Methodological integration for sustainable natural resources management beyond field/farm level:

Lessons from the Ecoregional Initiative for the Humid and Sub-Humid Tropics of Asia

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Abstract

Integrated natural resources management (INRM) has to address both the livelihood goals of farmers and ecological sustainability of agro-ecosystems and natural resources. Under the Ecoregional Initiative for the Humid and Sub-Humid Tropics of Asia—Ecor(I)Asia—one major set of activities has been the development of approaches, methodologies, and tools to meet the challenges of INRM research for sustainable agricultural development. Examples provided illustrate the role of these methodologies in the three main phases of knowledge development for improving INRM impact: knowledge generation, knowledge capitalization, and knowledge mobilization. The methodologies are designed for better integration across disciplines, spatial scales, and hierarchical levels of social organization. Attempts are made to quantify trade-offs between biophysical sustainability and socioeconomic considerations. The case is made for using these methodologies in a more complementary manner to help bridge the top-down and bottom-up approaches in INRM. Inherent in developing and implementing of these methodologies is the forging of partnerships and fostering linkages with multiple stakeholders as well as using the knowledge base and integrative tools as communication platforms.

Keywords: Integrated natural resources management, systems approach, methodology integration, bridging top-down and bottom-up approaches, empowerment of stakeholders, partnerships.

Contribution to the International Workshop on "Integrated Natural Resource management in the CGIAR: Approaches and Lessons"
21-25 August 2000, Penang, Malaysia

1. Introduction

Research challenges in natural resources management

Two main challenges face natural resources management (NRM) for long-term sustainable agricultural development. The first is to seek viable production systems that meet the livelihood objectives of farmers while sustaining the natural resource base on which they depend. The second is to apply location-specific findings from NRM research and development efforts to wider domains, for two important reasons. One is that concerns of ecological sustainability cover larger geographical areas than plots, fields, and farms. The second is the increasingly felt need to attain a more widespread impact of NRM research.

Integrated natural resources management: dimensions of integration

To face these challenges, NRM must be based on a holistic understanding of the interactions between the resource base and socioeconomic dynamics operating at different scales and among different levels of social organization. NRM issues need to be tackled from different facets, taking into account these interrelationships and interactions; hence, the notion of integrated natural resources management (INRM).

Specifically, to meet the two challenges mentioned above, research efforts need to move NRM further along three main axes or dimensions of integration: i.e. (1) to go beyond sectoral considerations to an interdisciplinary perspective, (2) to span broader geographical scales beyond the plot and field, and (3) to strengthen linkages along the research-development-policy continuum (Figure 1).

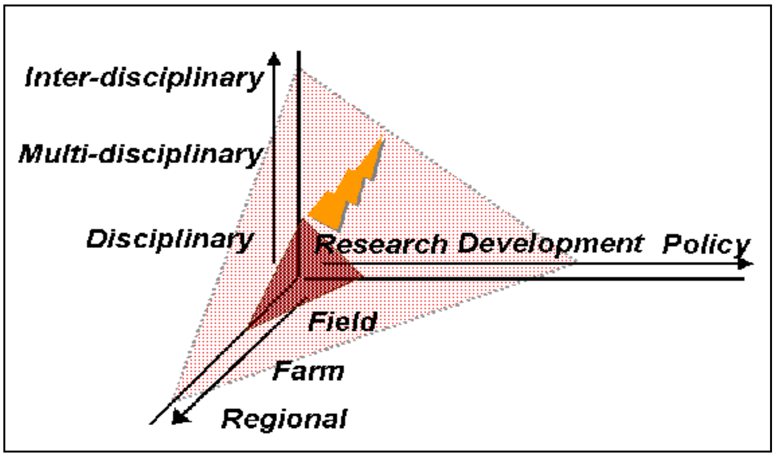

Figure 1. *The dimensions of integration in natural resources management.*

An interdisciplinary approach is important. Although the effects of the over-exploitation of natural resources are more commonly studied as biophysical phenomena, the underlying causes and consequences are largely socioeconomic and institutional/political in nature.

