Integrated Natural Resource Management Research in the CGIAR

A Brief Report on the INRM Workshop
Held in Penang, Malaysia
21-25 August 2000

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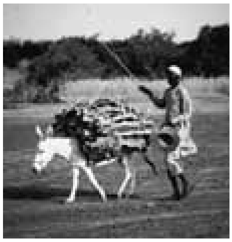
List of Participants
in the INRM Workshop in Penang

Name	Institution	E-mail
Ablan-Lagman, Ma. Carmen	ICLARM, Malaysia	m.ablan@cgiar.org
Ashby, Jacqueline*	CIAT, Colombia	j.ashby@cgiar.org
Belcher, Brian	CIFOR, Indonesia	b.belcher@cgiar.org
Bergmark, Christine*	USAID, USA	Cbergmark@usaid.gov
Bie, Stein	ISNAR, The Netherlands	s.bie@cgiar.org
Bossel, Hartmut	Germany	H.Bossel@T-online.de
Campbell, Bruce	CIFOR, Indonesia	b.campbell@cgiar.org
Chandler, Fiona*	ICRAF, Kenya	f.chandler@cgiar.org
Dar, William	ICRISAT, India	w.dar@cgiar.org
El-Beltagy, Adel*	ICARDA, Syria	a.el-beltagy@cgiar.org
Erskine, William	ICARDA, Syria	w.erskine@cgiar.org
Garrity, Dennis	ICRAF, Indonesia	d.garrity@cgiar.org
Grant, Stewart	ICLARM, Malaysia	s.grant@cgiar.org
Hagmann, Jürgen	Germany	jhagmann@aol.com
Harrington, Larry*	CIMMYT, Mexico	l.harrington@cgiar.org
Harwood, Richard*	Michigan State University/TAC, USA	Rharwood@msu.edu
Izac, Anne-Marie*	ICRAF, Kenya	a.izac@cgiar.org
Jarvis, Devra	IPGRI, Italy	d.jarvis@cgiar.org
Kam Suan Pheng	IRRI, Philippines	s.kam@cgiar.org
Keatinge, Dyno	IITA, U.K.	d.keatinge@cgiar.org
Kerridge, Peter *	CIAT, Philippines	p.kerridge@cgiar.org
Lal, Padma	ANU, Australia	Padma.lal@anu.edu.au
Lovell, Christopher	Centre for Ecology and Hydrology, U.K.	chris@iofhchz.icon.co.zw
Lynam, Tim	University of Zimbabwe, Zimbabwe	Lynam@trep.co.zw
Molden, David	IWMI, Sri Lanka	d.molden@cgiar.org
Myers, Bob	ICRISAT, India	r.myers@cgiar.org
Nelson, Michael*	TAC/SPIA, Chile	Mnelson@entelchile.net
Palm, Cheryl*	TSBF, Kenya	Cheryl.palm@tsbf.unon.org
Penning de Vries, Frits	IBSRAM, Bangkok	Penningdevries@ibsram.org
Poulsen, John	CIFOR, Indonesia	j.poulsen@cgiar.org
Reid, Robin	ILRI, Kenya	r.reid@cgiar.org
Sanchez, Pedro*	ICRAF, Kenya	p.sanchez@cgiar.org
Saxena, Krishna	Jawaharlal Nehru Univ., India	Kgsaxena@jnuniv.ernet.in
Sayer, Jeffrey	CIFOR, Indonesia	j.sayer@cgiar.org
Shapiro, Barry	ICRISAT, Mali	b.shapiro@cgiar.org
Swift, Michael*	TSBF, Kenya	Mike.swift@tsbf.unon.org
Tarawali, Shirley	ILRI & IITA, Nigeria	s.tarawali@cgiar.org
Terry, Eugene	The Wold Bank, USA	Eterry@worldbank.org
Thomas, Richard	CIAT, Colombia	r.thomas@cgiar.org
Tutwiler, Richard	ICARDA, Syria	r.tutwiler@cgiar.org
Van Noordwijk, Meine*	ICRAF, Indonesia	m.van-noordwijk@cgiar.org
Vanclay, Jerry	Southern Cross University, Australia	JVanclay@scu.edu.au
Walker, Brian	CSIRO Wildlife and Ecology, Australia	brian.walker@dwe.csiro.au
White, Douglas	CIAT, Peru	d.white@cgiar.org

* *Denotes members of the working group assigned to write this brief*



Foreword

The first CGIAR system-wide meeting on integrated natural resource management (INRM) was held in September 1999 at Bilderberg in the Netherlands. That meeting was held in response to recommendations from the 1998 CGIAR System Review, and the results were presented at the CGIAR's International Centres Week 1999. As a follow-up, a second meeting was held from 20-25 August 2000, at the new headquarters of ICLARM in Penang, Malaysia. Convened by the Centre Directors' Natural Resource Management Task Force, four dozen scientists from 13 of the 16 CGIAR centres and their partner institutions discussed integrated natural resource management in relation to the CGIAR's research programme. This report summarises some of the issues discussed at that meeting.

A Web site set up in conjunction with the 1999 meeting provided an opportunity for ongoing dialogue in preparation for the Penang meeting. Scientists from all the CGIAR centres were invited to prepare papers on scientific aspects of INRM research for the Penang meeting, and 38 papers were received. They were posted on the Web site prior to the meeting and were subject to peer review. The papers were not presented formally in Penang, but the contents offered many points for discussion at the meeting. All of the papers are available from CIFOR on CD-ROM. The papers that passed the initial peer review are being developed further, and will be submitted for publication in a special issue of the on-line journal *Conservation Ecology*. All the papers prepared for the workshop, once revised, will be published in a book set for release in 2001.

The production of scientific papers, however, was not the main objective of the Penang meeting. Instead, the participants sought to share knowledge and strengthen cooperation in carrying out INRM research in the CGIAR. The most important outcome was greater elucidation of ways to assess the impact of INRM research in relation to the five forms of capital (natural, human, social, financial and physical). It was strongly agreed that impact assessment is an integral part of all INRM research, and is essential to provide the feedback necessary for sound, adaptive management of natural resources. Measures selected to assess impact are not absolute but must be decided through negotiations by stakeholders. This is significantly different from how the CGIAR has generally assessed impact. In an

analogy, the CGIAR's traditional approach to impact assessment approach is like an end-of-year school exam, while INRM-based methods are more like continuous assessment of students, which includes regular feedback to improve performance.

At the Penang meeting, the participants discussed the conceptual underpinnings of INRM as well as how it might be undertaken or expanded to help the CGIAR fulfill its mission of improving food security and reducing poverty without causing lasting damage to the environment. Topics of discussion included the need to shift from empirical to process-oriented research and to use systems approaches; to focus on ways of making ecosystems and natural resource managers such as farmers and others more capable of adapting positively in response to change; to work at multiple scales; and to suggest ways of dealing with the tradeoffs that are inevitable in various resource management options. Also examined was how INRM research can enhance the impact of germplasm improvement, which has been the core of the CGIAR's success for three decades. Several case studies from Asia, Africa and Latin America were presented at the meeting to illustrate how INRM research has successfully addressed real-life problems [see Appendix 1].

Background

History has all too many tragic examples of how mismanagement of natural resources has caused or exacerbated human misery and environmental devastation. The effects include hunger and poverty, conflict, water scarcity and contamination, declining soil fertility, increased soil erosion and loss of biodiversity. These conditions are a threat to millions of people around the world, especially those who live on marginal lands that have lost the ability to biologically adapt to the deterioration and loss of essential natural resources.

Rapid population growth coupled with society's weak ability to manage natural resources in ways that provide sustained benefits to people and ecological integrity over the long term is seriously straining the carrying capacity of the planet. Ian Johnson, chairman of the Consultative Group on International Agricultural Research (CGIAR), has observed that the mismanagement of natural resources may be the 'Achilles heel' of long-term sustainable development.

Research over the past 30 years by the international agricultural research community, including the CGIAR centres, has been highly successful in boosting productivity and alleviating poverty in developing countries. Today, however, there is greater recognition that agricultural advances and development often have effects that resonate across a landscape, sometimes undermining the broader base of natural resources that people depend on critically for a wide range of needs. Fortunately, a new management and research approach is emerging that addresses this situation: integrated natural resource management (INRM).

What is Integrated Natural Resource Management?

Integrated natural resource management offers a way of doing development-oriented research that aims to simultaneously reduce poverty, increase food security and achieve environmental protection. These three key factors that influence human well-being are inextricably linked with the health of the ecosystems in which people live and work. INRM reflects these broad interactions. It focuses on ecosystems rather than commodities; on underlying processes (both biophysical and socioeconomic) rather than simple relationships; and on managing the effects of interactions between various elements of an ecosystem.

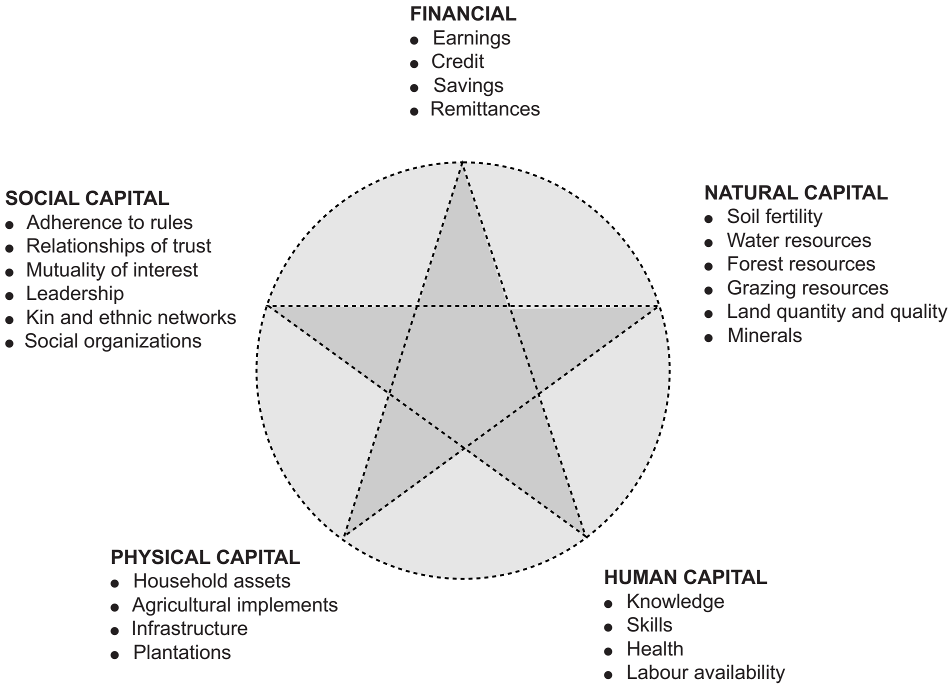
The Emerging INRM Research Paradigm

INRM research is centered on the interactions that occur between elements of natural capital and the four other realms of capital, especially social capital [see Figure 1]. The CGIAR, in working to meet its mission, originally concentrated on building physical capital (through improved crop germplasm) and human capital (through training of national agricultural research systems, or NARS, scientists). In the last decade or so, the CGIAR system broadened that focus to also include building of natural capital (through INRM research) and social capital (through participatory research approaches and collaboration with NGO's).

