource. These IMPACT studies help us to interpret the results that we obtain with the TOA system, but it also helps us to define specific scenarios that are realistic and in line with farmers objectives.

The highly detailed surveys for the IMPACT model, where few farms are monitored for a longer period, also provide insight in the core objectives and constraints of the farmer managing his enterprise. These objectives and constraints form the basis for looking for alternative management practices and the most effective policy interventions. Subsequently, these practices and interventions can be evaluated again using the TOA model to assess the impact at another scale level.

#### **4. In Retrospect**

All in all, we see three models operating at three spatial scales and interacting in defining most promising agricultural land-use systems in future. In doing so, there are intensive contacts with both policymakers and farmers to generate the most appropriate options, trade-offs, and farming systems. Local research institutes, such as Kenya Agricultural Research Institute (KARI), guide research and are assisted by ILRI and Wageningen and Montana Universities. Courses are organized to transfer and discuss technologies. This arrangement comes close to what the Fund was intended to do.

The case study clearly shows the added value of the research chain where different research methods are used in combination to answer the complex questions by policymakers and to streamline research activities. CLUE helped us to identify regions where changes are likely to take place and to focus data-intensive methods like the TOA. The IMPACT model allows for the definition of various scenarios to be analyzed with the TOA and to interpret and check the subsequent results.

The Kenyan Highlands project is still in the design phase. Policy decisions have not yet been made and implementation is not yet relevant, except for educational programs familiarizing farmers, policymakers, and local researchers with the new tools in a joint-learning mode.

## **B. REACTING TO TRADE LIBERALIZATION**

The explosion of free trade agreements (FTAs) has marked the last decade. This seems to be the norm for a country to have a full membership in a globalized world, in spite of the criticisms from grassroots organizations and environmentalists, among others. Small countries like Panama receive a lot of pressure to sign FTAs with more powerful nations, oftentimes putting their food security at stake.

### **1. Signaling Phase**

Sprouted by an invited conference given by the International Potato Center (CIP) in September 2000 at the occasion of the 25th anniversary of the Panamanian Institute for Agriculture and Livestock Research (IDIAP), the minister of Agriculture invited CIP again in January 2002, through IDIAP, to become familiar with the advances in ecoregional research. After the exchange, the minister highlighted the new challenges faced by the agricultural sector under the FTAs the Panamanian Government was negotiating and their possible impacts on farmers. His plan was to get funding from the Central Government for IDIAP to start using the tools and methods available, with backstopping from CIP and partners. The key question was “What can the Panamanian government do to help farmers to compete under the new rules of globalized markets?” Even though money was set aside by the Central Government and CIP’s DG traveled to Panama to agree on terms and conditions, a new minister was appointed and the funding was assigned elsewhere.

In spite of the lack of Government funding, Panamanian institutions—IDIAP, ministries, particularly agriculture and health, cooperatives,

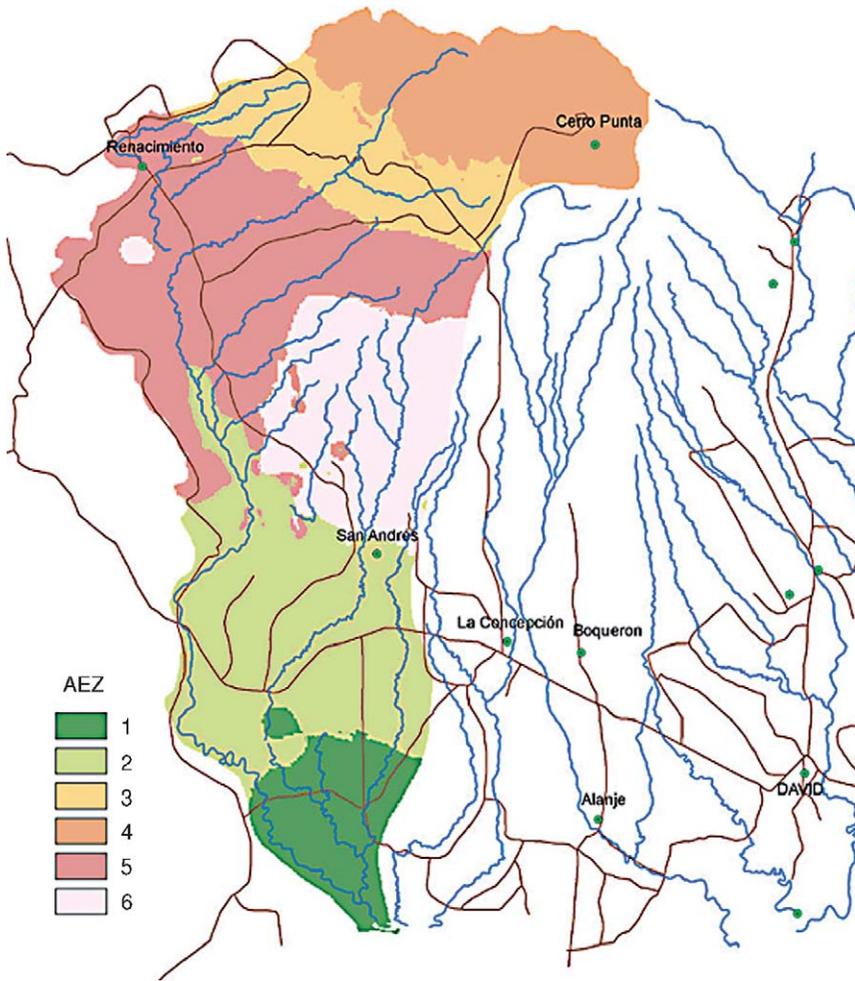
the private sector, and NGOs—complemented the seed funds provided by the Ecoregional Fund to initiate the research in a pilot site. One of the most important watersheds in the country, the Chiriquí Viejo, was selected. The upper watershed is encroached in a natural park containing the main forest reserve to produce clean water for the province of Chiriquí.

The first part of the signaling phase was completed. The problems to be addressed were identified. On the one hand, there are international pressures to sign FTAs, notwithstanding the unpreparedness of the sector involved, in this particular case the agricultural. On the other hand, environmentalists defend the role the upper watershed plays as clean water provider. Stakeholders from different sectors agreed to work together and use the experience as a hands-on learning process.

The characterization of the current conditions was taken as the next challenge. The experience gained by CIP and the University of British Columbia, in a comparative watershed analysis between the Andes and the Himalayas, was instrumental. Ten hypermedia CD-ROMs from these studies were presented and made available to all stakeholders. The friendliness of the format and the richness of the contents caught the attention of all the participants. Seeing how much can be accomplished when data is shared and how all the participating institutions can claim ownership of the product was appealing. The way geospatial data is combined with table, texts, numbers, and pictures was highlighted as a key attribute of the products. The experience gained in Phase 1 of The Fund was also shared; the Ecuadorian CD-ROM contained the findings of Phase 1 in El Carchi, Ecuador. The first few versions of the Chiriquí Viejo Watershed CD-ROM were assembled with the data provided by those who wanted to share plus the maps belonging to the public domain, processed under CIP's leadership. The advances were presented at the coordination meetings, led by IDIAP and the private sector. Those institutions reluctant to share at the beginning soon realized that it was better to have their logo included as participating institution than being left out in the process.

Soil fertility layers were constructed for the Chiriquí Viejo Watershed. Samples analyzed by IDIAP from the last 30 years were georeferenced and used to interpolate the attributes into the following thematic maps: texture, organic matter, pH, CEC (cation exchange capacity), Al saturation, P, K, Ca, Mg, Zn, Cu, Fe, and Mn. The results were combined with other thematic attributes such as topographic variables, accessibility to markets, and climatic variables. Principal component analysis was used to reduce the redundancy of information in the variables, followed by a clustering procedure using the maximum likelihood rule.

Six agroecological zones (AEZ) were defined (Fig. 4). AEZ 1 is a coastal area with potential for intensive agriculture (e.g., banana, sugar cane, and beef cattle). AEZ 2 is also in the lowlands and suitable for maize, rice,



**Figure 4** Agroecological zones in the Chiriquí Viejo Watershed, Panama.

sorghum, tropical fruits, and livestock production. AEZs 3 and 4 are located at intermediate altitudes. The most striking differences between these two zones are the rainfall and the topography. AEZ 3 presents rainfall above  $5000 \text{ mm year}^{-1}$  and beef cattle and some dairy cattle are feasible. AEZ 4 is suitable for bean production, some maize, and beef cattle. AEZ 5 is a special niche for gourmet coffee and AEZ 6 is the horticultural area.

AEZs 3, 5, and 6 are the water towers of the province of Chiriquí, the most important agricultural area of the country. During the last 40 years, the forests were drastically reduced from 78% to less than 40% of the total cover,

and substituted by horticultural crops and pastures. Large, nonarable areas have been planted making the zone and the water towers highly vulnerable.

## 2. Design Phase

The agricultural sector is greatly concerned with the FTA trade implications, particularly those affecting resource-poor farmers. The project helped local partners to identify hotspots, assess the vulnerability of the farming systems in the project area, and systematize research results into simulation models to ex ante assess the impact of technology adoption on the competitiveness of three selected commodities in a liberalized market. The analysis was complemented with the assessment of the environmental cost in term of soil erosion and water quality, both under actual practices and future scenarios.

Crop and livestock process-based models were used to systematize historical research findings prior to the upscaling of results to the watershed level. A strong component of the project was the training of local professionals in the use of systems analysis and ecoregional methods.

For the last 40 years, the Government of Panama has invested in pasture and livestock research. The project focused on systematizing research findings into the LIFE-SIM models (León-Velarde *et al.*, 2006) to calibrate them and teaching local researchers how to use these tools to complement their research. The models proved robust in predicting beef and dairy production by grazing and stalled animals and combined feeding strategies (Fig. 5). Simulated experiments were run to assess alternative feeding strategies, the incorporation of legumes into grasslands, determination of optimal stocking rates, and so on. Response surface designs were used to find optimal combination of management strategies (León-Velarde and Quiroz, 1999) simulating FTA scenarios.

Although the process-based models used adequately simulated results from field research, the scaling up of the scenarios for the entire watershed was still a challenge. To model livestock production, time series of vegetation indexes were converted into available green dry matter (Jongschaap and Quiroz, 2000; Quiroz *et al.*, 2000). The quality of the pasture and grasslands was already determined by IDIAP. A geospatial version of the LIFE-SIM (simulating pixel by pixel) was used to estimate beef or milk production from the pasture lands in the watershed.