The second dimension relates to scale issues in NRM. One aspect of scale is that different resources ought to be managed at different scales to ensure sustainability. For example, nutrient management may be done at the field scale, but water can be managed effectively only beyond the field and farm scale. Another aspect is that socioeconomic and institutional/political forces, as well as the interests and concerns of different stakeholders, are also directed at different scales. Although socioeconomic gains from exploiting natural resources accrue directly to individuals and households, the environmental costs may not be borne by the same people who benefit.

The third dimension, fostering closer linkages between research and development, helps nurture the enabling social, institutional, and organizational conditions for enhancing the impact of NRM research.

Demand for INRM research methodologies

The Red River Program (RRP) is an example of an NGO-government collaborative effort in Vietnam to promote rural development (VASI-GRET, 2000). The Program adopts a highly participatory approach in agricultural development activities that embraces INRM principles. Figure 2 illustrates its systems approach in identifying problems and key intervention points to break the spiral of non-sustainability in one of its projects in Tam Dao District of Phu Tho Province. Both the livelihood concerns of the community and the ecological linkages across the toposequence, from sloping land to valley bottom, are considered in seeking ecologically sound and viable agricultural production systems.

The project adopted a step-wise problem-solving approach, emphasizing mutual learning and blending desirable elements of indigenous knowledge with modern technologies. The agricultural production systems adopted also demonstrate a good understanding of the flows of products between crops and livestock systems, and use these linkages effectively. Distinctions were made between interventions at the individual farm level and those requiring efforts at higher organizational levels (e.g., community-based seed production units and maintenance of water reservoirs). By accumulating a knowledge base of innovations that are ecologically sensitive and economically attractive, the local communities are better able to manage their production systems and resources in a more sustainable manner (Figure 3).