> **INRM Defined**
>
> *Integrated natural resource management is a conscious process of incorporating multiple aspects of natural resource use into a system of sustainable management to meet explicit production goals of farmers and other uses (e.g., profitability, risk reduction) as well as goals of the wider community (sustainability).*

At the same time, the CGIAR has been shifting toward systems thinking and integrated approaches in working to solve pressing world problems. One early example of this is the multiple cropping work done in the mid-1960's by Dr. Richard Bradfield of the International Rice Research Institute. His outreach site in Sri Lanka became a model for more than 60 NARS sites in various agroclimatic zones throughout tropical Asia. Many of the CGIAR centres have similar examples of this approach, which came to be known as farming systems research.

Figure 1. The five capital assets (modified from Bebbington 1999 and Carney 1998)



Early efforts such as this to address natural resource problems in an integrated, systematic way at the level of farm systems contributed greatly to the professional development of several generations of scientists both in national agricultural research systems and in the CGIAR centres. Research moved away from research stations – where all variables except the one being studied were controlled – and into farmers' fields. With hindsight, however, the farming systems approach had significant limitations: It was mainly descriptive, it sought to understand the entire system by looking at it from the outside, and it did not lead to knowledge about the processes that occur within farming systems. In general, farming systems research had limited impact.

Today, new knowledge and technologies are making it possible for scientists to address natural resource problems in ways that take into account the broader context. Natural resource systems — like other systems — are inherently complex. Better conceptual understanding, innovative research tools and a multidisciplinary focus are enabling researchers to deal with that complexity in working to solve natural resource problems. INRM research approaches build on the achievements of farming systems research, but have the potential to achieve broader impact.

Key Features of INRM Research

Can INRM research really deliver the goods, as its proponents promise? The question is an important one, and is raised by many people. Some seem to view the approach as a kind of intellectual exercise, concerned more with defining the intricacies of the process than with producing results. Yet delivering results is the bottom line for the CGIAR —tangible, science-based results that can be shown to have had a lasting impact in benefiting people and the environment. Clearly, it will be necessary to show that INRM research can achieve this, across relatively large areas and within reasonable time frames.

Participants in the Penang workshop identified a number of characteristics they agreed should be present in any INRM research the CGIAR undertakes. Such research must:

- Follow a systems approach.
- Be process-oriented.
- Work at multiple scales and involve multiple stakeholders.
- Address the issue of tradeoffs.
- Employ new tools and models.
- Be amenable to scaling up and out.
- Complement research on germplasm improvement.
- Lead to measurable impacts.

The following sections summarize some of the discussions in Penang related to these aspects of INRM research.

EDWARD PARKER, WWF

A Systems Approach: Toward Adaptive Capacity


TIMOTHY BOYLE

Integrated natural resource management is concerned with the processes controlling an ecosystem and its health — the relationships between people and the natural resources around them. Accordingly, INRM research methods are those of systems science.

Three fundamental dimensions of any agroecosystem are production, environmental services and human well-being. Within each of these areas are many elements and sub-systems that play a role in determining how well the overall system works. Production encompasses cropping, livestock, aquaculture, forestry and other sub-systems; environmental services include water, nutrients, biodiversity and carbon storage; human well-being is linked with people's access to means of acquiring income, avoiding poverty and hunger, and feeling capable of protecting their interests and guaranteeing their future.

All the different interactions in an ecosystem occur in an environment marked by change. Whether caused by influences inside or outside the system, such change is inevitable and, to a large extent, unpredictable. To insure the resilience and long-term health of an ecosystem, its stocks of key resources — biodiversity, nutrients, water sources and many others — must be managed carefully so the ecosystem can adapt well to shocks and changes.

At the same time, the processes used to determine natural resource use and conservation must recognize the possibility of changing conditions and allow for management adjustments as necessary to achieve the desired goals of the community, ecoregion or other area. One stream of INRM research is developing methods, tools and models that can help people and institutions acquire this adaptive capacity.

Process-oriented Research

Some people view INRM research as site-specific, and therefore not likely to be widely applicable and useful. Yet the same charge could be made in regard to the traditional research approach. Empirical reÅiarch generally seeks to obtain knowledge manifested

in the form of 'whats' — knowledge derived from so-called input-output relationships. An example is research to determine how the yield of a given crop changes in relation to various levels of nitrogen enrichment at a particular site. Such research is clearly site-specific, as the same applications of fertilizer at other sites may not produce the same results because of different variables.

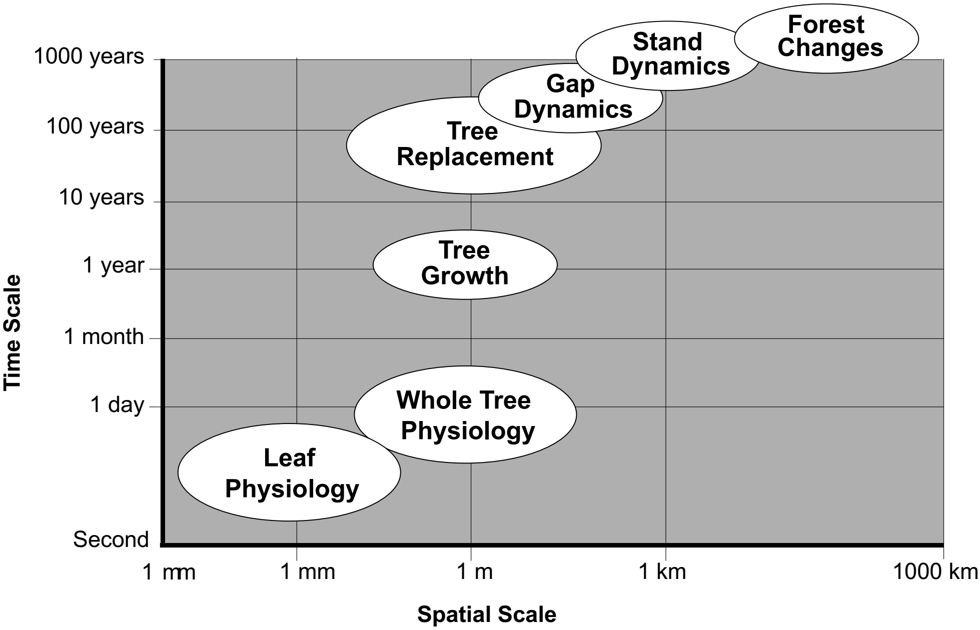
Studies designed to produce answers in the form of 'whats' are an essential part of INRM research. Yet INRM research approaches expand that interest to include efforts to understand the 'whys'. This means looking at the processes that contributed to the results. Studied from an INRM approach, the same example used above would entail focusing as well on the context and externalities associated with the use of nitrogen fertilizer. It would make farmers and field hands active partners in studies to determine whether fertilizer is the limiting factor (so-called participatory research). It would also consider whether the results are amenable to scaling up through the use of spatial models, and would investigate alternative sources of nutrient inputs. Finally, this research would look at market conditions and other socioeconomic factors that may constrain fertilizer use. In this instance, the ultimate focus of the research is soil fertility — in contrast to the narrower 'input' (fertilizer) focus of the traditional research approach — along with management options available to farmers and constraints that limit fertilizer use.

By focusing on the underlying processes that affect the availability and use of natural resources within an area, and not a single factor or commodity, INRM research will produce results and knowledge applicable to other sites and spatial scales. Through innovative applications of GIS, information technology, modeling and other tools, the results of INRM also should make it possible for resource managers to better predict how ecosystems and basic stocks of natural resources will be affected by change and various disturbances.

Working at Multiple Scales

As noted above, ecosystems encompass many ecological, social and economic sub-systems, whose individual elements interact at different scales in time and space [see example in Figure 2]. Certain elements may be self-contained in a particular scale, but they are 'nested' in higher scales. Fields, for example, are nested in farms; farms in communities; communities in ecoregions; and ecoregions in a global system. This is also true in regard to temporal scales. Research might be done during a single rainy season, but it must take into account the impacts of rotation effects and climatic variability over multiple seasons. This situation, in turn, occurs within longer-term climatic patterns. Also, different variables change at different speeds. For example, groundwater changes, depletion of biodiversity and loss of soil nutrients are 'slow' variables, or conditions manifested over long periods. INRM research must consider these slow variables, which have gradual and limited impacts on a system over time but could eventually hurt overall performance if overlooked.

Figure 2. Forestry research issues at various temporal and spatial scales



Thus, a requirement in doing INRM research is that it must examine systems at various spatial and temporal scales. Theoretically, INRM can and should function at a global scale. Realistically, however, it will be most relevant and useful — and is far more likely to be successful — at smaller scales, such as farm, watershed and ecoregion levels. It has been proposed that, as a rule of thumb, INRM research should extend its range of focus to include one spatial scale above and one below that of the particular sub-system being addressed.

Working with Multiple Stakeholders

Because they offer a wide range of benefits that people want and need, natural resources must be managed to provide a balance of uses while insuring their continued availability over time. This process is difficult when there are competing demands for a particular resource — say, water for irrigation, domestic use or livestock —that lead to conflicts between different groups of stakeholders. Depending on the problem being addressed, stakeholders might include, for example, farm families, urban dwellers, government officials, policymakers, livestock owners and timber companies.

INRM researchers play a crucial role in working with these stakeholders to help them identify and analyze problems, collect relevant data and devise options in which the relative


CHRISTIAN COSSALTER

benefits and costs are known. Knowing who will gain and who will bear the costs in various solutions is essential in wise decision making. Through this process of analysis and negotiation, stakeholders will strengthen their ability to respond to changing economic and environmental conditions.

Key determinants of how well natural resources are managed are institutions (broadly defined), regulations and patterns of behaviour. Further complicating the picture are considerable differences in the size, strength and legitimacy of institutions that play a role in natural resource management. Institutions with legitimate interests in, say, access to a particular forest and its resources might range from local community groups, to provincial and national governments, to the international community (represented in global environmental agreements).

Two kinds of institutional issues can hinder effective integrated natural resources management: sectoral divisions (agriculture versus the environment versus finance ministries) and command-and-control structures. Both constrain the increase of human capital (knowledge and skills) and the realisation of strong civil society at the local level (social capital), which are needed for successful INRM.

In the face of these and other institutional constraints, making INRM work effectively poses a three-part challenge: first, how to foster alternative institutions that are viable, conciliatory and viewed as legitimate; second, how to reconcile the competing interests of institutions at different levels (local, national and global); and third, how to accommodate greater involvement by stakeholders in resource management. A common thread running through all these issues is the need to develop strong institutions by empowering people, especially disenfranchised groups, so they have the confidence and skills they need to play an active role in managing the resources they depend on.

Using New Tools and Modeling

Given the complexity of INRM research, a major issue is what methodologies are appropriate for implementation and evaluation. Yet a major strength of INRM research is its ability to tap the many powerful tools now available to researchers. New ways of addressing issues such as strengthening the adaptive capacity of systems, working at

multiple scales and balancing the needs of multiple stakeholders are beginning to emerge, based on the use of information technology, GIS and participatory techniques. Among these new tools, for example, are methods to integrate farmers' knowledge with empirical research results; GIS-based systems to predictively map tree species; techniques to expand our knowledge of biodiversity conservation in relation to farms and other systems; and participatory exercises to improve understanding of processes involved in natural resource management.