The analysis produced by the animal scientists with the newly adopted simulation tools indicated that with the adoption of IDIAP's technology, particularly the utilization of mixed grass-legume pastures, farmers can produce beef at a cost nearing US\$0.80 kg<sup>-1</sup> and an internal rate of return of near 25%. In short, the Chiriquí Viejo Watershed can produce beef at

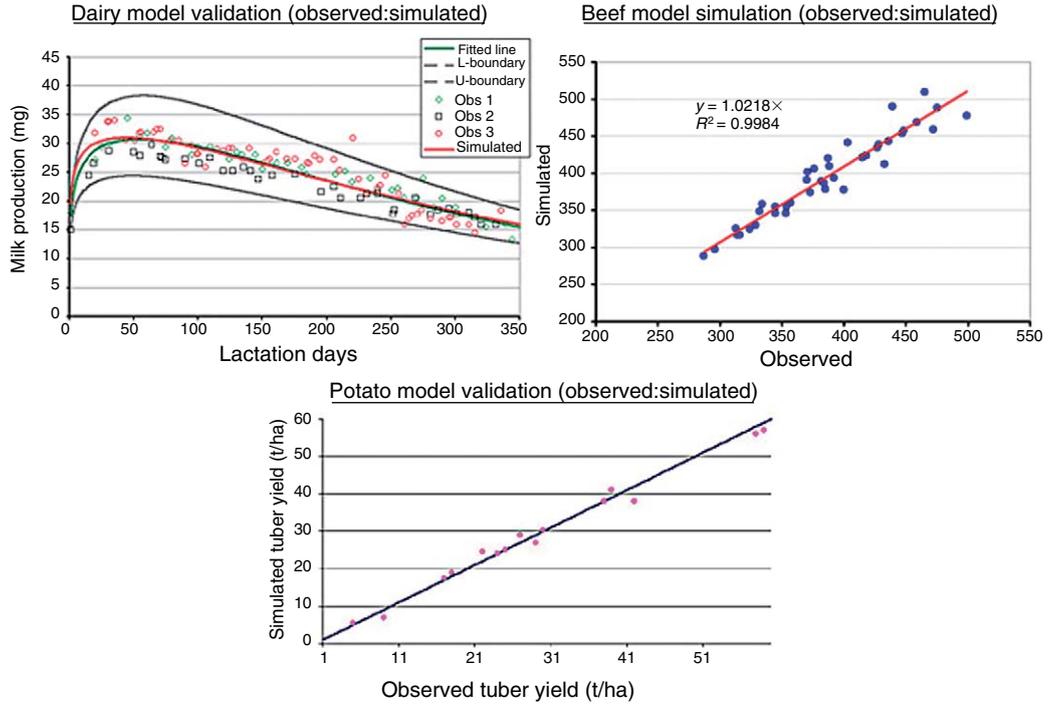


Figure 5 Model's validation presented as the confidence interval or a 1:1 regression line between simulated and measured data.

competitive prices in a globalized market, not only for the national but for the export markets as well. The lowlands do not seem to be competitive in milk production, but the upper watershed, if reconverted to a grazing-based grass-legume pasture can compete to retain the national market. Actual production cost per kilogram of milk is around US\$0.24. Farmers are profiting since they currently receive up to US\$0.31 kg<sup>-1</sup> of liquid milk. Prices in countries that have already signed an FTA, such as Chile, have fallen as low as US\$0.15 kg<sup>-1</sup>. Production costs per kilogram of milk under grazing conditions could fall to less than US\$0.10. The reconversion, due to costly equipment, elite breeds, and high-tech milking parlors, would be costly. Simulating livestock production and calculating gross margin at the expected prices under an FTA scenario highlighted the areas in the watershed where the livestock sector could compete under an FTA with the United States or other countries. Gross margins (\$ ha<sup>-1</sup>) ranged from 1100 to 1300 and from 1400 to 1900 for dairy and beef production, respectively.

CIP has supported potato research in Panama since the research program started. Varieties released by IDIAP come from genetic material originated at CIP. Potato models calibrated for CIP materials (Bowen *et al.*, 1999) were used to assess management strategies under FTA scenarios (Fig. 2). For the spatial simulation, soil and climate data are required on a pixel by pixel basis. The fertility data came from the interpolated maps described above. For the temperature, split windows algorithm using remotely sensed data (Pozo Vásquez *et al.*, 1997) are used. Rainfall data using traditional geospatial methods (Immerzeel *et al.*, 2005) did not provide the accuracy needed. A new method developed within the project was used.

Daily rainfall data from local weather stations were jointly analyzed with a dataset containing 197 ten-day composite normalized difference vegetation index (NDVI) images derived from the SPOT-4 and -5 VEGETATION instruments. The periodical behavior of the two signals (frequency, periodicity, and amplitude) was performed using the Fourier transform [ $F(f)$ ]:

$$F(f) = \int_{-\infty}^{\infty} f(t)e^{-i2\pi ft} dt,$$

where  $f(t)$  is the signal and  $t$  the time when data was collected. The ratio of the mean value of the two signals or characteristic amplitude was used to bring both signals to the same scale. The lag between the phases of the two signals was also determined and corrected. As a result, a signal with similar scale and phases was obtained. This new signal was processed with the wavelet transform [ $Wf(\lambda, u)$ ] of the signal  $f(t)$ :

$$Wf(\lambda, u) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{\lambda}} \psi\left(\frac{t-u}{\lambda}\right) dt$$

where  $\psi_{\lambda,t}(u)$  is the mother wavelet,  $\lambda$  represents the scale factor which is related to the frequency, and  $u$  represents the translation associated with time. Both signals (rainfall and NDVI), measured at the pixel corresponding to the weather station, were decomposed twice (second level decomposition) using the Wavelet Symmlet2, a high frequency filter. The two spectra obtained for each signal—low frequency (base) and high frequency (noise)—were used in the reconstruction. The “base” signals, for each pixel different from the ones where the weather stations were located, were combined with the “noise” extracted from the rainfall signal from the respective weather station, to reconstruct the daily rainfall for each pixel in the target area. The validation of this method produced coefficients of determination ( $R^2$ ) ranging from 0.71 to 0.85. This fit is higher than the ones reported in the literature for daily rainfall (Immerzeel *et al.*, 2005). A modified LINTUL-potato model coupled to GIS software was then used to simulate potato production.

Local researchers and the private sector determined—based on their research findings and modeling alternative scenarios—that to retain the national potato market, farmers must produce at least 35 ton ha<sup>-1</sup> at a maximum cost of US\$0.16 kg<sup>-1</sup>. The agroecological conditions are mainly suitable during the dry season. During the rainy season, the presence of pests and diseases increases not only the cost but also the negative effect on the environment. In the past, IDIAP evaluated CIP materials tolerant to late blight, but farmers did not like them because they produced too much foliage and were long-cycle (late) cultivars. Could it be that the new rules of the game will provide room for these types of materials that minimize the use of chemicals? Overall, potato/horticulture farmers do not seem to be competitive without tariffs given the size of operation and the excessive presence of pests and diseases, typical of tropical highlands.

### 3. What Is the Cost?

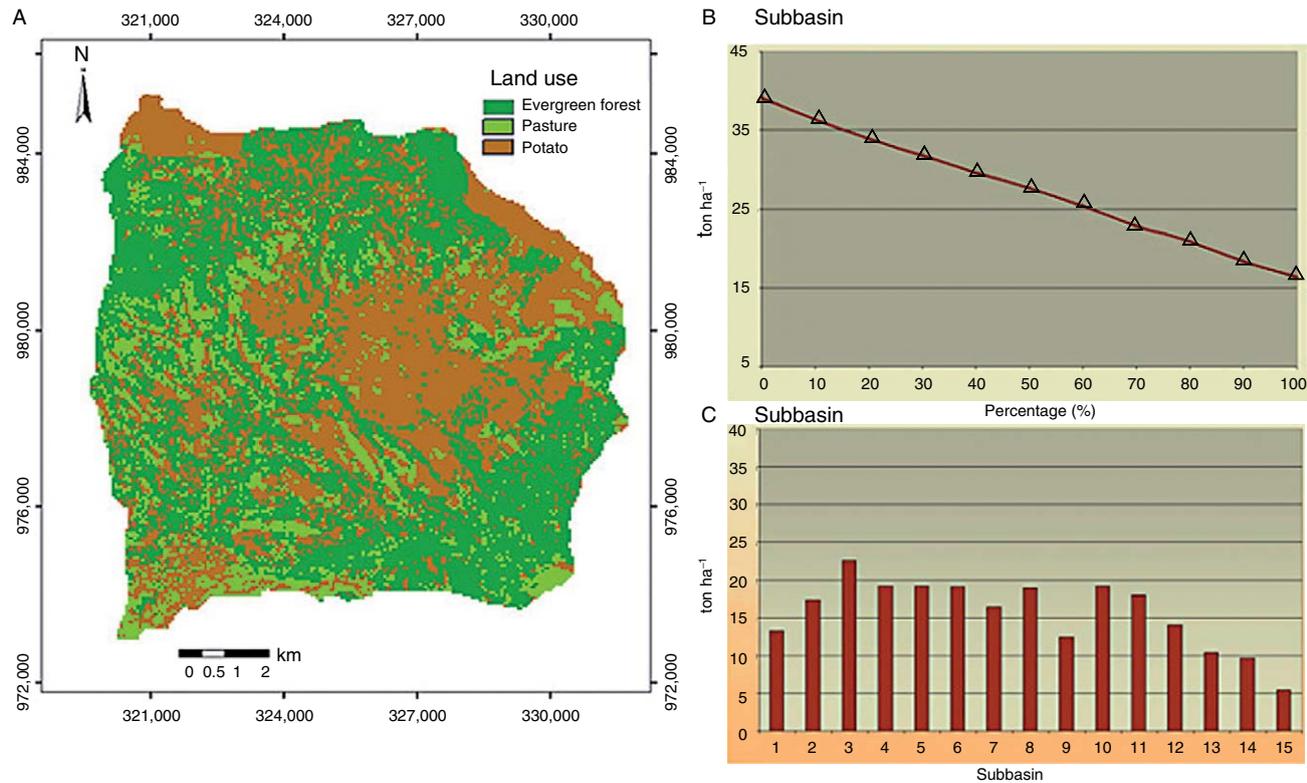
In Section IV.B.2, we described how research combined with decision support tools could be used to ex ante assess competitiveness of key commodities under FTA scenarios. We also indicated—based on simple economic analysis—that with the adoption of the technologies promoted by IDIAP and MIDA the beef and dairy small farmers could profit even if prices decrease due to FTAs. On the other hand, potato farmers would have more difficulty under such conditions; they require some protection from the central government. According to a recent official presentation, potato and other horticultural crops are classified as sensitive commodities. It is highly likely to get a grace period with tariff protection.