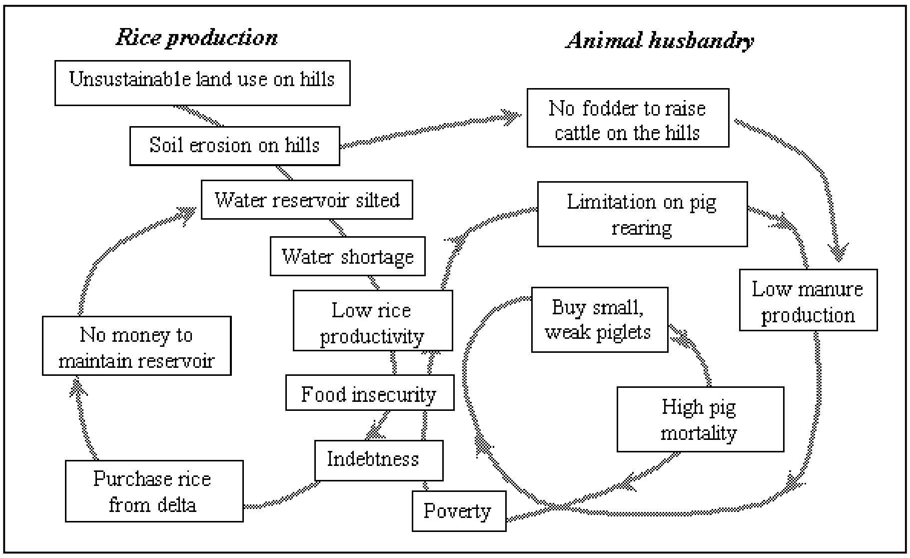

Figure 2. *The spiral of non-sustainability: Case example of Tam Dao, Vietnam.*

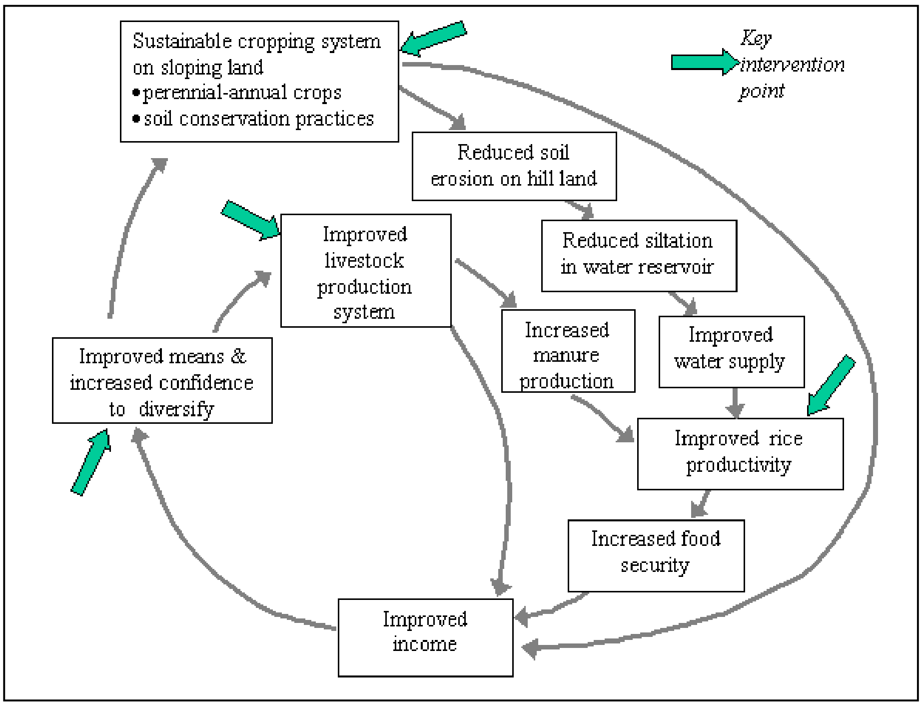

Figure 3. *The cycle of sustainability: Case example of Tam Dao, Vietnam.*

Several success stories have emerged from the 10-year efforts and experience of the Red River Program. Although spontaneous diffusion of certain types of innovations to neighboring villages does occur, the project teams recognize their limitations in being able to "multiply" their successes to larger areas.

This highlights the need for more research support to such development-oriented projects in several aspects, such as the following:

a. in providing technical and scientific input into testing and evaluating innovations, both indigenous and modern;
b. in systematic characterization and analysis to determine the key success factors and to identify technological, management, and policy interventions;
c. in determining target areas for effective delivery of INRM practices; and
d. in documenting the operational methodology and quantifying the impacts of INRM practices on livelihood improvement and conservation of the natural resource base.

2. The Ecor(I)Asia

Such examples provide the motivation and impetus for methodological development efforts under the Ecoregional Initiative for the Humid and Sub-Humid Tropics of Asia (Ecor(I)Asia - one of the eight ecoregional programs of the Consultative Group of International Agricultural Research Centers, CGIAR) to address complex NRM issues in a more holistic and integrated manner. Under the Initiative, we undertake INRM research within biophysically defined ecoregions while taking into account the socioeconomic circumstances and institutional/policy environment, embodying the concept of the ecoregional approach (Rabbinge, 1995; Manichon and Trébuil, 1999).

2.1 Knowledge development for INRM

The fundamental role of INRM research is to develop knowledge and make it available to the people who manage the natural resources on which they depend. We identify three main phases of knowledge development: knowledge generation (i.e., gaining understanding and insight), knowledge capitalization (i.e., building upon the understanding to develop technologies, tools, methodologies) and knowledge mobilization (i.e., bringing the knowledge to the target groups). Dynamic feedback loops exist among these three phases. In capitalizing on and mobilizing knowledge, new insights and understanding are gained, thus spurring better ways of tackling new problems that may arise. These three phases of knowledge development are equally valid for specific NRM technologies (e.g., crop, soil, water, pest management) as they are for more integrated strategies for managing resources (Table 1).

Our approach focuses on increasing the relevance and impact of single discipline-based NRM research by adopting a more holistic approach to identify the needs for, and implications of, introducing NRM interventions. Recognizing that there may be conflicting uses of natural resources, new methodologies are needed to determine trade-offs between biophysical sustainability and socioeconomic considerations. Stakeholders are involved in developing, testing, and implementing these methodologies to ensure their relevance.

2.2 Case examples

Three examples (summarized in Table 1) are presented to illustrate how the framework described above is implemented under the Ecor(I)Asia.