At the same time, technological advances are fueling the development of simulation and other types of models that will aid natural resource management and INRM research. As in many other fields, such models represent a breakthrough in our ability to address the problems of complex systems. They will enable us to understand the dynamics of change that occur in agroecosystems, and improve our ability to predict what the various consequences of different management options are likely to be. Many projects are already working to produce the kind of tools well suited to integrated natural resource management, such as initiatives sponsored by the Fund for Methodological Support to Ecoregional Programmes [see box].

Fund for Methodological Support to Ecoregional Programmes

Managed by the International Service for National Agricultural Research (ISNAR), the Fund was established in response to a move in the CGIAR and the international agricultural research community over the past decade to pursue ecoregional activities that combine integrated national resource management and productivity concerns. Initial funding was provided by the Netherlands and Switzerland.

The goal of the Fund is to stimulate ecoregional initiatives within or outside the CGIAR for the development and implementation of sustainable, productive agriculture, rural development and natural resource management. The Fund supports the development of methodologies for: (1) research that is ecoregional in scope and (2) enhancing the implementation of new approaches to natural resource management and rural development in ecoregions.

Among other things, research that is ecoregional in scope entails analysis of information from different spatial and temporal levels. It also requires tools and processes that integrate socioeconomic concerns into collective decision-making and action to manage natural resources.

Source: ISNAR Web site

Determining Tradeoffs

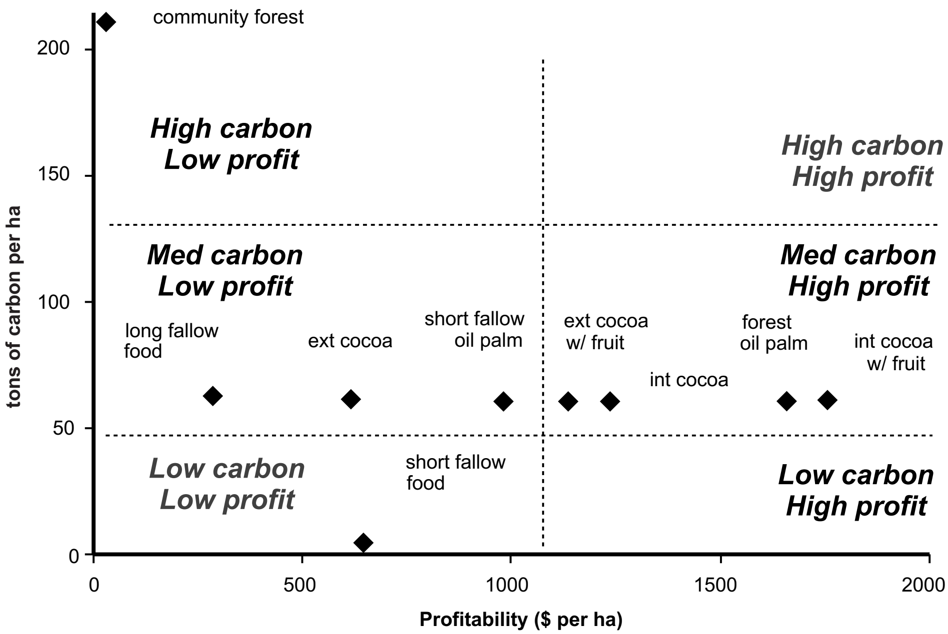
Achieving a soundly functioning agroecosystem involves tradeoffs and choices between alternative options for resource management. Higher productivity or protection of environmental services? Greater profitability or accommodating cultural concerns? Such

choices, decided by resource manager and users, must be made across the full spectrum of human needs and with awareness of potential economic, social and environmental consequences. Research is needed to develop ways of helping people acquire information and analyze tradeoffs in options for natural resource management.

It may be found that encouraging the adoption of INRM research results to help resolve existing resource management problems requires sanctions and incentives, so that people are willing to accept tradeoffs and honor the terms of any resulting agreement. Unfortunately, 'win-win' solutions to agroecosystem problems are rare, but stakeholders must come to believe that finding solutions is better than ongoing conflicts.

The tradeoff diagram in Figure 3 portrays soil management options in terms of a global benefit (carbon sequestration) in competition with a private benefit (a farmer's profitability). As in most tradeoffs, there are no real 'win-win' situations in this case (high carbon sequestration + high profit), but there are 'lose-lose' ones (low carbon sequestration + low profit). Tradeoffs occur when choices are made among the options that provide moderate levels of carbon sequestration with high levels of farmer profitability.

Figure 3. Carbon sequestration and profitability tradeoffs in alternative systems to slash and burn agriculture in Southern Cameroon (time averaged C stock)



Expanding Impact: Scaling Up and Out

MAURI RAUTKARI, WWF

By linking the strategies and methods of INRM research with technologies, the results can be extrapolated to broader regions and more sites. The CGIAR centres, with their strong track record of strategic research and international research partnerships, have a central role to play in this. In fact, they have a number of comparative advantages for conducting INRM research, as discussed later in this report. Among other things, the knowledge and technologies they and their national counterparts produce — for livestock feeding and management, coral reef management, use of tree species and soil fertility improvement, to name a few — are a critical ingredient in natural resource management decisions. While managing natural resources is a complex process, interventions to address certain problems may in some cases be quite simple.

The kind of methods employed in INRM research, involving methods such as 'action research', lie somewhere on the continuum between research and development. Linkages between INRM research and development initiatives are natural, because there is growing recognition that participatory and collaborative development is critical to achieve lasting and sound resource management.

The CGIAR centres are unlikely to ever become development institutions — they have no comparative advantage in this area. Nonetheless, it is reasonable to think they could achieve their goals of poverty reduction and environmental protection more quickly and with broader impact by developing strategic, science-based partnerships with development-oriented institutions. Such partnerships are increasingly important in these days of shrinking funds, when demonstration of significant impact is under greater scrutiny.

INRM research is highly compatible with a shift by the CGIAR toward more regional approaches. Since the early 1990's, the CGIAR has supported the establishment of consortia-based ecoregional programmes aimed at resolving major agricultural and development problems related to the sustainable use of natural resources within an ecoregion. According to TAC (1992), research that is ecoregional in scope addresses problems of natural resource management and sustaining food production across a broad region, defined in agroecological and socioeconomic terms. This requires methodologies — as opposed to particular solutions —that can be applied to resolve these problems under varying conditions.

Synergies Between INRM and Genetic Improvement Research

The CGIAR System Review in 1998 identified integrated natural resource management and integrated genetic resource management as the two 'pillars' of the CGIAR. There is considerable synergy between the two, although this may not be obvious. Some examples may be helpful to illustrate this.

In areas that are well endowed with key natural resources, such as soil and water, the main biophysical constraint to reducing hunger and poverty is often the need for improved crop germplasm. This situation has spurred research that resulted in major increases in productivity, as in the case of the Green Revolution. Once these improved crop varieties have been shown to produce bigger yields, governments often respond by funding new irrigation systems, subsidising fertilizer use and providing marketing assistance and other forms of support.

INRM research complements germplasm improvement by seeking to guarantee the availability of natural resources that go hand in hand with agricultural advances in reducing hunger and poverty and improving human well-being.

The Green Revolution reduced pressures on the environment by introducing more intensive methods of agriculture that made it possible to grow more crops on the same plot instead of cutting down trees for additional farmland. The Intercentre Working Group on Climate Change recently noted that results of the Green Revolution saved more than 400 million hectares of forests and grasslands that otherwise would have been converted to cropland. This forest preservation, in turn, offered carbon storage benefits that prevented an estimated 0.6 gigatons of carbon per year from being emitted into the atmosphere over the last 30 years. This is equivalent to one third of the amount of carbon the United States emits each year from all sources.

CIFOR

On the other hand, when the natural capital in an area is inherently low or has been depleted through catastrophe or misuse, the first priority must be replenishing this stock. Only after that has been accomplished will technological innovations such as improved germplasm be relevant. Often, natural capital is replenished as a result of community-based action — an enhancement of social capital. Several examples of this are described in the case studies included in the annexes of this report [see Appendix 1].

An ‘entry point’ for resource management is likely to come from an existing natural resource problem rather than being a matter of choice. In areas of Africa where soil nutrients are low and water is very limited, the lack of widespread impact from improved crop germplasm underscores the necessity of first addressing the natural resource constraints, which can be readily identified through participatory techniques. Once soil fertility is improved, crop germplasm advances can be implemented to enhance productivity.


CAROL COLFER

There are also opportunities for synergies in relation to other major issues. There is little question that climate change will occur in the near future, probably resulting in drier, more erratic rainy seasons in much of Southern Africa and more humid climates in parts of the Andes. These changes will have a direct impact on growing seasons and the prevalence of diseases. The ability to more accurately predict climate changes that will occur in various ecoregions over the next decade would enable plant breeders to direct their attention to overcoming climate-related constraints on productivity. Predictive ability like this could make crop improvement more strategic.

Measuring the Success of INRM Research

Given all these complexities, assessing the impact of INRM research is difficult. Productivity is one important measure of impact assessment, but impacts on the other benefits and services an ecosystem provides and on human well-being are also important. Unfortunately, social and environmental conditions are not presently amenable to monetary assessments of their value, making it difficult to calculate internal ‘rates of return’ in the traditional way. The valuation of natural, social and human capital requires methods that are still being developed.

In general, however, assessing the impact of INRM research requires moving away from the static, linear models of ex-post assessment used for commodity crops towards more dynamic, process-based techniques. Systems models make it possible to focus on the adaptive capacity of entire systems. Models for impact assessment are shown in Figure 4.