The analysis in the upper watershed of Río Chiriquí Viejo went beyond the cost–benefit analysis. An attempt was made to quantify some of the ecological costs of maintaining the “status quo.” Horticultural production poses two potential environmental problems: soil erosion and chemical leaching. Most of the erosion comes from the areas nonsuitable for cropping such as steep slopes. The Soil and Water Assessment Tool (SWAT), developed by USDA, was calibrated with field data and used to assess alternative land uses. By converting the hillsides into pasture for milk production or practicing conservation agriculture, the level of erosion in the entire upper watershed can be reduced to tolerable levels (Fig. 6). This is a nonattractive business for farmers because they can make around US\$2000 ha<sup>-1</sup> year<sup>-1</sup> in milk production and between US\$10,000–\$20,000 ha<sup>-1</sup> year<sup>-1</sup> in horticulture, at actual prices. This reconversion could be suitable under a no-tariff FTA scenario because expected revenues from horticulture are calculated to decrease to less than US\$3000 ha<sup>-1</sup> year<sup>-1</sup>. An additional possibility is for farmers to receive a premium for producing clean water. This might be an issue of importance in the near future since the government is interested in increasing the number of hydropower plants in the country and river has been selected as a good candidate.

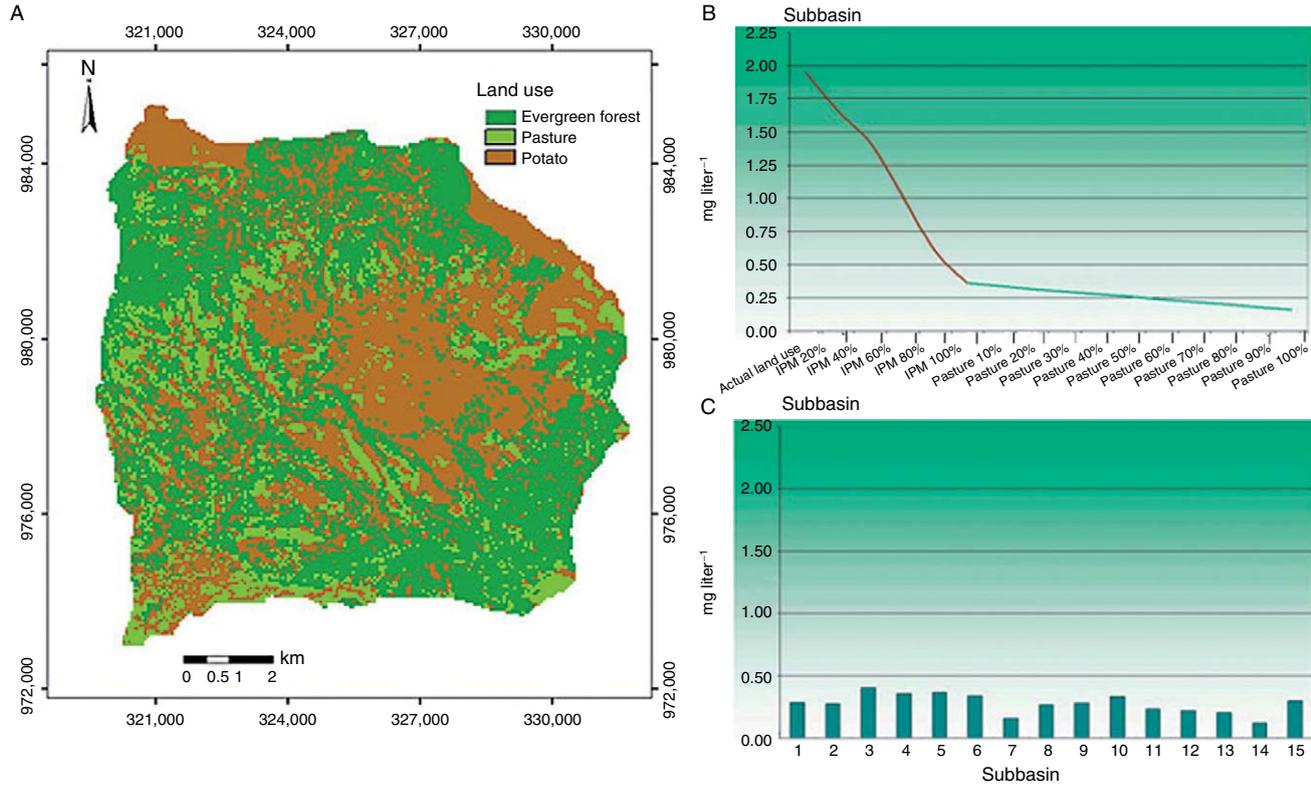
The second environmental issue presented for horticultural production is carbofuran leaching. The levels estimated at the outlet of each subbasin are, by EPA standards, above the permissible levels. Integrated Pest Management (IPM) can reduce substantially the levels of carbofuran in the river. Additional reductions can be obtained by reconverting the hillsides into pasture (Fig. 7). Several policy scenarios were analyzed using the minimum data TOA model (Antle and Valdivia, 2006), for example, giving a premium price for IPM products. Even though this type of policy showed to be attractive in terms of expected adoption with minor increments in premium prices, local decision makers do not see this as a feasible policy under an FTA environment. The analysis was then centered on the production of environmental services. The trade-off curves shown in Fig. 5 illustrate that small incentives to farmers per kilogram of active ingredient reduced could induce adoption of IPM and reconversion of hillsides into pasture thus producing a substantial reduction in carbofuran in the river. Expected adoption rates seem to be high. One partner in the alliance made a study on water consumers’ perceptions and their willingness to pay for water services. Users are willing to pay additional US\$0.04–\$0.08 month<sup>-1</sup> to guarantee a good quality of drinking water.

#### 4. Lessons Learned

Several lessons were learned in this experience. The first one was how difficult it is to engage decision makers in countries with high political turnover rates. Second, it is better to work with more permanent professionals



**Figure 6** Changes in soil erosion due to land-use changes: from potato to pasture.



**Figure 7** Changes in carbofuran leaching as a function of IPM adoption and land-use change.

in spite of the fact that they are not at the top of the decision-making pyramid: the message gets across and remains within the institution. Third, having something to show for at the onset of the project, based on previous experience, makes the difference and allows the proactive approach followed by CIP. Hypermedia CD-ROMs provide user-friendly interfaces to promote ecoregional tools and methods. Fourth, robust process-based models capable of predicting research results are good entry points to attract researchers' attention and, once validated, constitute a solid base for geospatial analyses. Fifth, presenting land-use alternatives and the expected impact on income and environment seems to be attractive for policymakers, but it also imposes a higher demand on quantitative thinking to define scenarios and to interpret a large set of options. These tools are seen as a threat to a few conventional policymakers and even advisors using traditional methods. A continuous effort is needed to demonstrate the effective use of these techniques. Sixth, the process is outstanding to build permanent R&D partnerships.

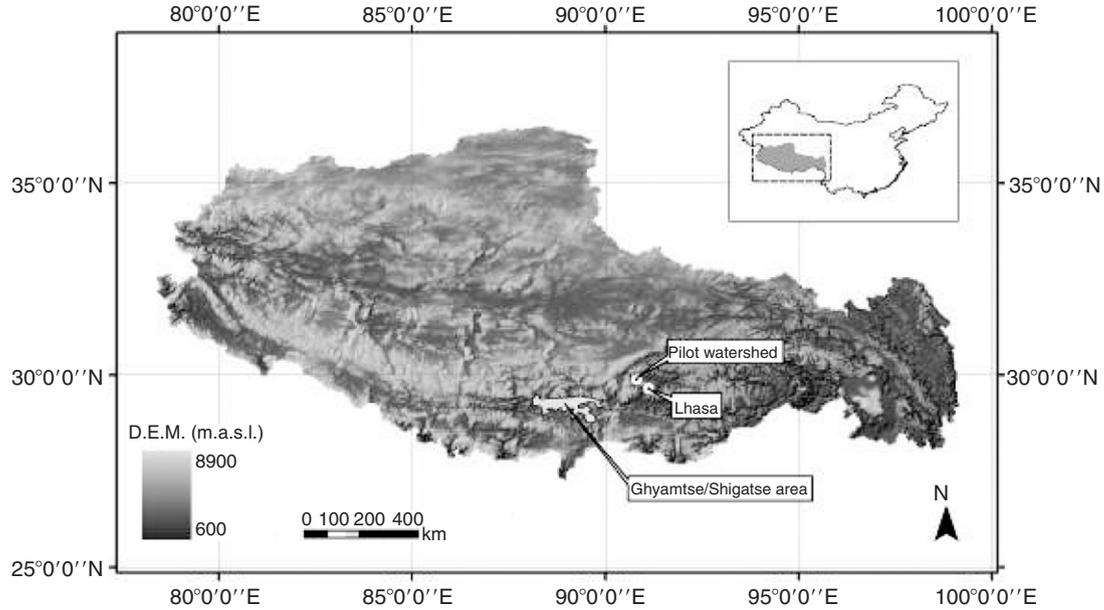
The process has now reached the decision phase where input by research is limited and restricted to further explaining the various scenarios and their implications. Once decisions have been made, research has again a function during implementation because unexpected developments are likely to take place requiring additional analyses but now in a defined context. The effective partnership between CIP and IDIAP, based on a concerted mutual effort, forms an excellent basis for further activities by IDIAP. The Ministry of Agriculture has already assigned funds to IDIAP to conduct similar analyses in five important watersheds in the country. The Panama Canal Authority is holding meetings with IDIAP to conduct a similar study in the Panama Canal Watershed. FAO is interested in cofinancing CIP's and Montana State University's backstopping to IDIAP to look into options for payment for environmental services in the canal watershed.

## **C. SIGNALING CONSTRAINTS IN SUSTAINABLE USE OF WATER RESOURCES ON THE TIBETAN PLATEAU**

### **1. The Tibetan Plateau**

The Tibetan plateau is located in the southwestern part of China and covers an area of 1.2 million km<sup>2</sup>. The elevation ranges from 400 m above sea level (m.a.s.l.) to the summit of Mt. Everest (8848 m.a.s.l.) with an average altitude of over 4000 m (Fig. 8).

Tibet is considered the water tower of Asia and rivers originating in Tibet flow into various regions in Asia. The Mekong, the Yellow river, the Yangtze, the Brahmaputra, the Indus, and the Karnali all originate on the Tibetan plateau and support hundreds of millions of people downstream.



**Figure 8** Location of Tibet within China, the capital city Lhasa, the pilot watershed, and the main agricultural area around the cities of Ghyamtse and Shigatse.