North Thailand diversification-soil erosion risk study

A study was conducted in the Mae Salaep watershed in Chiang Rai Province, North Thailand, to determine the effect of diversification of farming systems on soil erosion risk.

Table 1. *Phases of knowledge development for INRM.*

Technology development for NRM		Phases of knowledge development	R&D linkage for attaining impact of Integrated Natural Resources Management				
Objective	Activity		Objective	Activity	Soil erosion study, North Thailand	SAM example, Red River Basin of Vietnam	LUPAS example, Red River Basin of Vietnam
Seek promising technologies	Experimentation and characterization	**Knowledge generation**	Understand the existing situation ecological processes social dynamics market	Characterization	Multi-scale diagnostic study of changes in erosion risk in relation to changes in cropping systems	Analysis of agrarian systems evolution and differentiation; compilation of innovations data base	Resource evaluation Yield estimation Input-output estimation
Develop innovation	Field testing, demonstration and distillation of scientific knowledge to simple rules	**Knowledge capitalization**	Add value and make use of knowledge	Development of tools and methodologies for decision support	Multi-agent systems (MAS) modeling of land use change dynamics and soil erosion	Testing of sustainable NRM innovations; SAMBA multi- agent system based simulation modeling	Interactive Multiple Goal Linear Programming
Deliver technology to users	Transferring of technology to users	**Knowledge mobilization**	Empower stakeholders	Delivery and implementation of decision support systems	Using MAS as "companion modeling" to support discussion and negotiation among multiple stakeholders	Establishment of resource center; Making knowledge base accessible to local community Using SAMBA role-play	Stakeholder consultation, training and operationalizing of decision support system

Notes: *SAM = Mountain Agrarian Systems; LUPAS = Land Use Planning and Analysis System*

Knowledge generation: At the field level, an on-farm diagnostic survey analysed the influence of the main cropping systems on the risk of soil erosion under various slope and climatic conditions. At the farm level, a typology of rapidly diversifying household-based farming systems was developed to understand farmers' differentiated management strategies. At the watershed level, a GIS-based analysis of land use changes was carried out for the period 1990-98 (Turkelboom and Trébuil, 1998). The study found that several practices adopted by farmers in diversified farming systems actually improved soil and water conservation (smaller fields, terraced paddies replacing upland rice fields on sloping land, and more perennial crops).

Knowledge capitalization: Multi-agents system (MAS) modelling (Ferber, 1999) was used to facilitate knowledge integration across scales and disciplines (Bousquet, et al., 1999), using data sets and information collected at the three levels of organisation—fields, farms, and village/watershed. The model simulates and identifies agro-economic conditions consistent with farmers' dynamics that further improve soil conservation. Figure 4 shows mapped results depicting yearly changes in cropping systems and corresponding changes in erosion risk. Appendix 1 gives details of the MAS approach.

Knowledge *mobilization:* A simplified version of the MAS model will be translated into a role game to validate it. The validated model will then be used to build and explore possible scenarios of evolution of the current agrarian situation, with the participation of local government agents and farmers.