Unquestionably, impact assessment must be built into the conceptual framework of any INRM research. One initiative that will eventually play a large role in this is current efforts to develop ‘criteria and indicators’ of sustainability. This involves identifying a few key variables for various aspects of sustainability, then adopting representative indicators for these that can be used to monitor changes in a landscape and suggest

Figure 4. Impact assessment

Continuum, not mutually exclusive	Main client	Characteristics	Assumption
Final outcome on PPE	Donors	Typical mainstream, static ex-post	Static, linear, predictive system
Process	Self-learning organisation at all scales	Focus on dynamic, ex-ante ('in via'?) integral to the project, monitoring	Allows adaptation to complex, dynamic and unpredictable processes of the system; there are no 'end points'
Whole system	*Idem*	Focus on adaptive capacity of multiple layers and feedback, hard to fully operationalize as yet; build models right at day 1	Drastic changes occur during short phases of sub-system reorganisation not in an incremental predictive fashion

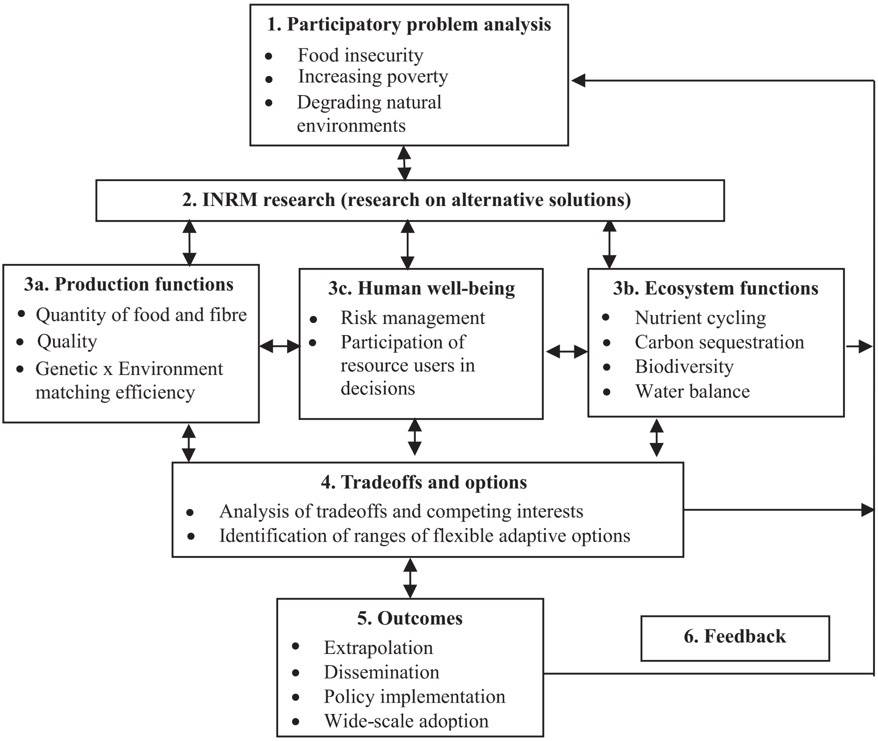
corrective measures needed to preserve the overall health of the ecosystem. Impact assessment of an agroecosystem would include, for example, not only measures of productivity but also measures of social well-being and environmental conditions.

A Framework for INRM Research

Figure 5 is a working model of the INRM research process, in six stages, that was developed in the Penang workshop. It illustrates how INRM research can be carried out in relation to the CGIAR and its partners and what scientific disciplines should be involved at the various stages.

First, natural resource problems must be identified, through a participatory process that includes farmers, policymakers and others. Using ‘entry points’ identified in the first step, researchers then conduct interdisciplinary studies of alternative solutions to the problems. Agronomists, economists, animal production specialists and others focus on aspects of production, while researchers from the biosciences address ecosystem services.

Figure 5. Model of the INRM research process



Social scientists must be involved as well to assess human well-being. Because agroecosystems are driven by the interaction of ecological, economic and social variables, INRM research must work across these three dimensions, as well as at different scales in time and space.

As indicated, the research outputs are separated into production and ecosystems functions and their effects on human well-being. Because 'win-win' solutions are rare, the next step consists of analyzing the tradeoffs between competing interests and identifying a range of flexible options. Finally, the outcomes emerge from extrapolation, dissemination, policy development and other actions, and their impact is assessed. Much of this work is likely to be done by more development-oriented partners.

Thus, the impact of the research is assessed at three levels: productivity, ecosystem resilience and adaptive capacity. Feedback loops occur at all stages of the research process so adjustments can be made to better insure the intended results, reflecting the adaptive nature of INRM research.

The CGIAR's Role in INRM Research

The CGIAR centres are just one network now undertaking INRM research. However, the nature and location of their operations gives the CGIAR centres many comparative advantages, as spelled out below. The papers submitted to the Penang workshop show that the CGIAR centres are already making considerable progress in INRM research. Overall, however, there is a need to shift the CGIAR's research programme even further in this direction. The range of products emanating from the CGIAR centres must be expanded to include, for example, new knowledge of institutional and organisational processes, which are a critical part of achieving integrated natural resource management.

In identifying reasons why the CGIAR should play a more prominent role in INRM research, participants in the Penang workshop drew up a list of comparative advantages the CGIAR has in relation to other institutions that conduct INRM research, as indicated below [see Boxes].

Role of INRM in Achieving the CGIAR's Mission

- *Production ecology will contribute to food security for poor people in marginal areas largely bypassed by the Green Revolution.*
- *The private sector is unlikely to provide the public goods products of INRM research.*
- *There is potential for large-scale impacts.*
- *The potential for significant benefits to the global community (i.e., adaptation and mitigation of climate change) increases the range of stakeholders and investors.*
- *Links global benefits with benefits to the rural poor.*

CGIAR's Comparative Advantages in Global INRM Research

- *Scientists based in the developing world*
- *Expertise in working with farmers and other key stakeholders*
- *Expertise in key skills (e.g., germplasm improvement, coral reef management, livestock feeding) and tools for integrating it*
- *Interdisciplinary nature of research*
- *Experience working in a variety of ecosystems, such as forests, marine areas and desert margins*
- *Access to relevant research sites throughout the developing world*
- *Access to NARS, policymakers in the South and development organisations*

Putting INRM Research into Practice

Many of the CGIAR centres and their partners have already employed various aspects of INRM research for at least a decade. The eight case studies in the annexes of this report indicate a strong start in moving further toward this research approach [see Appendix 1]. (The case studies are presented here based on a framework developed at the Penang meeting. Other versions of the individual papers are available on request.)

Through problem analysis at various sites done in conjunction with research partners, the CGIAR has identified a number of natural resource management issues that relate to declining food or fibre production: soil erosion on hillsides resulting from the loss of vegetative cover associated with deforestation; decline in soil fertility caused by the mining of soil nutrients over continuous cropping; lower water supply and quality related to salination and sedimentation; and increased incidence of pests stemming from the gradual loss of floral and faunal biodiversity. These on-site conditions often lead to serious off-site effects as well, such as lower quality and quantity of both fresh and marine waters resulting from siltation, irrigation and use of agrochemical pollutants.

Solutions to these and similar problems almost invariably entail some improvement in crop, tree or livestock germplasm, along with changes in crop and soil management. Often, but not always, these solutions may indirectly affect the declining resource base [see the case from CIMMYT]. For example, nitrogen-fixing legumes are often introduced into agroecosystems with the intent of rebuilding the soil. ICARDA, ILRI/IITA, ICRAF and CIAT have introduced food and fodder legumes into cereal cropping systems, which has led to a doubling of yields. In the case of ICARDA, a change in the cropping patterns also brought environmental benefits in the form of increased soil organic matter and soil nitrogen, a two-fold increase in efficiency of water use, and fewer pests and diseases because of increases in biodiversity. Similar results may also have occurred in the other examples, but measurements of the environmental effects have yet to be made.


BRIAN BELCHER

In another example, ICRAF has introduced N-fixing trees and shrubs as improved fallows in East and Southern Africa. As a result, crop yields have risen dramatically, with double to quadruple increases over previous levels. Environmental effects include increased stocks of soil nutrients, potential doubling of carbon stocks when high-value trees are added, reduced erosion and nutrient runoff, and alternative sources of fuelwood, which eases pressures on surrounding woodlands and thereby helps preserve their biodiversity.

Other approaches more directly address natural resource management problems. Both CIAT and ICRAF have introduced vegetative filter strips along contours of deforested hillsides plagued by erosion and loss of soil and water, as well as vegetative buffer zones along waterways in Colombia and the Philippines. These interventions have resulted in stabilised hillslopes, reduced runoff and erosion, and increased protection of biodiversity in neighbouring natural forests.

The Alternatives to Slash and Burn (ASB) Programme, a CGIAR system-wide programme, has developed guidelines for integrated assessment of impacts on production and environmental services in various land management systems, which includes attention to the tradeoffs [see Figure 3 earlier]. By implementing this integrated assessment approach, researchers have identified several agroforestry and tree-based systems in the humid tropics that can provide food security while simultaneously maintaining moderate carbon stocks (of 60 to 80 tonnes per hectare) and moderate levels of above- and below-ground biodiversity. Working with the Indonesian Ministry of Forestry and local NGO's, ASB scientists played a significant role in developing a way to assure property rights in communities with highly productive complex agroforests.

Methods for introducing, promoting and disseminating INRM approaches are more difficult than those used to introduce successful germplasm improvement. This is related to several issues of INRM research: expanding the management process to involve multiple resource users with often conflicting interests, seeking benefits from private versus public goods, and realizing benefits over the longer term. Nonetheless, several CGIAR centres and their partners have developed or adopted methods that entail empowering local

communities, such as the LandCare approach that ICRAF has used in the Philippines, CIAT's CIAL's (local agricultural research committees) in Latin America and CIFOR's design of techniques for adaptive co-management of forest resources. Through these and other methods, the results of INRM research now extend to a huge number of resource users in the developing world, resulting in greater food security, poverty reduction and ecosystem resilience.

The Next Steps

As a result of the productive discussions at the workshop in Penang, the participants agreed that the CGIAR centres will undertake a number of joint scientific activities to further develop integrated natural resource management concepts and tools.

One initiative agreed on is inter-centre development of model-based methodologies that can be used to assess the performance of large natural resource systems. A decision was made to organise modeling workshops at ecoregional sites in Southeast Asia, South-Central Africa and the Western Amazon. In addition, further work on the development of methodologies for impact assessment of INRM research is planned. One interim product of this work will be a multi-authored paper written for a leading scientific journal. These and similar efforts should well complement the tools and techniques being developed in projects sponsored by the Fund for Metholodological Support to Ecoregional Programmes and others. A progress report on the inter-centre initiatives will be presented at the CGIAR's International Centres Week 2001.

ALAIN COMPOST

Products of these efforts will help to strengthen 'communities of practice' in which the international development community and local groups around the world share ideas, information, knowledge and experience in addressing the challenges of improving the environment and quality of life for millions of poor and hungry people.

Appendix 1: Case Studies

Case Study 1: Increased Use of Food and Feed Legumes in Dryland Cereal Production Systems in West Asia and North Africa

Lead center: ICARDA

Natural resources managed: Soil, water

Partnership: ICARDA and NARS partners

Problem Analysis

Rain-fed cereal cropping systems dominate Mediterranean drylands of between 250 and 500 mm rainfall per annum. In the last few decades, land use has intensified and annual cereal monoculture has replaced traditional cereal/fallow and cereal legume rotations. As a consequence, rain-fed cereal yields have stagnated, farmers are more dependent on inorganic chemical fertilizers and the incidence of cereal pests and diseases has increased. At the same time, income from cereals has become increasingly linked with subsidies.

INRM Research

ICARDA and its NARS partners have developed a range of food- and feed-legume options adapted to the environments and production systems of the region. The legumes include chickpea, lentil and common vetch. An important approach to increase the efficiency of water use in the region is to concurrently change both management practices and cultivars to achieve a quantum leap in crop productivity combined with increased yet sustainable water use efficiency. An approach with chickpea that involves replacing traditional spring sowing with winter sowing offers additional benefits in the form of a doubling of biological nitrogen fixation, which contributes to the already limited supply of soil nutrients in the dry lands; however, the approach works only with cultivars possessing cold tolerance and resistance to a key fungal disease, Ascochyta blight. More robust and erect cultivars of lentil and chickpea, which allow machine harvesting, overcome the high cost of labour and increase net returns. Crop diversification with legumes improves cereal root health by breaking the pest cycle. Small ruminants account for 40% of agricultural products in these systems. The resulting legume straw is a high quality feed for small ruminants, which is in short supply regionally and improves crop-livestock interaction.