Since Asia is monsoon dominated, with precipitation concentrated in just a few months, the perennial flow of the rivers largely relies on the constant flux of the glaciers in Tibet. As the pressure on Tibet's water resources is mounting because of rapid economic development, its conservation becomes ever more important. Population growth, increased incomes, and urbanization have joined forces and agriculture cannot keep up with the increasing demands of this emerging, new society (Ecoregional Fund, 2005). Yields are restricted by a short growing season, large diurnal temperature ranges, and above all a shortage of water. Annual precipitation is only 600 mm and is concentrated in the monsoon months July and August (Immerzeel, 2005). The proportion of arable land is only 0.3% of the total land area and more than 60% of this land is arid and has a low productivity. Gaps between actual and potential yields of the main crops barley and wheat are very large and this is caused by a poorly developed irrigation infrastructure (Tashi *et al.*, 2002). Increasing the irrigated acreage and promoting new technologies, such as greenhouse horticulture, are the only answer to sustain the increased demand for more and diverse products (Immerzeel, 2005).

Climate change is another major threat to the future of Tibet's water resources. Widespread accelerated glacier retreat and shifts in stream flow timing, from spring to winter, are likely to be associated with climate change (Houghton *et al.*, 2001). There are serious concerns about the alarming rate of retreat of Himalayan glaciers. It has been predicted that the coverage of glaciers in western China, accounting for up to 70% of the Himalayan glaciers, will decrease by 27% by 2050 (Qin, 2002). In the short run, the glacier melt may increase water availability but also major waterborne disasters are likely. Rapid accumulation of water in glacial lakes can lead to a sudden breaching of the unstable "dam" behind which they have formed. The resultant discharges of huge amounts of water and debris—a glacial lake outburst flood (GLOF)—often have catastrophic effects to people, both upstream and downstream. In the long term fresh water shortages could cause severe problems for the livelihoods of the mountain people. Changes in timing and available volume of water available for irrigation will threaten agricultural productivity (Houghton *et al.*, 2001) and will impact heavily on the economy of the region (Matthews *et al.*, 1995). The ability to feed the growing population, a significant number of which already undernourished at this time, is being threatened (FAO, 1999; UNICEF, 1999).

## 2. Research in Mountainous Areas

Mountainous regions globally are considered "the blackest of black boxes in the hydrological cycle" with respect to data availability and understanding (Klemes, 1988). The Ecoregional Fund has acknowledged the importance of

applied research in mountain ecosystems by funding the development of a comprehensive geospatial database on natural resources in six Himalayan countries by the International Centre for Integrated Mountain Development (ICIMOD, 2003). The Fund decided on a follow-up activity to harness the potential of this approach in a Tibet case study. Ecoregional analysis, which aims at linking multiple scientific disciplines with the policymaking process, is a pristine area in Tibet. A traditional, highly hierarchical scientific structure, lack of data, known and unknown political sensitivities, and the sheer physical inaccessibility of the area led to a challenging starting point. Tibet, however, is also the ultimate laboratory to show what role science can play in signaling potentially large problems to policymakers, using modern technologies to overcome insurmountable obstacles that would be found when traditional technologies, based on field surveys only, would be available.

### 3. The Case Study

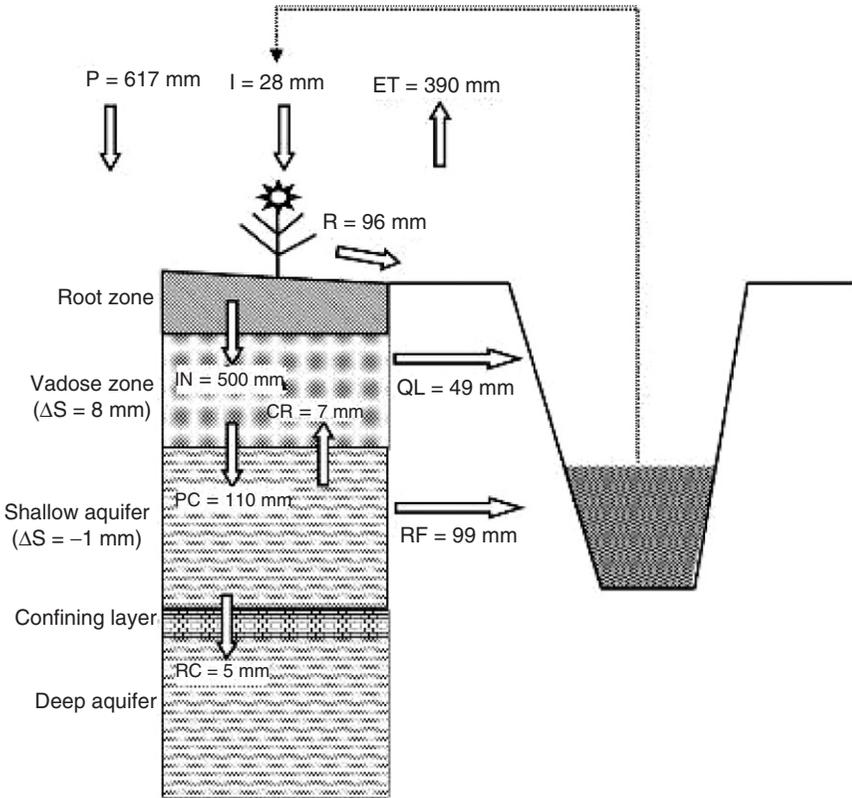
The case study operated on two scales. First, the Tibetan plateau as a whole was studied. Lack of data on local precipitation, which is essential to assess agricultural potential, required the development of a new technique to derive such data from available remote sensing satellite data. A relationship was quantified between precipitation and the NDVI (Tucker, 1979) derived from satellite imagery. In data scarce environments time series analysis of remotely sensed NDVI data can provide valuable information when assessing spatially defined linkages between climate properties, vegetative phenological cycles, and rain fed land use. The Tibetan plateau is characterized by harsh climatic conditions, and food production is mainly depending on fragile rangelands and (irrigated) crop production systems. Annual rainfall and temperature are the dominant determinants in ensuring food security in this sensitive landscape. Only local data are available at this time and only for short periods (Tashi *et al.*, 2002). The high temporal resolution and the up to date character of the NDVI imagery enables and facilitates prediction and spatial interpolation of climate parameters. The research provided insight into the complexity of relating NDVI-derived parameters (NDVI increments between consecutive 10-day periods) to precipitation and land use. Harmonic analysis (the Fast Fourier transform) was applied to correct the NDVI time series for noise.

Regression analysis with 15 meteorological stations has shown that the total amount of precipitation during the growing season exhibits a strong relationship with NDVI-derived parameters ( $R^2 = 0.72$ ). Interannual NDVI variation based on Fourier transformed time series was studied and when linked to food production it can provide a robust early warning system, since very early in the season the expected weather conditions of the upcoming

season can already be predicted. It was concluded that harmonic analysis clearly has added value over the analysis of original NDVI time series which are disturbed by atmospheric noise, sensor instability, or orbit deviations (Immerzeel *et al.*, 2005). This study clearly demonstrates how modern techniques, such as remote sensing by satellites, can rapidly fill critical data gaps that could never be filled with traditional monitoring studies which would be far too costly and would take far too long to implement. The study also shows that cutting-edge research, publishable in the international literature, can be based on questions raised in the context of development-oriented work. When used in a broader policy analysis, as was done here, the value of such data is much higher than when it is published as a technical study as such.

The second part of the project focused on a specific watershed. The hydrological model SWAT (Neitsch *et al.*, 2001) can be used to quantify effects of land-use change and specifically effects of intensification of agriculture, on water resources downstream. The selected site was a small watershed about 40 km northwest of the capital city Lhasa (Fig. 8). SWAT applies a process-based approach to hydrological modeling and is designed to predict the impact of different land management practices on water quality and quantity over long periods in large complex watersheds with highly variable conditions. Using public domain data and limited locally available data on elevation, land use, soils, meteorology, and farming practices a base model was built for the watershed.

The steep slopes, shallow and sandy soils and a short growing season resulted in low yields for the main crops cultivated (0.7–1.7 ton ha<sup>-1</sup>). Surprisingly at first sight, the analyses show that increasing irrigation did not result in significantly higher yields because the physical conditions do not allow water to be retained in the root zone of the soils and is therefore not available to plants for evaporation (Immerzeel, 2005). Figure 9 shows the average annual water balance of the watershed from 2000 to 2003. The watershed receives an average amount of 617 mm of precipitation and 28 mm of irrigation. The amount of irrigation water in the watershed water balance is relatively small since only a proportion of the watershed is arable. Of this 645 mm of water that enters the watershed only 390 mm evapotranspires, a small amount considering a potential evapotranspiration of nearly 1000 mm year<sup>-1</sup>. Due to the steep slopes in the watershed a considerable amount of precipitation is lost due to runoff (97 mm). Only if significant soil conservation measures would be introduced (e.g., terracing, strip cropping, contour tillage), the runoff can be reduced and made available to plants for transpiration. At the same time the sandy and shallow soils with high hydraulic conductivities result in a low water retention capacity of the soil. The result on the water balance is evident; percolation to the shallow aquifer is 110 mm, of which 99 mm is diverted back to the river as return



**Figure 9** Average annual water balance based on data from 2000 to 2003 derived with the SWAT model with data from 2000 to 2003. (P, precipitation; I, irrigation; ET, actual evapotranspiration; R, surface runoff; IN, infiltration; CR, capillary rise; PC, percolation; QL, subsurface flow; RF, return flow; RC, recharge to deep aquifer;  $\Delta S$ , change in storage.)

flow, and subsurface flow to the river is 49 mm. In other words, the steep slopes, sandy and shallow soils, and high potential evaporation result in unfavorable conditions for cost-effectively increasing agricultural yields.

Since many similar watersheds are found across the plateau, it could mean that the overall potential for irrigation improvement in Tibet might very well be much lower than planners and developers think. This is a highly significant and new insight at this time, with profound policy implications. Investments in irrigation will only pay off in a few high potential areas. In other areas investments are likely to be wasted. On the basis of this type of exploratory research, the potential for both crop and livestock production should be explored through further research in other areas. Only such work will provide a rational basis for a regional dialogue as to how regional development and

the associated water use can be fine-tuned to allow agricultural development in potentially successful areas only, avoiding unproductive water losses elsewhere and allowing downstream users to maintain access to clean water resources in future.