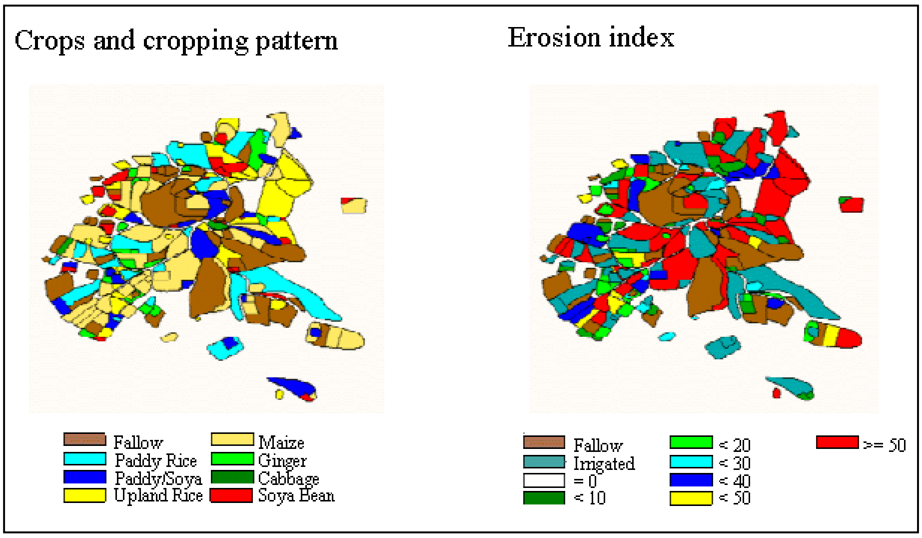

Figure 4. *Example of outputs from the MAS model for watershed erosion risk analysis, Mae Salaep watershed, North Thailand.*

Mountain Agrarian Systems Project, Red River Basin of Vietnam

In the northern uplands of Vietnam, population pressure, changing political systems, and policies on land allocation (from collective to individual management) resulted in shifts in resource endowments of ethnic groups. These changes influence their ability to meet increased food production needs and their level of exploitation of the natural resource base across the toposequence (Castella, et al., 1999a). Farmers often lack the knowledge to seek alternatives to their traditional slash and burn practices that have become unsustainable.

The Mountain Agrarian Systems (SAM) Project in the uplands of the Red River Basin aims at improving food security of the ethnic minority groups while ensuring sustainability in agricultural production and the natural resource base of the fragile environment. The cropping systems component of the project (SAM-CS) concentrates on seeking viable alternatives to the present unsustainable production systems at the field/farm level, while the regional component (SAM-R) focuses on developing research and operational methodologies to scale up location-specific studies.

Knowledge generation: The SAM-R component develops multi-scale approaches to characterize and understand the evolution of agrarian systems in the context of biophysical, socioeconomic and policy environments. It also focuses on evaluating the performance of existing and promising farming systems, using a combination of field, survey, and remote sensing techniques (Castella, et al. 1999b).

Knowledge capitalization: GIS tools are used to consolidate the knowledge gathered at the various spatial and temporal levels as well as across the various disciplines. A multi-agent systems-based model, SAMBA, was developed to mimic the process of farming systems differentiation over a 40-year period to determine the driving forces of the observed changes. Figure 5 illustrates how SAMBA is used to test whether a limited number of household socioeconomic characteristics can sufficiently explain the differentiation of household typology in terms of production strategies. This modeling approach allows aggregated results of individual household behavior to be represented at the village level and to be scaled up from the village to commune level. It provides the basis for developing a regional model, that is, a multi-disciplinary parallel of "pedo-transfer functions", thus allowing for up-scaling of research and development findings in INRM.

Knowledge mobilization: A network of communes is replicating the technical innovations developed by SAM-CS. A resource center has been established at the provincial capital, where the databases from relevant studies are deposited. The resource center provides the focal point for interactions among R&D partners and stakeholders. Converted into a role game, SAMBA is being developed as a tool to explore options and anticipate implications of current and promising NRM practices. It promotes mutual social learning, whereby the interactions that it elicits among stakeholders provide better insight into the local social dynamics.