Production

ICARDA's research on long-term rotation with legume crops has shown that barley seed yields increased to 0.9 t/ha and those of straw to 1.5 t/ha compared with barley monoculture. In seven years' rotation trials of durum wheat, a yield advantage of 630 kg/ha was achieved. In a less favourable drier site, barley in rotation with vetch produced seed yields of 1.55 t/ha and straw yields of 2.7 kg/ha, compared with 1.1 t seed and 1.65 t/ha straw yields from barley monoculture. These results have translated well to farmers' fields. Harvests increased yields of barley by 0.63 t/ha in barley-vetch rotation in comparison with barley monoculture, and 1.3 t/ha durum wheat in durum-vetch rotation compared with durum-barley rotation. Farmers in Syria and neighboring countries are using these rotation practices to realize maximum yields and greater net return.

Lentil, vetch and chickpea are legumes commonly used in rotation with barley and wheat. On average, lentil produces 0.8-1.2 t/ha of seeds and 2.5-3.0 t/ha of straw in medium to low rainfall areas. In a wide range of environments, vetch biomass yields range from 4.0 t/ha to 7.9 t/ha. The use of winter sowing over spring sowing with chickpea can increase yields up to 100% as a result of increased water use efficiency and higher biological nitrogen fixation.

Environment

Growing legumes in cereal monoculture breaks disease and pests cycles, thus reducing the use of chemicals and protecting the environment. In addition, through biological nitrogen fixation and increasing soil organic matter, these crops improve soil health by enhancing nutrient recycling and soil fertility. Crop diversification with legumes also provides avenues for perpetuating soil microorganisms, thus preserving soil environment.

Human Well-being

With increased crop productivity, farmers in the region gain higher return from cereal and legume cultivation. Moreover, by growing legumes in their cropping systems, the farmers need less inputs (fertilizer, chemicals) to grow succeeding cereal crops. The cereal-legume cropping system has led to a viable and sustainable farming system, thus improving food security in the region. Crop diversification has led to greater food diversity in the diet, with positive effects on human health, as well as an increased range of feed options for small ruminants. Furthermore, legume options leading to diversification of the system have reduced agricultural risk.

Tradeoffs and Options

Farmers in the region have been cultivating improved legume and cereal varieties following crop rotation and have substantially reduced dependency on external inputs. The Germplasm Enhancement Programme at ICARDA has developed cereal and legume varieties that are well adapted to low rainfall areas. Thus, sustainable use of soil and water resources and adoption of improved cultivars have increased production in the region and enhanced export potential. From identifying a range of food and feed legumes, farmers have several options for including these crops in their cropping systems.

Outcomes

The replacement of spring-sown with winter-sown chickpea is conservatively estimated to have occurred on approximately 150,000 ha in WANA region. Using a conservative estimate of a yield increase of 0.5 t/ha, increased chickpea production has risen to 75,000 t, which is worth US$ 37.5 million (US$ 500/t). Through the development of suitable lentil varieties for machine harvest, the total cost of production has been reduced substantially (46% for hand harvest and 19% in case of machine harvest). Production of legume straw/fodder has risen and its use in combination with cereal straw/hay has improved the nutritional status of small ruminants in the region. However, quantification of increased cereal production as a result of rotation with legumes has not yet been done.

Overall, the technology has provided a sustainable production system in rain-fed agriculture in WANA. This has improved soil and human health in the region. A further benefit has been dissemination of the technology to farmers in similar environmental and production systems.

Feedback (Lessons Learned)

Cereal monoculture in dryland cropping system in WANA is unwise. Inclusion of legumes in rotation with cereals has led to sustainable farming system in WANA.

Case Study 2: A Buffer Zone Management System to Alleviate Poverty and Protect Biodiversity and Watershed Services Based on a Landcare Approach in the Philippines

Lead center: ICRAF

Natural resources managed: Biodiversity, soil

Partnership: ICRAF, the Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (PCARRD) and partners in the Sustainable Agriculture and Natural Resources Management (SANREM) Programme; the Biodiversity Consortium within SANREM was composed of collaborating organisations that included Central Mindanao University, NGO's, government agencies and ICRAF

Problem Analysis

The work focused on the buffer zone of the Mt. Kitanglad Range Nature Park in the upper reaches of the Manupali watershed in central Mindanao, Philippines. Mt. Kitanglad is one of the most important biodiversity reserves in the Philippines, supporting the richest known vertebrate fauna in the country. It is one of the three global sites of the SANREM Programme. There are serious research challenges to implementing integrated natural resource management to increase the prosperity of smallholder communities in upper watersheds while protecting natural biodiversity and watershed services. The approach of integrating conservation and development is attempting to link enforcement with assistance to the communities that are directly affected by the presence of the park. Severe poverty among smallholder farmers in the upper watershed communities is a driving force in deforestation, biodiversity loss and settlement pressure in and near the boundaries the protected area. The most likely future trajectory for farming systems in the buffer zone is toward continuous vegetable production on a portion of the farm (0.1-1.0 ha), with perennials (timber and fruit trees) grown on the remaining farm area, particularly on the steeper parts. Land tenure conflict between indigenous communities, migrant settlers and the state has created uncertainty and pervasive lack of trust.

INRM Research

The research aimed to develop the elements of a workable *social contract* between buffer zone communities and non-local stakeholders concerned with resource protection. ICRAF and its partners developed tools and approaches to improve the integration of biodiversity conservation and agroforestry development through the active involvement of communities. Our initial work focused on determining an appropriate mix of species of interest to farmers, and testing diffusion strategies to incorporate them into farming systems.

We introduced germplasm of a range of other fast-growing timber species, with emphasis on new accessions of *Eucalyptus deglupta* and others. This was followed by a series of experiments that evaluated the available commercial species for comparative performance by elevation. We also experimented with three types of smallholder nursery systems. These activities resulted in a major acceleration of tree production in the buffer zone.

Continuous crop production on steep slopes in Mindanao induces annual rates of soil loss that often exceed 100-200 t/ha. The installation of contour buff strips reduced these losses by 50-99% and created natural terraces that stabilized the landscape and facilitated further management intensification. We refined an indigenous practice called natural vegetative strips (NVS). This entails laying out the contour lines on sloping fields, then allowing them to revegetate naturally. NVS were exceptionally effective in soil conservation with minimal maintenance, and required no outside source of planting materials. The tree farming and contour buffer strip practices had immediate potential to help farmers in the buffer zone intensify land use and increase profitability, while sustaining land resources. Widespread adoption of these practices has 'backstopped' institutional innovations and provided pragmatic alternatives to encroachment in the park.

Production

The introduction of a simple farmer-refined natural vegetative buffer strip system for hill slope farming increased maize yields by an average of 0.5 t/ha. Fruit and timber tree production increased dramatically increased, re-establishing tree cover and providing more diverse sources of income in the degraded grasslands of the buffer zone.

Environment

Encroachment in the natural park has been reduced 95% in the past three years as a result of the presence of Landcare groups in the park's buffer zone; this offers a dramatic improvement in biodiversity protection. Soil erosion and runoff has decreased substantially, with natural vegetative strips installed on several hundred sloping farms. Stream corridor vegetation was restored by local Landcare groups. Current research is estimating the aggregate effects of the vegetative buffers and filters on the hydrological functions at the landscape level.

Human Well-being

The work assembled the information needed to guide the development and implementation of a natural resource management plan for the Municipality of Lantapan. It fostered the development of a dynamic grassroots movement of farmer-led Landcare groups in the villages near the park boundary. It also analyzed the ancestral domain claim of the Tala-andig people in relation to the natural resource management issues of the natural park and the surrounding municipalities. Increased diversity of enterprises on the farm, and increased

landscape filters, reduced production and income risk. Landcare groups have provided support, knowledge and capacity for community action on farm and natural resource management problems. Enhanced empowerment and social capital through vibrant local organizations have increased the capacity to anticipate and to cope with perturbations in the local ecosystems

Tradeoffs and Options

Currently, the different interests of the three domains (the park, the ancestral domain claim, and the municipalities) are being resolved. Current work aims to provide options, processes and strengthened institutions to guide resolution. The basis of a negotiation support system has been introduced to reconcile the three types of interrelated management plans that are required for sustainably managing the upper watershed ecosystems: a natural park management plan, an ancestral domain management plan a municipal natural resource management plan.

Outcomes

Significant progress has been achieved in assembling the elements of an effective social contract aimed at protecting the natural biodiversity of Kitanglad Range Natural Park while improving the livelihoods of the communities in the park boundary. The local government-led natural resource management planning process and the Landcare approach were adopted as a national model for watershed management in the Philippines. A movement of farmer-led Landcare organisations was stimulated. More than 300 self-governing groups are now operating. More than 1500 households in the region have adopted contour buffer strips. Finally, more than 400 community and household nurseries have produced more than 150,000 seedlings during the past four years, all through voluntary efforts and with no external financial support.

There is evidence that the integrated approach we implemented has created an effective linkage between development and conservation. Through the strong support for natural resource management planning and implementation at the local level, and the efforts of the grassroots Landcare farmer groups, a conservation ethic is evolving and biodiversity protection is coming to be viewed as a local responsibility, pursued with pride. Among the key factors of success that have been identified is a strong consortium of research and development institutions, local government entities and donors that share a commitment to an integrated systems approach. This group developed a common vision and the patience to nurture that vision in the face of highly constrained funding. In fact, funding constraints may have been a blessing; increasingly, commitment to and impact by integrated conservation-development may be stimulated by a 'drip-feed' approach rather than by large, externally funded efforts.

The major challenge yet to be resolved is reconciliation of the ancestral domain claim, park jurisdiction and security of land tenure among immigrant settlers in the buffer zone. These kinds of critical upland tenure issues are manifested in various forms throughout Southeast Asia. The Negotiation Support System is a tool being developed to facilitate the resolution of such conflicts. Components of this tool are being developed and refined through work at three key watersheds in the region: Sumberjaya, Indonesia; Mae Chaem, Thailand; and the work at Manupali, the Philippines, described above.

Case Study 3: Improved Crop-livestock Systems in the Semiarid Savannas of West Africa

Lead centers: IITA, ILRI and ICRISAT

Natural resources managed: Soil and with implications for water, biodiversity, air (not measured)

Partnership: In **Mali**, IER (Institut d'Economie Rurale, OHVN (Office de la Haute Vallee du Niger), CMDT (Compagnie Malienne pour le developpement des Textiles), DRAMR (Direction Regionale de l'Appui au Monde Rural) and PNVA (Programme National de la Vulgarisation);
in **Niger,** INRAN (l'Institut National de Recherches Agronomiques du Niger), IFDC, Niamey;
in **Nigeria,** IAR (Institute for Agricultural Research), Kano and Zaria, NAPRI (National Animal Production Research Institute) Zaria;
also, IFDC (International Fertilizer Development Centre, Niamey, Niger) and CORD (Centre for Overseas Research and Development, University of Durham, UK) at all sites

Problem Analysis

In the dry savannas of sub-Saharan Africa, traditional farming systems are breaking down, fallow periods are non-existent and cropping has expanded onto marginal land. The consequences of these changes are lowered land productivity and the emergence of unsustainable farming practices with potentially disastrous results for poor people, their food security and their environment.