#### 4. Discussion and Conclusions

The objective of the project was to acquire insight into the issues related to the water tower function of Tibet and to signal these issues to policymakers. The case study did not completely succeed in the latter objective for several reasons. First, the site selected for field research turned out to have been chosen more for its accessibility from the capital city than for its representativeness. Tibet's most productive agriculture is located not to the northwest of Lhasa but well to its west, on the plains near the plateau's two other major cities, Shigatse and Ghyamtse (Fig. 8). Soils here are deep and relatively fertile, so the potential for irrigation and efficient water use is much higher there. The reported study provides the data to support this different focus. A second, and related, limitation was that the study did not succeed in meeting its major aim of attracting the attention of policymakers. Partly because the location is not recognized as strategically important, but there are also cultural and political factors at work here. Issue-driven applied science is not yet valued highly as a basis for decision making in China. Researchers are not used yet to engage policymakers in their work by showing their results and its implications which are rather dramatic in this particular case. In time, also here a more proactive attitude by researchers is required but at this time this is contrary to the established hierarchical customs. Further complicating factors are Tibet's status as an outlying region, remote from the center of power, and its limited capacity for local research. Local scientists who are well educated and proficient in English tend to climb the career ladder quickly, escaping the relative tranquility of Lhasa for a more challenging position elsewhere. There could also be a deeper reason why policymakers showed so little interest in the study. China is intent on harnessing Tibet's water for its own uses and might not welcome a reminder that these resources should be shared with other countries—or that environmental concerns should curb its headlong rush for development. China's flag should not be the only one on the water tower, but its government may be reluctant to acknowledge this. Despite these limitations, the Tibet study successfully demonstrated the potential of modeling tools to “open windows” onto prospects not previously viewed by policymakers. The future of Tibet's water tower is a new issue on which almost no research has yet been done. Although this project did not draw an immediate response from policymakers, it afforded a glimpse of a problem

that is bound to clamor for increased attention in years to come. In short, it was good signaling, even if no one is yet heeding the signals.

#### **D. MULTIPLE GOALS FOR LAND USE IN SOUTHEAST ASIA**

##### **1. Using Systems Analysis to Study Pressing Land-Use Problems**

During the early 1990s, post-Green Revolution issues, such as stagnating crop yields in Haryana and Punjab in India and environmental degradation in Haryana, Ilocos Norte in the Philippines, and Can Tho in Vietnam, were seen as major problems by Local Government Units (LGUs) and National Agricultural Research Systems (NARS) in the various regions of the humid and semihumid (sub)tropics. Environmental degradation was mainly the result of crop diversification and excessive use of irrigation and agrochemicals in rice-based cropping systems. NARS scientists realized the need for interdisciplinary approaches to allow the necessary integrative studies on agricultural development and land use. They were, however, not equipped to perform such studies and contacts were established with the IRRI, asking for support. In response, the Systems Research Network for Ecoregional Land Use Planning in Support of Natural Resource Management in Tropical Asia (SYSNET) program was established in 1996, the first project to be funded by the Ecoregional Methodology Fund and, in retrospect, one of the very successful ones (see also [ISNAR, 2004](#)).

Issues at stake in rice-based ecosystems of the (sub)humid tropics of Asia are complex. Increased yields do not necessarily imply higher farm income, which is the primary driver for rural development. Intensification of agricultural practices may have quite adverse effects on environmental quality and these have to be considered when defining alternative land management practices. To make such complex issues more transparent and to allow generation of quantitative trade-offs between economic, social, and environmental considerations at the regional level, SYSNET developed the Land Use Planning and Analysis System (LUPAS) ([Hoanh \*et al.\*, 1998](#)). LUPAS was applied and evaluated in four regions of Southeast Asia: Haryana State (India), Ilocos Norte Province (Philippines), Kedah-Perlis Region (Malaysia), and Can Tho Province (Vietnam). LUPAS is a modeling framework using interactive multiple goal linear programming as the integrative component to generate potential land uses in a given region that correspond with best solutions for certain political scenarios, each one considering a characteristic mix of economic, social, and environmental aspects as well as technological developments ([Roetter \*et al.\*, 2005](#)). LUPAS shows potential land-use patterns and is not based on current land use, there by allowing a fresh look at possibilities. LUPAS presents land-use maps with geographically defined results of different politically inspired scenarios.

Thus, LUPAS can deliver important input into all phases of the policy debate. While the strength of LUPAS lies particularly in supporting the signaling and design phase (Van Ittersum *et al.*, 2004), it is also very useful in the decision phase. Using modern (web based) technology, it allows rapid generation of maps in response to stakeholders' assumptions once the underlying database is available. Also, now that LUPAS is available on the web, accessibility of the methodology is no longer a problem. An illustration of the methodology will now be presented for a province in the Philippines.

## 2. An Illustration for Ilocos Norte Province, The Philippines

The LUPAS model for exploratory land-use scenario analysis developed for Ilocos Norte Province maximizes a selection of development goals subject to constraints on land, water and labor resources, agricultural technology, and local demand for agricultural products.

Data on resource availability and local demand have been assembled and adapted from a number of secondary sources. The total area available for agriculture for the year 2010 was estimated at 119,850 ha (assuming an overall land-use conversion rate of 7% from agriculture to nonagricultural uses) (Roetter *et al.*, 2000). This area was divided into a total of 200 relatively uniform land units by overlaying biophysical characteristics (irrigated areas, annual rainfall and distribution, slope, and soil texture) and administrative units, comprising 22 municipalities and 1 township. Provincial demand for agricultural products was assessed on the basis of information on per capita demand and projected population from the Provincial Planning Office. The demand for rice was estimated at 112,610 ton. Labor force and irrigation water were quantified per month and per land unit and month, respectively, based on census data and hydrological data (rainfall, ground, and surface water) from the province and trend projections. Details on the procedures applied to assess resource availability and constraints have been described by Roetter *et al.* (2000, 2005).

The cropping systems or so-called land-use types (LUTs) are selected on the basis of farm surveys and composed of (1) single cropping: root crops, sugarcane, and rice followed by fallow; (2) double cropping: two rice crops, rice in rotation with (yellow or white) corn, garlic, mungbean, peanuts, tomato, tobacco, cotton, potato, onion, sweet pepper, eggplant, and vegetables; and (3) triple cropping: three rice crops, rice in rotation with garlic and mungbean, with (white or yellow) corn and mungbean, and with water melon and mungbean.

The basic scenarios analyzed, based on intensive consultations and discussions with stakeholders (Roetter *et al.*, 2000) and after having explored the biophysical potential of the province, were: (1) emphasis on increasing

farmers' income, while meeting minimum demands for rice and some selected other crops, and taking into account current water and labor constraints, (2) emphasis on rice production meeting minimum demands for rice and some selected other crops, and taking into account current resource constraints.

In further stakeholder discussions it became obvious that most interest groups do not regard rice production (though important) a promising future perspective for Ilocos Norte but rather a variety of other agricultural and tourism activities. These discussions led to examine the possible impact of R&D targeted at knowledge-intensive technologies. For this, 3 variants (or subscenarios) to scenario 1 were analyzed (Table I). The aim was to look at the likely effect on maximum income if all farmers could choose between different production technologies. For each LUT three technologies were defined, as follows: technology 1: "average farmer practice," technology 2: "high yield/high input," and technology 3: "high yield/improved practice." The relevant input-output coefficients for technologies 1 and 2 were derived from farm surveys in Ilocos Norte Province, while technology 3 (SSNM, site-specific nutrient management) was generated based on quantitative relationships between yield and soil conditions and fertilizer management practices. These quantitative relationships (established using the QUEFTS procedure, i.e., the quantitative estimation of the fertility of tropical soils system) were derived from comprehensive experimental data sets from different locations in Asia.

For the Ilocos Norte case, technology 1 involves average values for all farms (after data cleaning). Technology 2 depicts the land use of a group of survey farmers obtaining higher than average output through intensive use of inputs. For yields, the mean of the values with a yield level between the 90th and 95th percentile of the survey data was reported. Fertilizer and pesticide use were assumed 100% higher and labor 70% higher, other inputs remaining identical to those in the average practice. For the "improved

**Table I**  
**Results of the Regional Explorations (Year 2010)**

Variable	Unit	Maximize farmers' income		
		Technology 1	Technology 2	Technology 3
Income	10 <sup>9</sup> Pesos	15.3	30.4	36.6
Rice	10 <sup>3</sup> ton	119	226	241
Employment	10 <sup>6</sup> labdays	9.5	17.8	12.1
Biocide	10 <sup>3</sup> kg a.i.	75	161.6	79.5
N fertilizer	10 <sup>3</sup> ton	13.5	33.8	15.9
Land used	%	100	91	96

Scenario 1. Maximize farmers' income (constraints: land + water + labor and provincial demand for important food crops satisfied).

practice” or SSNM variant (technology 3), the same, high, yields as in technology 2 were assumed, but biocide inputs were reduced by 20% compared to those in “average farmers” practice. We, moreover, assumed higher fertilizer use efficiency than in the first two technologies. For defining realistic improvements in fertilizer efficiency, we screened data from fertilizer experiments in the Philippines and other Southeast Asian countries.

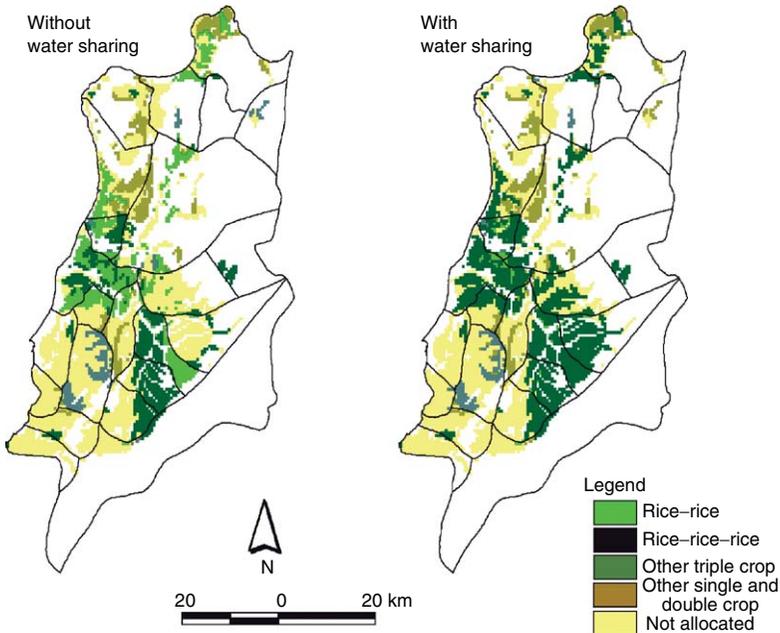
Results for scenario 1 show, among others, that if all farmers in Ilocos Norte would apply technology 2, their income would be considerably higher than with technology 1. However, this would be achieved at the cost of high use of agrochemicals. If all farmers would apply technology 3, even higher income levels than with technology 2 could be achieved at about 30% lower inputs of fertilizers and pesticides.

For all technologies, in scenario 1, total rice production would exceed the current production levels. Site-specific and more balanced nutrient and pest management practices could lead to considerably higher incomes at reduced environmental costs, while still satisfying local demand for the main food crops: a clear win-win situation (at least, as predicted by this exploratory analysis at the provincial level). This does, of course, not imply that all farmers will adopt these technologies; however, the methodology illustrates specifically what might happen if they did, and as such, it presents motivation for change.