INRM Research (Integrated Analysis of Alternative Solutions)

Research has been implemented at benchmark sites selected to represent key farming systems within the agroecology. The approach, which is evolving, includes developing with farmers 'best bet' management options involving elements of crop varieties, crop geometry, residue and livestock management. These are assessed on farm using a holistic strategy that includes biophysical and socioeconomic monitoring. In this environment, crop-livestock integrated systems are believed to have the highest potential for increasing farm production and productivity in a sustainable manner. At sites in Nigeria, farmers tested the following options:

BB+: improved varieties of cowpea and sorghum with minimum inputs; livestock feeding and manure returned to the fields

BB: as BB+, but no inputs in 1998, with inputs but local sorghum in 1999

L: farmers' own practice for cowpea and sorghum

Production

For BB options, cowpea grain production was increased more than two fold; sorghum grain and fodder quality were superior. Preliminary indications are that small ruminants on the BB+ option gained more weight (1.75 kg/animal) over the 12 week feeding period than those fed from farmers' traditionally managed plots (0.03 kg/animal). Based on a small sample, the nitrogen content in manure was estimated to be about 1.5 times more for BB+ than for traditionally managed animals. (Note: These results are very preliminary. On-farm livestock feeding such as this requires careful statistical assessment to address the many confounding variables. The figures given here are for un-assessed data.)

Environment

Improved fodder means better fed livestock that produce more manure of better quality, thus improving nutrient cycling when this is returned to the field. In-field rotation with the cowpea legume enhances nutrient cycling and soil fertility. There are implications (not measured) for other natural resources: livestock receiving better quality feed produce less methane; households with increased incomes (from having more grain and fodder or livestock to sell) are more likely to install wells for fresh water. Improved feed resources from cultivated fields decreases pressure on the biodiversity of the natural vegetation, and in this instance, maintaining a mixed crop pattern decreases the risks associated with monocropping.

Human Well-being

By providing more options and increasing productivity and profitability, farmers' risk is reduced. There is anecdotal evidence (from the farmers' wives) that increasing cowpea grain in the diet has positive effects on human health.

Tradeoffs and Options

Local sorghum yields were higher than the improved variety because the former has longer, thicker stems. Farmers preferred the improved sorghum for fodder, but recognized that the local sorghum stems are better for alternative uses such as building.

Cowpea grain and fodder production can be balanced through variety, use of spray (for insects) and harvesting practices. Strategies that promote grain often will result in reduced fodder yields, with implications for livestock feed and manure production.

Outcomes

Research has begun in northern Nigeria at sites representing intensive crop-livestock systems in the wetter part of the dry savannas. Similar options are being tested in conjunction with farmers at benchmark sites in Mali that represent intensive systems in

which a cash crop (cotton) has implications for the economic situation. In Niger, the crop-livestock systems are more extensive, and millet replaces sorghum in the best bet options. Research at such well characterised benchmark sites can readily be extrapolated to other regions of the dry savannas.

Feedback (Lessons Learned)

Farmers were most impressed and interested in the increased grain yields. They also recognized the value of improved grain and fodder quality, and the better fed livestock. We need to recognize that while farmers' first priority is often food followed by income, they do recognize the importance of natural resource management.

Most farmers did not adopt some interventions, such as the suggestion to initially double cowpea crop. This afforded the opportunity to recognize a few innovators who did try this option and subsequently obtained very high quality fodder as well as some grain. Such farmers are now encouraging their colleagues to test this approach. We can learn that we don't have to take a perfect finished product to the resource users; there is scope for farmer innovation and modification, which may help farmer-to-farmer transfer.

The benefits of working together with many institutions and farmers have been synergistic rather than merely additive.

Case Study 4: Alternatives to Slash and Burn in Indonesia (a consortium of national and international research institutions, linked to work in Cameroon, Brazil, Peru and Thailand)

Lead center and other participating centres: ICRAF, CIAT, CIFOR, IITA and IFPRI

Natural resources managed: Forests, soils, atmosphere and biodiversity

Partnership: TSBF; NARS in Indonesia, Brazil, Cameroon, Thailand, Peru and the Philippines; local NGO's

Problem Analysis

Rapid conversion of tropical forests leads to loss of biodiversity, massive carbon release into the atmosphere, smoke and haze problems, and impacts on watershed functions. Part of this forest conversion is poverty driven, but it interacts with logging, tree crop plantation development, government sponsored resettlement programs and increased accessibility and road construction. Poverty at the forest margin includes large risks, while there are strong negative perceptions about forest squatters and they have little or no voice in the public debate. Yet a number of local solutions to food crop-based shifting cultivation appear to be promising, such as complex agroforests that have replaced crop-fallow rotations. These land use systems are not recognized at policy level, however, and do not appear on the maps and statistics that are collected. Current policies may hinder these solutions and thus aggravate problems.

Thus, there is a need for integrated analysis of a broad range of land use alternatives, which must include quantifying the local, national and global benefits they provide as well as the institutions that favour or hinder further development, as alternatives to slash-and-burn conversion of forests to unsustainable land use practices.

Production

The ASB research project developed descriptions of the productivity on a 25-year time frame, considering labour and other inputs, for locally relevant representatives of major land use systems, ranging from the collection of non-timber forest products, via agroforest management to systems based on food crops or large-scale tree crop plantations. Technical options for using more productive tree germplasm in smallholder agroforests are combined with efforts to understand the ecological and economic constraints on a range of management intensities. The ASB project works with farmers on experiments to achieve

an in situ rejuvenation of agroforests, without the use of slash-and-burn clearing cycles in rotational systems. Agroforestry development on degraded lands and frequently burned *Imperata* grasslands depends partly on better information on tree-by-site matching of tree germplasm, as existing farmer efforts run large risks in El Niño years with long dry seasons.

Environment

For all land use categories, we quantified the impacts on plot-level above- and below-ground biodiversity, assessed the time-averaged C stocks characteristic of the system and integrating over the life cycle of a system, and measured the net emissions of other greenhouse gases. As there is little undisturbed lowland rainforest left in Sumatra, the agroforests of low management intensity have become the major reservoir of forest species, a large number of which have a direct use value and many of which could become a resource in the future. Most of these species survive because they are simply tolerated; a few are actively managed at the local level.

We are currently quantifying the impacts of these land use systems on water use and sediment flows, and trying to derive the rules that govern watershed functions in a mosaic of land use practices, in a coordinated effort involving Thailand and Philippine ASB sites. A globally agreed set of sustainability indicators was quantified, with nutrient cycling and soil organic matter studies done. To address the immediate impacts of forest conversion on smoke (haze) production, we quantified smoke production during forest conversion as a function of the amount of wood that is removed from the plot before the burn.

Human Well-being

Risks for resource-poor farmers at the forest margin are linked with vertebrate ‘pests’, fire, and economic shocks and sudden changes in prices. Maintaining an array of potentially productive options in the agroecosystem plays a role in managing these risks. In El Niño years the existence of forest resources suddenly gains in importance.

As follow-up to participatory surveys, farmers can acquire a voice in discussions at the local policy level, and the ASB project helped various segments of society come to grips with the real issues and opportunities.

We reviewed the policy constraints on tenure arrangements and helped achieve policy change that secures access to forestlands under certain restrictions, obtaining recognition for farmer-developed options of agroforests.

Analysis of Tradeoffs, Range of Flexible Options

We summarized the indicators of local, regional and global benefits of a range of land use options in a matrix format, and analyzed the tradeoffs and synergies between profitability, C stocks and biodiversity — both between land use systems and for a range of management intensities within the major systems, including agroforests.

In a comparison between systems, the agroforest option is shown to provide a good opportunity for maintaining forest biodiversity and fairly high C stocks in a system that produces an attractive return to labour. Within agroforest land use, however, a tradeoff exists between local (productivity) and global (C stock and biodiversity) impacts. We are currently analyzing these tradeoffs in more detail.

For the land use practices that are attractive from a local as well as a global perspective, we analyze an array of factors that influence decision making by farmers, including economic and institutional incentives or disincentives posed by current policies.

Feedback

A major outcome of the ASB project was contributing to local and national level policy dialogues on ways that forest functions can be maintained in the context of development, leading to identification of entry points for intervention on degraded lands as well as at forest margins.

Policy recognition of the existence and role of agroforests at national and provincial levels offers a first step toward empowering the farmers who manage these systems.

A review of trade policies and taxes on farmer-grown trees helped make the argument that rules developed to slow 'illegal logging' of natural forests currently provide a disincentive for farmers to grow trees on their farm. Much of the wood burned in slash-and-burn fires could be used in more productive ways if rules were changed.

The ASB project now supports negotiations between stakeholders in regard to access to state forestland, in the light of protecting watershed functions, reducing pressure on continued migration toward new forest margins and improving the livelihoods of the poor who migrate to the forest margin because of too few economic opportunities elsewhere.

We analyzed the policy options for managing fire and smoke and reducing across national boundaries the impacts of smoke from forest-clearing fires, and assisted a re-evaluation of resettlement policies. Overall, our results are helping existing extension services to appreciate farmer-developed options and resource integration.

Case Study 5: Methodology Integration for Tackling INRM Issues from Field/farm to Regional Scales in the Uplands of the Red River Basin, Vietnam

Lead center: IRRI

Natural resources managed: Land and water resources of the fragile uplands ecosystem

Partnership: The Ecoregional Initiative for the Humid and Sub-Humid Tropics of Asia is one of the eight Ecoregional Programmes of the CGIAR; the Red River Basin is one of the pilot sites of the Initiative; the study described involves the NARS of Vietnam Agricultural Science Institute, the National Institute for Soils and Fertilizers, the National Institute for Agricultural Planning and Projection, the Bac Kan Provincial and District agricultural services, IRRI, ICRAF and CIAT, a number of advanced research institutes, including CIRAD, IRD, Thai Nguyen University and Hanoi Agricultural University, together with NGO's (particularly GRET) and local farmer groups

Problem Analysis

The uplands of the Red River Basin constitute a highly diverse and complex agroecological and sociocultural and economic environment. Population pressure, changing political systems and policies on land allocation (from collective to individual management) resulted in tensions and shifts in resource endowments of ethnic groups, influencing their ability to respond to food production needs and increased market integration and their level of exploitation of the natural resource base across the toposequence from the sloping lands to the valley bottoms. The characterisation of the problems may be summarized as follows:

- Food security and increasing poverty: It is an area of deficit, subsistence production and poverty.
- Degrading natural environments: There are strong ecological linkages and interactions between the sloping lands and the valley bottom from the biophysical aspect — soil erosion on the slopes resulting in sediment yield — and degradation of water quality and quality in the valley floor.
- Policy constraints: Changes in political systems and national policies over the past two decades influenced sociocultural and land tenancy relationships (from collective to individual management) and resource use allocation.