To study the farmers’ perspective in more depth, a PhD study and a follow-up project were launched to supplement the regional results with farm household analysis in Batac (Laborte, 2006) and Dingras municipalities ([www.irmla.alterra.nl](http://www.irmla.alterra.nl)).

Aside from scenarios 1 and 2, mentioned above, a large number of additional scenarios have been analyzed for Ilocos Norte Province by SYSNET following interaction with user groups and policymakers. These are available on CD-ROM. One major concern deals with use of irrigation water. Figure 10 illustrates, for example, the shifts to be expected in land-use allocations for rice cropping systems under the assumption of the possibility to share water among the irrigation systems of the province, making water use more efficient. Associated calculations indicate that rice production could increase by 40% and farmers’ income by 16%, partly because sharing water implies that the triple-rice cropping systems could be more widely applied, be it only in certain areas! This example illustrates how a relatively abstract concept of increasing water-use efficiency can be “translated” into specific financial terms for a region and into associated land-use patterns that land users and policymakers can identify with.

Application of LUPAS has “lubricated” discussions in the different countries by showing what the consequences might be for a given region of major departures from current land use and agricultural practices. Of course, each region has a characteristic “window of opportunities” and LUPAS is



**Figure 10** Results for scenarios 2 and 3: Land-use allocations for different future resource availabilities/alternative choices: Water sharing among irrigation systems within the province (left: without; right: with).

particularly suitable to provide a sketch for that window. Rather than making an obvious statement such as: “anything” cannot be done “anywhere,” LUPAS allows statements as to what “might” be done “where” under certain, well defined, conditions. With that kind of information regional development objectives and targets can be generated for policy objectives. This is combined with considering interventions at the farm level, making sure that scenarios at regional level are realistic, while at the same time providing specific stimuli for local farmers when the potential benefits of certain changes on a regional level can be made visible for the farm level as well. This joint effect on policy and farm level has been analyzed for Ilocos Norte Province in the Philippines (Laborte, 2006) and Pujiang county in China ([www.irmla.alterra.nl](http://www.irmla.alterra.nl)).

### 3. What It Takes to Apply the Methodology in Practice

In order to integrate use of LUPAS into the practice of land-use planning, during the period 2001–2005, it has been applied independently to several provinces of Vietnam by local teams from Cuu Long Delta Rice Research

Institute (CLRRI) in the Mekong Delta and by the National Institute of Soils and Fertilizers (NISF) in North Vietnam. Studies have been performed in close consultation with local governments and stakeholder platforms established during the SYSNET research process (Roetter *et al.*, 2000; Van Paassen *et al.*, 2006). In Malaysia, independent applications have not been reported due to “brain drain” of IT and computer specialists at Malaysian Agricultural Research and Development Institute (MARDI). The SYSNET team in India has applied modules of the LUPAS system, such as the technical coefficient generator (TCG), in a number of policy-relevant land-use studies and has expanded the TCG to include calculation of greenhouse gas emissions. The Philippine team, supported by IRRI, finally, has continued to look concurrently at the adoption of knowledge-intensive technologies and supportive policies on sustainable agricultural development in Northern Luzon. Similarly, iterative multi-scale analyses of technology and policy options have been performed in follow-up projects to SYSNET such as in the IRMLA project between Zhejiang University and local government organizations, for example, the Agricultural Bureau in China ([www.irmla.alterra.nl](http://www.irmla.alterra.nl)).

Changes in land management practices and policies that can be attributed to SYSNET and its follow-up projects include, for instance, abandonment of heavy agrochemical use in dry season crops in Ilocos Norte, Philippines, increased investments and special R&D programs for participatory development and dissemination of IPM and site-specific nutrient management practices in Ilocos Norte (Philippines), Can Tho Province in the Mekong Delta and Tam duong district in the Red River Delta (Vietnam) and in Pujiang county (China). Through results from scenario analyses the awareness of excessive nitrogen and pesticide use in rice-based systems has been clearly raised, and policy objectives to achieve this have been introduced in policy documents of local governments (in particular in the Mekong Delta, Vietnam, and in Zhejiang Province, China) (Van Paassen *et al.*, 2006).

Several follow-up R&D projects have been realized in Southeast Asia and this has been made possible by substantial investments in institutional capacity building made by SYSNET project (ISNAR, 2004; Van Paassen *et al.*, 2006).

## E. FROM ENVIRONMENT TO HUMAN HEALTH

The DME-NOR project from the first phase of the Fund is one of the few projects that, in combination with significant leverage funding and follow-up projects, has covered the entire policy cycle. Although the commercial farmers of the Carchi region in Northern Ecuador are probably some of the better endowed in the rural communities of the Andes, it became increasingly apparent that the use of pesticides in intensive potato production was not only a blessing but a curse as well. In the early 1990s, researchers, farmers, and

NGOs paid increasing attention to the negative effects of the intensive use of pesticides. The farmers in the Carchi region were very much dependent on these pesticides to control pernicious pests and blight. Intensive on-farm research revealed some of the major health and environmental impacts associated with these pesticides. The intensive use of highly toxic pesticides resulted in significant neurobehavioral effects on farmers and pesticides were detected in ground water as well as streams that serve irrigation and domestic use downstream. A broad signaling phase with large groups of stakeholders, however, also drew the attention to soil erosion. Many fields revealed the light-colored subsoil on the upper parts of the fields and the common perception was that water erosion was the main cause. However, research showed that water erosion was not responsible for the erosion of the topsoil due to low rainfall intensities in combination with a high infiltration capacity of the volcanic ash soils. The steep fields cultivated with potatoes require intensive tillage. All tillage and harvest operations transport topsoil material down the slope. On fields tilled with tractors the situation is even more serious. As slopes are too steep for contour plowing, tractors plow downslope. Rather than water erosion, tillage erosion was in this case the main cause for the observed erosion processes. This example clearly shows the importance of stakeholder input but also the impact of scientists in the signaling phase, avoiding misperceptions that could easily have led to irrelevant routine research on water erosion.

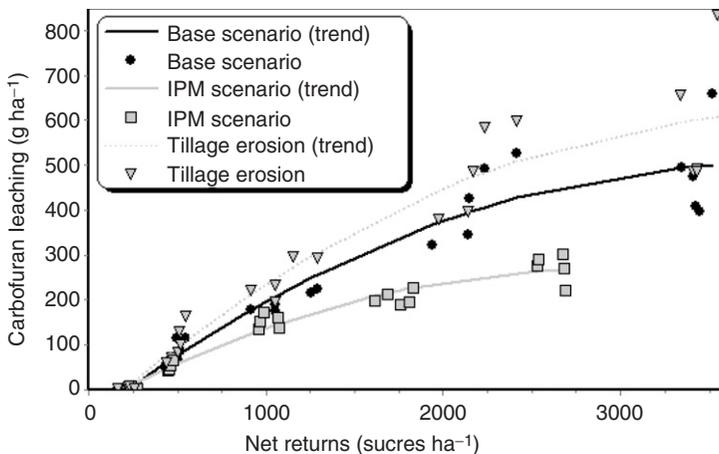
After signaling and quantifying the key sustainability factors, that is, human health and environmental impacts of pesticide use and tillage erosion, the question that remained was how to intervene. Clearly, the reduction of pesticides also pesticide handling issues were the two elements to focus on to reduce the environmental and health impacts of pesticides. To reduce the impact of tillage erosion, very few technical solutions were available. The potato crop requires intensive tillage and any tillage practice on these steep slopes automatically results in soil erosion. The only practice that significantly reduces tillage erosion is based on the little-known pre-Columbian limited tillage/cover potato system *Wachu rozado* that is still being practiced in Northern Ecuador. In this system seed potatoes are placed on top of the pasture and the grass mat is folded over the potatoes.

In the DME-NOR project the TOA methodology has been developed that was also applied in the Kenya research (see [Section IV.A](#)). A 2-year dynamic farm survey provided insight in the management decisions of the farmers in the Carchi region. This resulted in an economic simulation model allowing for the ex ante evaluation of alternative policy and management scenarios (Crissman *et al.*, 1998; Stoorvogel *et al.*, 2004a). The TOA methodology addresses two key elements: first, it provides an organizational structure around which to design successful interdisciplinary research that assesses the sustainability of production systems; second, it provides a

successful means to communicate research findings to policymakers and the public.

Farmers are the Andes' most numerous and most important soil resource managers. Agricultural technology ranges from traditional, extensive, low-input, low-output systems to modern, intensive, high-input, high-output systems. The traditional systems have to be maintained within their ecological constraints and, as a result, are generally perceived as environmentally friendly and sustainable. However, due in part to shrinking farm size, traditional systems have proven to be economically and socially unsustainable. With a closed agricultural frontier in most parts of the Andes, the fundamental option for Andean farmers is to increase the physical and financial output from the existing farm. This inexorable pressure provides a strong incentive to shift to the higher output modern systems. The basic quest of agricultural and environmental research for sustainable farming systems is to match the environmental friendliness of traditional farming systems while reaching the higher outputs and, thus, the economic and social sustainability found in modern farming systems.

Figure 11 shows an example of the type of answer one can expect from the TOA system. The trade-off curves between net returns and carbofuran (one of the most commonly applied highly toxic insecticides) leaching are constructed by varying the potato prices. In the base scenario the current management system is evaluated. The trade-off curve shows that with increasing potato prices, the net returns of the systems increase coinciding with an increase in carbofuran leaching. The latter is due to an increase in the potato area but also due to a more intensive management of the potatoes.



**Figure 11** The effect of IPM and tillage erosion on net returns and carbofuran leaching in the Carchi region in Northern Ecuador.

Two alternative scenarios have been evaluated: the effect of tillage erosion and the effect of the introduction and adoption of IPM. Due to tillage erosion we see that carbofuran leaching increases. This can be explained by the removal of the organic matter-rich topsoil that fixes carbofuran. IPM shows an opposite effect where the trade-off curve is moving down. Less carbofuran is being applied and as a result leaching is going down. However, the reduction of IPM comes at a cost. Alternative management practices are required to control the pest requiring farm labor. As a result net returns are slightly decreasing.

The TOA provided information on possible interventions both at the political level as well as at the farm level. In various follow-up projects the policy cycle has been closed. While pesticides have not been eliminated from the Carchi communities, they are now generally used more cautiously. There is also momentum at a policy level for reducing pesticide dependence. In 1999, all stakeholders were brought together to discuss pesticides and health. This meeting resulted in the Carchi declaration demanding the elimination of the highly toxic products, the inclusion of IPM in university level agriculture training, and a wider dissemination of information on the effects of pesticides. In addition, farmer field schools have been set up in which farmers and the research community developed IPM technologies but also pesticide handling measures to reduce the impact of pesticides. The effects of various management changes, as part of IPM, on these farmer field schools are striking. The number of pesticide applications was reduced from 12 in conventional plots to 7 in plots with IPM. Even more important, the overall amount of pesticides applied dropped dramatically. The amount of fungicides decreased by 50% while insecticide quantities dropped between 40% and 75%.

The Carchi story is illustrative for a combined effort in which farm surveys, advanced simulation modeling, GIS techniques, IPM research, stakeholder meetings, and farmer field schools led to a strong reduction of pesticide use in the Carchi study area. It illustrates the strength of the research chain rather than a single method and/or project. The project was successful in designing innovative production systems for potatoes that were environmentally friendly while protecting the health of farmers. Political decisions were made about environmental and health regulations and they were implemented, so far only at the regional level. Educational programs for farmers were initiated during this research projects and are continued up to this day.

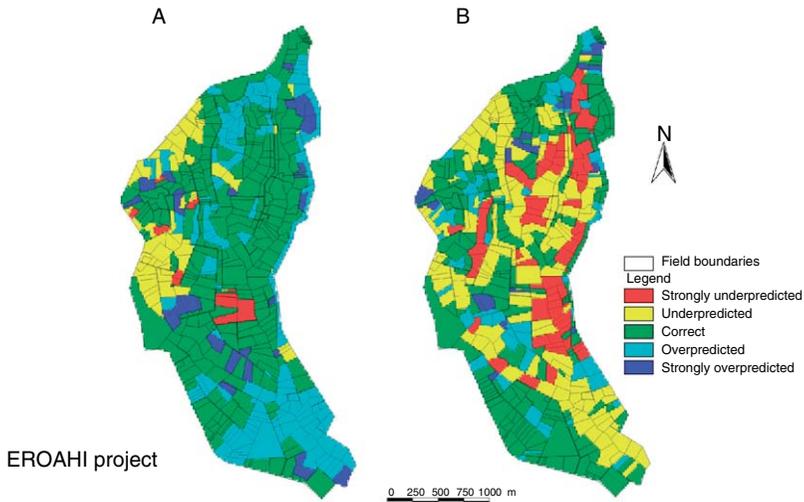
## F. REALLY DEALING WITH SOIL EROSION

Widespread soil erosion—one of the most studied topics in agricultural research—and the associated land degradation are caused by overexploitation of natural resources due to an increasing demand for food, fiber, and

fodder by growing human and livestock populations without the economic means to sustain the resource base. Exploitative land-use practices include deforestation for expansion of cultivation, excessive grazing, and removal of fuel wood and timber. This reduces the protective plant cover, thereby exposing the soil surface to the destructive impact of high-intensity rainfall. Land degradation can be reversed by soil and water conservation (SWC) practices that have been developed during many decades of research but results in the field have so far been quite disappointing. Often, farmers are blamed for this low success rate. They are accused of being ignorant, uncooperative, and conservative. This, however, is increasingly seen as an unfair judgment. Poor planning of SWC research rather than unwilling farmers, appears to be the core issue. Too much top-down research has been done without consulting farmers in the process, resulting in recommendations that did not match the priorities of the farmers who tend to focus on productivity loss rather than on soil loss as such. The question as to how farmers can be more involved in a meaningful manner in soil erosion research is therefore still relevant. Another aspect to be considered in erosion research is the need to look at larger areas than only single farms as local management practices may affect conditions elsewhere in the area through patterns of water movement. The so-called “catchment approach” looks at an entire natural geographic area which drains all rainfall within the area to a single outlet. Unfortunately, so far research methods for the catchment scale are not well available and this was a main reason to start a project to develop an improved method for SWC planning at catchment scale in the East African highlands (EROAHI). As discussed by [Van den Bosch and Sterk \(2005\)](#), experiences elsewhere with the catchment approach had been mixed so far at best. Involvement of communities of land users turned out to be difficult. Also, off-farm conservation work often not considered as emphasis was still on farms. To overcome the problems of nonparticipation and ineffectivity, new scientific tools and procedures were developed in the EROAHI project to tap the active and creative input of farmers and their communities in developing innovative and effective SWC measures on catchment level.

Research followed a number of steps: (1) a review of farmer’s perceptions on erosion and SWC measures. Emphasis on this first step led to serious farmer’s involvement right from the start and to insights into their perceptions; (2) identification and calibration of indicators of erosion. This step was essential to nail down perceptions outlined in step (1). Without this step, discussions would have remained unfocused; (3) construction of a tool for participatory soil erosion mapping. Having jointly defined the indicators, now a map is made of the entire catchment requiring active participation of all farmers and providing a platform for discussion and information exchange ([Okoba, 2005](#)); (4) surveys and modeling. Having defined the effects of erosion as seen by farmers, scientific procedures to study these

effects are applied and tested. Note that this more traditional form of research enters the discourse only in step (4). Three procedures were used here. The first was the internationally established method for Assessment of Current Erosion Damage (ACED). The second was the Morgan, Morgan, and Finney (MMF) model, an easy to understand empirical model with a physical base and a low data demand. The third was the LISEM model, based on physical—chemical laws and requiring many detailed data. This model is particularly suitable to estimate effects of a single rainfall event and was calibrated and validated by measuring outflow from the studied catchments; (5) comparison of the farmers map with the ACED survey and modeling results. Although there were expected discrepancies between farmers observations and ACED results, the predictions of the farmers were often closer to the ACED results than the model predictions (Fig. 12). Use of farmer's indicators for infield erosion assessment in combination with the ACED approach and MMF modeling provides a good basis for productive, joint work of researchers, extensionists, and farmers (Vigiak, 2005). The LISEM model has not only a prohibitively high data demand but it also needs intensive calibration after which it can predict total runoff from a particular catchment after a given rainfall event. However, erosion patterns over the catchment are not well predicted nor is the model suitable to predict average annual erosion rates (Hessel, 2006); (6) once overall erosion has been predicted, attention is focused on effects of particular SWC measures,



**Figure 12** Map of the Gikuuri catchment showing the difference between farmers' estimates and ACED field survey (A) and the difference between LISEM and the ACED field survey (B).

where field research provides specific data in the defining context described by procedures (1)–(5). Having this context makes such experiments much more valuable than having only isolated experiments. Here, hillside ditches turned out to be more effective than bench terraces and grass strips; (7) the financial effectiveness of SWC measures and construction of a practical tool for participatory financial analysis (Tenge, 2005). This aspect is very important for farmers and policymakers alike in the context of cost–benefit analyses that often form the ultimate criteria for success or failure; and finally (8) the project tested the developed tools under field circumstances. The tools developed in Kenya were tested in Tanzania and the Tanzania tools were tested in Kenya. Results indicated the general applicability of the developed tools and procedures ([www.ecoregionalfund.com](http://www.ecoregionalfund.com); van den Bosch and Sterk, 2005).

This project illustrates a particular form of signaling. The importance of soil degradation and erosion hardly needs signaling. Libraries are filled with data reflecting a century of research. Interestingly, signaling here was focused on the SWC profession itself, questioning basic premises of previous work. By starting with farmers' expertise and by introducing scientific survey and modeling techniques later, the design process was innovative and resulted in a true interactive process between farmers and researchers. The high-tech LISEM model, used routinely in many erosion studies, was shown to have serious limitations. The decision process focused on farmers and by providing jointly developed tools for both the technical and financial evaluation, their commitment was earned. Implementation was tested in the field in both Kenya and Tanzania and results, though necessarily of a preliminary nature, are promising. Evaluation in the end provides a clear message for the research community—rather than the usual technology push, time has come to move toward true interactivity with the land user which may be time consuming at first sight but which results in real effects in the field as a result of fine-tuned technology infusion into the social interaction processes occurring in catchment areas. Such messages, showing clear results, are a good starting point for renewed interaction with policymakers who have become unreceptive to generic complaints about soil erosion which they have heard so many times before.

### **G. REESTABLISHING FARMERS' CREDIT IN THE HIGHVELD REGION, SOUTH AFRICA**

The primary staple foods of southern Africa are grain crops. Large areas in southern Africa, which are classified as arid to semi-arid with irregular rainfall patterns, are planted under maize, sorghum, and millet. Due to climatic conditions, yields are irregular and unpredictable. The office of the "Agricultural Research Council-Grain Crops Institutes" (ARC-GCI) in Potchefstroom (South Africa) is responsible for research in the Highveld

region. The Highveld region, located within South Africa, is representative for most of the environmental and economic risks which are experienced within the other southern and eastern African countries. In the Highveld region 70% of the arable area is planted to maize. Up to 90% of the country's maize is produced in this region. As the main staple food, maize production plays an important role in the livelihoods of the rural communities.

Questions to be answered by ARC-CGI were not raised by scientists. Key questions were asked by banks, industry, government, and farmers: Can we assess the likelihood of crop failure in any given year? Is this land providing enough income to support farmers with credit? What is the expected regional maize production in the current growing season? and What are the expected effects of climate change on maize production in the Highveld region? Uncertainty about these issues had resulted in lack of credit and insurance facilities for farmers, as bankers considered risks involved to be commercially unacceptable. This created an emergency situation for the region.

ARC-GCI considers crop growth simulation models to be one of the key instruments to investigate the various problems surrounding the cultivation of the main crop. Questions being raised could not be answered with existing more traditional agronomic expertise and tools. Use of models resulted in various questions to the research community at ARC-GCI. For example: What are the genetic coefficients for the local maize varieties to be used in the crop growth simulation models? Are various existing crop growth simulation models providing us with reliable estimates? and Can we extrapolate weather conditions observed locally in a few weather stations both in space and time to the entire area? The ARC-GCI project developed specific modeling tools and focused on generating the required input data. They used the models and tools to provide specific answers to the questions of farmers, policy-makers, industry representatives, and bankers. The work was done in close interaction with these four groups of stakeholders, making sure that every step in the procedure was discussed, explained, and, if necessary, modified. Many of the tools currently being used by the research community are not geared to answering these practical questions. Significant changes were therefore required and specific utilities had to be developed to obtain an operational system. And all this had to be achieved with limited resources and time. In the end, researchers showed convincingly that the models were useful tools to answer the various questions but only after a significant investment in calibration and development of specific tools for the region. By developing the work in close consultation with farmers and bankers, results were readily and successfully adopted. In this project signaling by farmers and bankers was followed by a research-initiated design phase with a high participatory character. Results were such that bankers and insurers decided to embrace the system and provide again credit and insurance to farmers. The project of the Fund was terminated in 2002 and as far as we

know, the system still operates to full satisfaction of participants. Implementation of the modeling approach has led to many questions along the way which are still being addressed by the researchers of ARC. This successful project has covered the entire policy chain.