INRM Research (Integrated Analysis of Alternative Solutions)

This case project seeks to identify, steer toward and support positive trends of sustainable agricultural systems in uplands environments, and identify in conjunction with stakeholders the conditions for co-viability of agroecological dynamics and socioeconomic changes in a holistic approach to integrated natural resources management (INRM). The problems are being addressed using a bottom-up approach (i.e., focusing on the implications and cumulative effects of field/farm interventions at higher geographical levels of integration) as well as a top-down approach (i.e., analyzing scenarios of land use planning at regional level and the implications of resource allocation and utilization). A variety of research tools, including various field study methods, remote sensing techniques and simulation modeling tools, has been employed to generate, capitalize on and mobilize knowledge to enable the resource users to make better decisions and take more appropriate actions in INRM. Research efforts also have been initiated for integration of the approaches and methodologies in a complementary manner, to bridge the gap between the top-down and bottom-up approaches and to traverse the research to development continuum in INRM.

Production

Direct seeding and mulching of upland rice and maize improved yields and contributed to soil and water conservation, weed control and livestock fodder production. Community-based production of certified rice seeds ensures availability and independence from external seed sources.

Human Well-being

The development of diversity in cropping systems provides communities with livelihood choices that suit their household strategies and available resources; organisation of certified rice seed production by commune groups boosts community co-operation and confidence in engaging in enterprises.

Environment

The agricultural production systems being tested and evaluated are chosen not only for their ability to improve food security and livelihoods but also to address soil and water conservation, particularly on sloping lands.

Tradeoffs and Options

Compilation of a knowledge base on innovations and testing of various combinations, both modern and indigenous, provide farmers with a broader base of options. The conditions and implications of their choices, modeled using multi-agent systems and converted into role-playing games, help the communities identify tradeoffs between individual and collective interests as well as between resources users and resource planners and managers.

Outcomes

Field-level interventions (combining relevant indigenous knowledge and new technological innovations) are tested for different production systems. For example, introduction of direct seeding and mulching practices for upland rice has resulted in increased rice yields, incorporation of increased organic matter and soil stabilization to prevent erosion on hillslopes.

The project has engaged resource users in decision making.

- At the regional/provincial level, local governing personnel and resource managers are involved in providing knowledge and evaluating results of a GIS-based decision support tool for land use planning and analysis (LUPAS) using an integrated multiple-goal linear programming method. The LUPAS methodology is being used in exploring scenarios of tradeoffs between different and conflicting uses of the natural and human resource base for regional-level planning and resource use analysis, and to identify promising options given the targeted biophysical objectives, socioeconomic conditions and prevailing policy and political environments.
- At the farm community level, simulation modeling techniques based on multi-agent systems are used as a companion modeling tool and role-playing games among farmers are being used to elicit interaction and negotiation of resource use, particularly the use of common pool resources.

Replication of some of the technical innovations developed by at the field/farm level is being carried out in the network of communes. A resource center was established at the provincial capital as a pilot communication platform for INRM at the village and commune levels. This centre, where knowledge from all relevant studies is deposited, formally documents what until now were informal interactions between partners who share objectives and often confront the same constraints.

Feedback (Lessons Learned)

Lesson 1: The methodologies for developing INRM need to be highly adaptive, as no single method will prove successful everywhere, and an adaptive research approach is required. Methodological diversity and integration is important in INRM to address complex NRM issues at complementary scales and thematic, geographic perspectives.

Lesson 2: The way in which research is conducted is at least as important as the results. The role of researchers in the interactions with local and regional stakeholders changes from that of ‘experts’ or ‘lesson givers’ to that of facilitators in an interactive learning process.

Lesson 3: Convening organisations and facilitators initiating this new approach need to be real partners in the R&D effort. Researchers need to develop skills for social interactions with partners to facilitate strong local linkages, promote stakeholders' involvement in the R&D process and foster community emergence of NRM. The research is done by people for people, and it is not possible to force interactions between persons who do not share a common interest.

Case Study 6: Conservation Tillage and Establishment in Rice-Wheat Systems in the Indo-Gangetic Plains

Lead center: CIMMYT

Natural resources managed: Soil, water

Partnership: Rice Wheat Consortium for the Indo-Gangetic Plains, an ecoregional programme of the CGIAR that comprises NARS of Bangladesh, India, Nepal and Pakistan; five international centres, including CIMMYT (the convening centre), IRRI, IWMI, ICRISAT and CIP; a number of advanced research institutes, among them Cornell University, IACR-Rothamsted and CABI, along with NGO's, farmer groups and local private sector entities

Problem Analysis

Future food security of the region is threatened by an awkward combination of unfavourable trends: increased population growth and growth in demand for food grains; exhaustion of past sources of productivity growth in rice-wheat systems (modern varieties, fertilizers, irrigation investment); loss of sown areas to urbanisation and resource degradation, including soil fertility loss and groundwater depletion.

Research Approach (Integrated Analysis of Alternative Solutions)

In unraveling the complex chain of factors influencing rice-wheat system problems, a strong leverage point was identified: conservation tillage for crop establishment. This can be applied to rice and wheat crops in rotation, as well as to diversification crops (grain legumes and potatoes).

Three conservation tillage practices were identified, one developed by researchers (zero-till drill), one by the private sector (rotovator-cum-seeder for Chinese hand tractors) and one by farmers (surface seeding practices requiring no implements).

Production

Farmers and researchers have seen that use of these practices:

- increases rice and wheat yields (often by 1 to 2 tons per ha);
- reduces costs (from less tillage, including fuel savings);
- facilitates improvements in agroecosystem diversity (additional space in the system has led to farmer experimentation with mungbean in the rice-wheat rotation); and

- improves nutrient and water use efficiency (by as much as 30%), thus allowing higher yields with fewer inputs of nutrients and water.

Environment

Changing to a zero-till system on one hectare of land would save 98 liters of diesel and approximately 1 million liters of irrigation water. Using a conversion factor of 2.6 kg of carbon dioxide per liter of diesel burned, this represents about a quarter ton less emissions per hectare of carbon dioxide, a principal contributor to global warming.

Human Well-being

Farmers help adapt these prototype practices to local circumstances; develop their own technologies, which in turn are offered to other farmers in the region; and lead in the adaptation of farming systems and natural resource management practices to take full advantage of the new tillage and establishment options. Machine shop owners also help in the adaptation of implements, leading in commercial production of implements found to be useful, attractive and profitable to farmers.

Tradeoffs and Options

Although not formally done as part of the RWC activities, studies of water management issues have been done by others, including studies on competition for water resources. More work in this area needs to be included in activities of the consortium.

Outcomes

In two years, conservation tillage adoption in farmers' fields has spread from 120ha (1997) to 1200ha (1998) to 12,000ha (1999), with adoption constrained only by the pace at which small machinery and implement shops can manufacture drills and seeders. In a few years, adoption is likely to have expanded to hundreds of thousands of hectares or more.

Numerous institutions have begun to encourage farmer experimentation with conservation tillage practices, and to launch formal promotional activities. These include state colleges and universities, national programs, NGO's and state government institutions (e.g., the On-Farm Water Management Programme of Punjab State in Pakistan). In addition, World Bank agricultural sector loan resources managed by the Government of India and the Government of Pakistan are being used to accelerate rapid scaling out of conservation tillage practices in suitable areas.

Case Study 7: Community-based Watershed Management in the Tropical Hillsides of Latin America

***Lead center**:* CIAT

Natural resources managed:

***Partnership**:* CIAT, CIMMYT and CONDESAN, an ecoregional programme convened by CIP and community groups

Problem Analysis

525 m people have their homes in the hillsides, which contain 50% of the world's tropical forest and 20% of all fresh water. However, large numbers of people live in poverty and face food insecurity and an uncertain future because of declining productivity resulting from deforestation, water shortages and soil nutrient depletion. It has been estimated that 13 b t of soil is lost annually and an area the size of Switzerland deforested every two years. Downstream agriculture and urban and industrial users face problems of water quality and intermittent flooding. There is a lack of policies that provide incentives for improved resource management.

At the focus site in the Cabuyal River, Colombia farmers saw low declining real incomes as their main problem, which forced many to seek off-farm employment. They wanted to increase incomes by irrigating vegetables and fruit for an existing urban market but lacked a yearround water supply. They saw the problem arising from deforestation in the upper reaches of the watershed. Social cohesion was lacking.

INRM Research (Integrated Analysis of Alternative Solutions)

The problem of poverty linked with low productivity and a degrading resource base was addressed at farm, community and watershed levels through strategic research by international centres (CIAT, CIMMYT and CONDESAN), collaborating with more applied research institutions (NARS of Colombia) and adaptive institutions (community CIAL's, or Comités de Investicación Agricola Local — local agricultural research committees), with technology transfer facilitated by NGO's at a representative watershed.

The approach used was based on the formation or strengthening of multi-institutional watershed user associations or committees at the watershed scale, along with organisations at the small catchment scale, as a platform for decision making and negotiation. CIAT's hypothesis was that improvements in INRM and technology innovation will be accelerated by decision support that helps local actors to understand better the cause-and-effect relationships in the natural environment and the potential benefits of new management

practices. The Rio Cabuyal case supports this hypothesis because informed collective action helped target conservation efforts to a level where they would pay off and lower the costs of conservation for individuals. Moreover, planting trees, maintaining buffer zones and adopting rules to control (but not eliminate) slash and burn was tied to the promotion and introduction of more intensive, high value crops and market development as a form of compensation.

Another generic feature of this case is that capacity building emerged as a tremendously important aspect of the work done by local and external organisations. This catalyzed the ongoing development of a set of decision-support tools based on this experience, which are being used in many watersheds and development projects in Central America and have begun to be tested and adapted in hillside farming projects in East Africa and Vietnam.

The buffer areas were established initially at the headwaters of the Rio Cabuyal. After GIS analysis by researchers showed that the volume of water in the dry season depended as much on the feeder streams in the mid and lower sections of the watershed as on the upper water sources, local people realized they needed to establish buffer zones along all the secondary, feeder watercourses. In addition, communities began to encourage farmers to protect natural springs with buffer zones, and these were mapped and monitored. The buffer zones consist of spontaneous regeneration of secondary forest along the watercourses combined with tree planting for fuel, forage and fruits.

Production

- High value products: fruit, vegetable, dairy
- Added value: starch from cassava
- Contour production of berries
- Greater range of production (fruits, dairy products) and resource options (barriers, legumes)

Environment

The environmental benefits have not been quantified or valued in monetary terms yet, although qualitative improvements have been noted in the availability of water in the dry season in springs and feeder streams, regeneration of a lake and establishment of a mini-irrigation system.

Human well-being

- More options reduced risk
- Local research capacity(CIAL's)
- Local stakeholder consortium for information sharing, negotiation, rule setting, organising watershed level activities

Tradeoffs and Options

- A community organisation (CIPSALA) coordinated internal and external negotiation.
- Farmers in the lower part of the watershed assisted in reforestation in the upper part.
- A greater range of production (fruits, dairy products) and resource options (barriers, legumes) was introduced.

Outcomes

Fora are held in which the people of the watershed address questions of where to work, who the key people are, what the vision of the watershed should be, how to organise, what technological options are available, and what monitoring and evaluation should be done. The process is aided by guides of their choice. The guides are support tools for decision making that, for example, aim to guarantee sufficient quality and quantity of water over the next 20 years.