## V. WHERE DO WE STAND NOW AND WHERE TO GO?

When dealing with science in support of natural resource management and rural development in developing countries—the charge for the Fund—we have to look beyond the individual farm, realizing, however, that what does or does not happen on the farm will have a major impact on the region and country in which the farms occur. That is why *up-* and *downscaling* are so crucial. In other words, how can changes at farm level affect regional development and—a more dominant consideration—how do regional, national, and international developments affect the farm level? And what is and can be the role of research in all of this? In their “Strategy for Revitalizing Agriculture” the [Kenyan Government \(2004\)](#) lists five critical areas requiring attention. One of them is “promotion of research and technology development.” Our premise is that innovative approaches are needed for research at the regional level in future for it to be effective in promoting better natural resource management, contributing to rural development.

The problems we deal with are immense and baffling but with due recognition of the limitations of a single project and of all the good work being done elsewhere, we like to propose that our work has contributed in three ways.

### A. SHOWING NEW WAYS OF CONDUCTING RESEARCH

#### 1. Up- and Downscaling by Using Sequences of Models

Rather than study only isolated problems, a comprehensive analysis of the land-use system is needed, starting at regional and higher-scale level, with functional links to the local level. Computer simulation modeling is by now an indispensable tool, as has been demonstrated in the various case studies discussed here. User-friendly approaches and accessibility on the web allow use at even the most inaccessible locations. A sequence of models to be used has been demonstrated in the various projects of the Fund (e.g., LUPAS–CLUE–TRADE-OFF–IMPACT). Downscaling moves from left to right and upscaling from right to left. Rather than being defined as an abstract concept, scaling can thus be associated with and translated into specific questions, data demands and answers that are associated with various models, each one characteristic for a given scale level and focused on

questions that are unique for that particular level. The sequence CLUE–TRADE-OFF–IMPACT, including up- and downscaling was most clearly demonstrated in [Section IV.A](#) (African Highlands) and [Section IV.B](#) (Panama). For erosion, different sets of interconnected models were used for the farm and watershed level in [Section IV.F](#) (Kenya/Tanzania). This comprehensive systems analysis provides lots of opportunities for basic research as demonstrated by published papers for each of the case studies in [Section IV](#).

## 2. Covering the Entire Policy Cycle

Research should preferably cover the entire policy cycle from *signaling* problems to *implementation* of possible solutions. The traditional restriction of research to the *design* phase does not mobilize the available research potential (interestingly, in their strategy document the Kenyan Government does not speak of the policy cycle but of “*five steps of logical thinking*”). Demands on research are different when *signaling* a problem, when *designing* options for solving the problem, when advising policymakers to make *decisions*, or when helping to *implement* selected measures, rules, or regulations ([Bouma, 2005](#)). Due to time limitations, many of the more recent projects of the Fund have not moved beyond the *design* phase. Most experiences obtained referred therefore to the *signaling* phase. But some of the earlier projects, as described in [Sections IV.D \(Southeast Asia\)](#), [IV.E \(Peru\)](#), and [IV.G \(South Africa\)](#), have covered the entire cycle.

Significantly, *signaling* never followed the stereotype sequence of a project being formulated by a governmental agency or by researchers, followed by research ending with the delivery of a report. Different approaches were evident in the studies of the Fund.

1. *Governmental initiatives*. The Kenyan government was instrumental in putting agricultural development on the agenda ([Section IV.A](#)), but this was immediately picked up by local researchers of KARI and external researchers (the latter category includes researchers associated with CGIAR Centers and those associated with northern Universities) into a joint *design* process;
2. *Initiatives by external researchers*. The FTA study ([Section IV.B](#)) was initiated by CIP at an IDIAP conference, demonstrating effective communication of the possibilities of modern techniques studying land use. After that, the government joined external and increasingly local researchers into a highly interactive process of *design*. The innovative exploratory work in Tibet ([Section IV.C](#)) could not yet connect with local researchers let alone with policymakers. Still, indications are that

slowly policymakers are being convinced that modern land-use studies can assist their cause and local researchers may follow but only after extensive training. Studies in Southeast Asia (Section IV.D) were also initiated by external researchers who strongly involved local researchers, which, in turn, attracted governmental attention resulting in a truly joint-learning process in the design phase. Because this program has been proceeding since 1997, policy *decisions* have been made and there is clear evidence of *implementation*. The soil erosion studies of Section IV.F were initiated by external researchers who took a much-needed fresh look at available studies on erosion. They are involving local researchers and face the task to communicate their findings and recommendations to governmental agencies that have received abundant erosion advice over the years, leading to no significant advances in combating effects of erosion. There is clearly a certain degree of skepticism to be overcome.

3. *Initiatives by local researchers.* The foremost example of this is the farmers' credit study in South Africa (Section IV.G). Local researchers quickly picked up the signals of farmers and bankers, *signaling* the problem. They designed solutions in close interaction with farmers and bankers and made sure that the developed information systems were *implemented*. External researchers had limited but essential input in providing simulation models and climate expertise. A second example is reported for Ecuador in Section IV.E. Here, local researchers and stakeholders were worried about erosion of potato fields. External researchers showed that erosion was less a problem than toxic effects of biocides, used for the potato crop. An extensive education program was set up by external and local researchers while the latter group is now a prime actor in *implementation* of remediative action.

For researchers, the implications of this diversity in approach have as yet been largely unexplored and represent a new challenge to find the appropriate mix of initiatives and activities for each new project. It requires in any case an extended project period of at least 10 years to allow organic development of such projects and this is in stark contrast to the type of short-duration projects we see now. The *evaluation* aspect in the end is particularly valuable. It allows a learning experience based on an analysis of mistakes made and successes achieved, with the potential to improve the research process next time around.

### 3. True Interaction Requires a Long-Time Engagement

Covering the entire policy cycle requires intensive and long-term interaction not only with policymakers but also with a wide variety of land users. Case studies in Section IV illustrate this well. To be effective, this cannot be

an ad hoc activity but requires a structural arrangement, which, so far, has not often been realized in practice. As any situation is different it is difficult to formulate general rules, except for researchers to be engaged and open to dialogue without sacrificing their scientific virility. Researchers are most effective when they focus on a key element of democratic society, which is the necessary interaction and effective communication between citizens and their government. This is more effective than exclusive interaction of researchers with either governmental agencies or stakeholder groups, which is not uncommon at this time. Effective interaction results from injection of the right knowledge or expertise into the debate at the right time (including recognition of tacit knowledge of stakeholders as an essential ingredient) but also from being prepared to play the role of *mediators*. Two aspects need emphasis here: (1) as relatively neutral outsiders with no direct stake in the way resources are used in a particular region, scientists can be particularly effective in safeguarding sustainable development which requires a delicate balance between economic, environmental, and social requirements, and (2) the need for training and capacity building by initiating workshops with emphasis on *joint learning* rather than on *technology transfer*. Cases presented in [Section IV](#) provide examples of both aspects.

## B. SHOWING NEW WAYS OF PRESENTING RESULTS

A key element of work of the Fund is the systematic use of GIS which visualize different land-use patterns, ranging from actual conditions to possible patterns following certain land-use options. Good examples were provided in [Sections IV.A, IV.B, IV.C, and IV.D](#). Too many reports present their statements in texts and tables, making them difficult and tiring to read, understand, and interpret. Reports with long “Shopping lists” defining problems and other lists with possible solutions (without any indication as to how those solutions could possibly be attained) are all too familiar and discourage rather than stimulate the reader. Visualization is a powerful tool of communication and GIS maps form only a relatively simple mode. Accessibility of the programs on the Web makes them much more easy to use. In addition, modern 3D visualization techniques are widely used in the information and communication industry, for example, for gaming purposes. Initial plans to incorporate these techniques in our work could not be realized. We still feel, however, that such techniques should be more widely applied in land-use studies as users of information are usually quite susceptible to impulses in terms of “what” might happen “where” and “when.” The Kenyan Highland study ([Section IV.A](#)) was a good example of showing “hot” and “cold” spots of possible future developments including the possible effects of better marketing and improved

functioning of institutions, which are some of the critical areas defined by the Strategy for Revitalizing Agriculture in Kenya (2004).

Communication is not only an art but also a science. Involvement of science writer Simon Chater from Green Ink Ltd. (United Kingdom), who wrote two bulletins with the challenging title: “(More) Method in our Madness,” was essential, we found, in communicating our message to a broader audience than the usual one being addressed in scientific circles (Ecoregional Fund, 2005; [www.ecoregionalfund.com](http://www.ecoregionalfund.com); ISNAR, 2004).

### C. PRESENTING NEW MESSAGES TO POLICYMAKERS AND LAND USERS

The new message is that we would like to join in a permanent partnership with policymakers and land users in order to increase the effectivity of our research. We acknowledge similar considerations being made elsewhere, for example, at the Millennium Institute in Arlington, Virginia, United States ([www.millennium-institute.org](http://www.millennium-institute.org)).

Obviously, research cannot on its own define “ideal” solutions to complicated environmental problems and rural development. Rather than have ad hoc joint activities with policymakers and land users for (parts of) separate projects, we would prefer a structural arrangement where *joint learning* (including scientists) would be the overall objective. This arrangement has been called a *Community of Practice* (CoP) (Wenger *et al.*, 2002). Responsibilities of all parties involved, which are not only policymakers and land users but also possibly NGOs and representatives from industry, should be well defined. Researchers taking part in CoPs have their own responsibilities and should be keen to preserve their academic independence. They should listen well to other participants and try to learn from their experiences. At the same time, however, they have their own scientific input in the debate, not only on the basis of existing expertise which can now easily be tapped from the internet, but also on the basis of new research to be initiated because the CoP considers this to be necessary. Being part of a CoP does not necessarily imply that scientists glorify the input of other members of the CoP (which sometimes happened in farming system research where farmers’ expertise was uncritically embraced by some) but that they critically examine all input. Forming an effective CoP also requires discipline from the other team members: paying for a project does, for example, not necessarily imply that the answer should comply with preconceived ideas of the financier.

Effectively acting within a CoP puts a strain on the scientific community because demands on researchers are quite different than the traditional ones. Bouma (2005) therefore advocates next to a CoP, formation of *Communities of Scientific Practice* (CSP) within which the scientific community tries to get its act together. A group of workers from within the scientific community

interacts with different groups of stakeholders, policymakers, NGOs, and so on in a broader issue-oriented CoP. Each CoP requires a different CSP. Within a CSP there should be ample opportunity for interaction between basic, strategic and applied researchers in different fields, including the legal one, and communication experts. All projects of the Fund—and many others outside the Fund—show that CSPs are being formed now in which external and local researchers not only work well together but in which local researchers increasingly become leaders and initiators. This is an excellent development for the future.

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