This approach is described as decision support based on *discovery* because it is built around the provision of tools and technologies to strengthen the local ability to undertake research and acquire the information needed in making good decisions about watershed resource management. After being trained in use of the various tools, the local people or organisations can select the tools they feel are best suited to their particular purpose and area. We supply the training and tools; we do not make recommendations. Our approach helps people develop the capacity for *discovering* what it is that they ought to do. We support their process of finding out what the options are, evaluating the options and making well informed decision.

Case Study 8: Replenishing Soil Fertility through Agroforestry in Subhumid Tropical Africa

Lead center: ICRAF

Natural resources managed: Soil (nutrient capital), watersheds and biodiversity

Partnership: KARI, KEFRI, TSBF

Problem Analysis

Although threats to food security occur throughout the developing world, they are most acute in sub-Saharan Africa and are intrinsically linked with agricultural stagnation, degradation of the natural resource base and population growth. It is now recognized that soil fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per capita food production in sub-Saharan Africa. A marked decline in crop productivity is the main consequence of soil fertility depletion at the farm level. Other effects include less fodder for cattle, less fuelwood for cooking and less crop residue and cattle manure to recycle nutrients. Nutrient depletion leads to negative effects that extend beyond the farming household and into community, regional and national scales; these effects include lower returns for agricultural investment, higher food prices and a need for increased government expenditure on health and famine relief. The most important negative social externalities of soil fertility depletion are its links with lower employment and increased poverty and strain on rural households that spurs migration to urban areas, where unemployment, crime and political unrest sometimes result.

Soil fertility depletion also exacerbates several environmental problems, including increased soil erosion, particularly in steep areas; unwanted sedimentation; siltation of reservoirs and of coastal areas; and, in some cases, eutrophication of rivers and lake or loss of topsoil organic C associated with soil nutrient depletion, which leads to additional CO2 emissions into the atmosphere from declining soil and plant C stocks. Soil fertility depletion increases the degradation of forests and woodlands as a result of land clearing and collection of fuelwood.

The highlands of western Kenya have one of the densest populations in Africa, with soils that are widely depleted of nitrogen and phosphorus. Characterization studies identified declining soil fertility as the main factor limiting crop production, with many households producing only enough maize to feed themselves for a few months out of a year.

INRM Research (Integrated Analysis of Alternative Solutions)

Collaborative research by ICRAF and its partners has shown that the use of organic and inorganic inputs can replenish soil fertility and decrease Striga infestations (a parasitic weed of maize plants). On-farm trials have led to the development and testing of soil replenishment strategies that have been shown to be profitable at the farm level. These entail introducing natural resources to fields so crops can utilize them: obtaining nitrogen from the air through biological nitrogen fixation, phosphorus from indigenous phosphate rock deposits and nutrient-rich shrub biomass such as *Tithonia diversifolia* from roadsides and farm hedges. Once soil fertility has been replenished, farmers shift to producing high value products such as vegetables and tree crops, which can dramatically increase their income and help them rise out of poverty.

Production

Results over two to three seasons show that through use of leguminous tree fallows (those that fix nitrogen) in rotation with maize, enough nitrogen can be made available to maize plants to increase yields by up to two to three times the previous levels.

Environment

Preliminary studies suggest that when soil fertility is replenished, carbon sequestration rates become positive, averaging 1.5 tonnes C/ha/year. When trees are planted on field boundaries and as orchards, carbon sequestration rates can increase further, to 3.5 tonnes C/ha/year (estimates only). Soil fertility replenishment practices based on improved fallows and provision of rock phosphate and *tithonia* for 20 years is estimated to result in an increase in time-averaged C stocks by 32 tonnes C/ha. When trees are introduced after fertility replenishment, total time-averaged stocks reach 70 tonnes C/ha, which includes 24 tonnes C/ha in the above-ground biomass and 36 tonnes C/ha in the soil. The transformation of low productivity croplands to sequential agroforestry in subhumid smallholder Africa can, therefore, triple carbon stocks (from 23 to 70 tonnes C/ha) over a 20-year period.

Some pest problems related to low soil fertility are diminished when fertility is replenished. Besides replacing N, one-year fallows of sesbania have been found to encourage suicidal germination of the parasitic weed Striga.

As with crops, maintaining genetic diversity in fallows is important to forestall pests and diseases. Farmers from Luero village in western Kenya have observed that intercropping an insect-repelling fallow species such as *Tephrosia vogelii* with *Crotalaria grahamiana* can reduce damage to crotalaria caused by defoliating beetles.

Human Well-being

Food security is attained by these technologies. Villages no longer report periods of hunger, and some have surpluses of maize for sale. By switching from maize to high value products, some farmers in western Kenya have reported increases in their net profits from US $91 to $1,665 per year. Larger profits can be expected when farmers move to high value tree products, such as the bark from *Prunus Africana* (a timber tree indigenous to montane regions of Africa), from which a substance is extracted to treat prostate gland-related diseases and which has an annual market value of US $220 million.

Nitrogen fixing shrubs and trees planted on farms reduce the need for women farmers to go off-farm to collect fuelwood, thus reducing the impact on neighbouring forest land but also freeing up time and energy that these women can apply to other activities.

The move to food security and the community participation in the dissemination of the soil fertility replenishment strategies has brought a sense of pride and dignity to farmers and villagers associated with ICRAF's work in western Kenya.

Tradeoffs and Options

Soil replenishment requires a set of accompanying technologies and polices to be effective in raising and sustaining food production. By itself, soil fertility replenishment is a necessary but not sufficient condition for increasing per capita food production. Soil conservation technologies must be present to keep the nutrient capital investment in place and to prevent nutrient pollution of rivers, lakes and groundwater. In addition, enabling policies are required to provide a conducive environment for farmers to adopt soil fertility replenishment. For example, improvement in the availability of fertilizers, training of extension agents, greater opportunities for local access to credit at reasonable interest rates and improvement of infrastructure are requirements needed to sustain the benefits of soil fertility replenishment.

Outcomes

About 50,000 farmers are using these technologies with consistent results, thereby achieving greater food security. A further benefit has been knowledge transfer from village to village through various NGO's, NARS, development projects and local farmer groups. Extension workers have felt revitalized and professionally rewarded in being able to provide practical information to their constituents.

Appendix 2: Papers Submitted for the INRM Workshop in Penang

On the conceptual underpinnings of INRM:

Biological Management of Soil Fertility: An Approach to Integrated Management of Natural Resources, by Cheryl Palm and Mike Swift

Scaling, Lateral Flows, Filters, Sustainability and Negotiation Support Models for Natural Resource Management in Landscapes with Trees, by Meine van Noordwijk

Agrobiodiversity as a Natural Resource For Sustainable Production in Agroecosystems: Examples From IPGRI's Global In Situ Conservation on Farms Programme, by Devra I. Jarvis

On INRM research paradigms:

Blending 'Hard' and 'Soft' Science: The 'Follow the Technology' Approachto Catalysing and Evaluating Technology Change, by Boru Douthwaite, Nicoline de Hann, Victor M. Manyong and Dyno Keatinge

INRM or Adaptive Decision-Making Process (ADM Process) – A Case of Focus, Attitudes and Approach, by Padma Lal, Hazel Lim-Applegate and Michelle Scoccimarro

Prospects for Agroecologically Based Natural Resource Management for Low-Income Farmers in the 21st Century, by Miguel A. Altieri and Berkeley Jean-Marc van der Weid

On understanding the complexity and underlying science of INRM research:

Toward INRM: Three Paths Through the Forest, by B. Belcher, C. Colfer and K.G. MacDicken

Adapting Science to Adaptive Mangers – Spidergrams, Belief Models and Multi-agent Systems Modelling, by Tim Lynam, Francois Bousquet, P.d'Aquino, Olivier Barreteau, Frank Chinembiri and Bright Mombeshora

Methodological Integration: Lessons from the Ecoregional Initiative for the Humid and Sub-Humid Tropics of Asia, by S.P. Kam, J.C. Castella, C.T. Hoanh, G. Trebuil and F. Bousquet

Spatial Modeling of Risk in Agriculture and Natural Resource Management: Applying Plot-level, Plant-growth Modeling to Regional Analysis, by P.G. Jones and P.K. Thornton

Evaluation and Planning of Resource Utilization in Dry Region Using GIS and R emote Sensing, by S. Masahreh A. Taimeh and B. Hattar

On successful systems-based INRM:

Use of Grasses and Legumes for Increasing Productivity and Improved Resource Use in Smallholder Systems, by P. Kerridge, F. Gabunada, P. Horne, Ibrahim, G. Nakamanee, P. Phengsavanh, W. Stür, Vu Hai Yen

Integrated Natural Resource Management Strategy for the Dry Areas, by R. Tutwiler *et al*.

Integrated Natural Resource Management – Putting Livestock in the Picture, by S.A. Tarawali, J.W. Smith, P. Hiernaux, B.B. Singh, S.C. Gupta, R. Tabo, F. Harris, S. Nokoe, S. Fernandez-Rivera and A. Bationo

Sustainable Land Management: Contributions from the System-wide Soil, Water and Nutrient Management Programme, by R.J. Thomas, R. Delve, P. Dreschel, F. Penning deVries, M. Pala and U. Singh

Integrated Natural Resource Management: Approaches and Lessons from the Himalayas, by K.G. Saxena, K.S. Rao, K.K. Sen, R.K. Maikhuri and R.L. Semwal

On scaling up in INRM and related research:

Scaling Up of Adoption of Natural Resource Management Technologies in the Semi-Arid Tropics, by R.J.K. Myers, J.P. Dimes , B.Gerard, B.I. Shapiro and W.D. Dar

Scaling Issues in Integrated Natural Resource Management: Conceptual Considerations, by Christopher Lovell, Alois Mandondo and Patrick Moriarty

Taking It Higher: Thoughts on 'Scaling Up' Within Problem-solving Approaches to Research on INRM, by Larry Harrington, Jeff White, Peter Grace, Dave Hodson, Dewi Hartkamp, Kit Vaughan and Craig Meisner

On measuring the success of INRM and related research:

Assessing Viability and Sustainability: A Systems-based Approach for Deriving Comprehensive Indicator Sets, by Hartmut Bossel

Evaluating the Impacts of Integrated Natural Resource Management Research, by B. Campbell, J. Sayer, P. Frost, S. Vermeulen, M. Ruiz Perez, A. Cunningham, R. Prabhu, S. Waddington, E. Chuma

Assessing the Impact of Integrated Natural Resource Management: CIAT Challenges and Experiences, by María Verónica Gottret and Douglas White

Rural Sustainability Indicators: Lessons Learned from Central America, by Manuel Winograd, Lisa Segnestam and Andrew Farrow

On CGIAR structure and governance:

Integrated Research on Food and the Environment: An Exit Strategy from the Rational Fool Syndrome in Agricultural Science, by Jacqueline A. Ashby

New International Partnerships for Agroecological Natural Resource Management in the 21st Century, by Christian Castellanet, Jean-Marc von der Weid and Ann Waters-Bayer