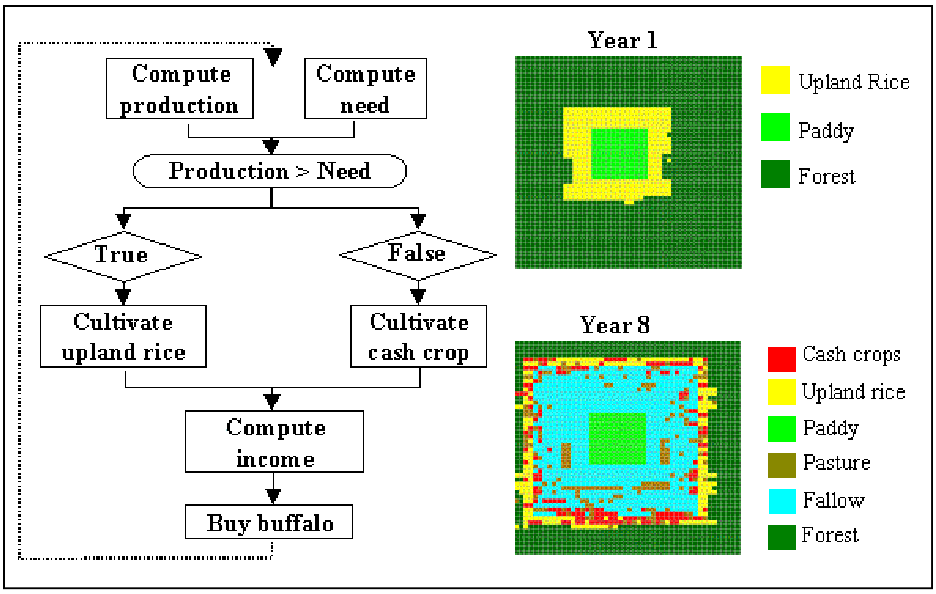

Figure 5. *The SAMBA model applied to simulation of land use changes, SAM-R study in the uplands of the Red River Basin, Vietnam.*

Land Use Planning and Analysis System (LUPAS)

Another major methodological development under Ecor(I)Asia addresses concerns about the use of natural resources at the regional level and linkages with policy and land use planning decisions. LUPAS, a computerized decision support system (DSS), was developed under the SysNet (Systems Research Network for Ecoregional Land Use Planning in Tropical Asia) project with four case studies in India, Malaysia, the Philippines and Vietnam (Hoanh and Roetter, 1998). LUPAS can be used to explore different land and resource allocation scenarios given conflicting land use objectives by quantifying trade-offs among these objectives and between biophysical sustainability and socioeconomic considerations. Figure 6 shows the conceptual structure of LUPAS (Roetter and Hoanh, 1999).

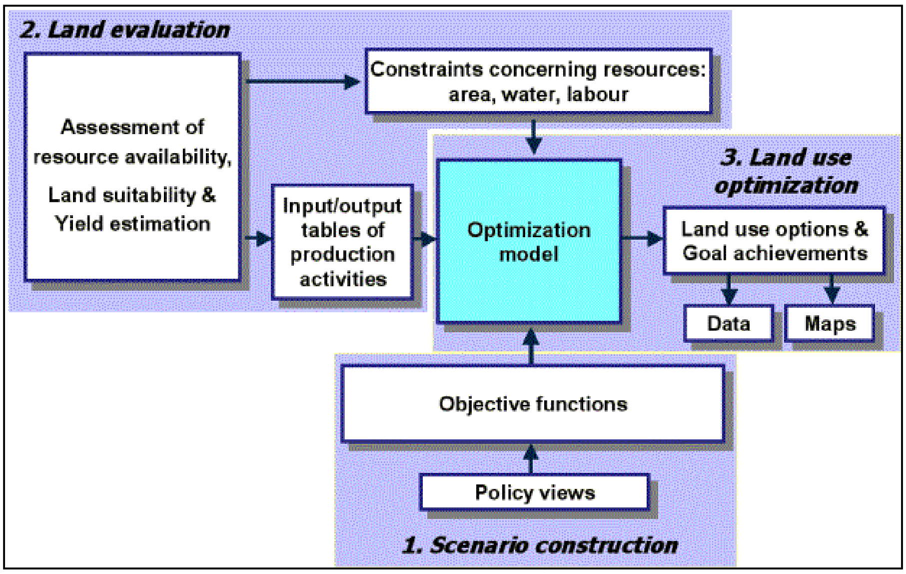

Figure 6. *Conceptual model of the Land Use Planning and Analysis System (LUPAS).*

Knowledge generation: In Component 1 of LUPAS (Figure 6), the major characteristics of the region are determined and objective functions are formulated based on the policy views of stakeholders. In Component 2, biophysical and socioeconomic data are collected for evaluating the capacity of the resource base to meet the requirements of existing and promising land use types.

Knowledge capitalization: Component 3, which is the core of LUPAS, uses interactive multiple goal linear programming (IMGLP) to model optimal land use options under user-assumed biophysical, socioeconomic, and policy constraints.

Knowledge mobilization: The multi-disciplinary study teams consist of researchers from advanced international institutes and their counterparts in national agencies who receive specialized training. The researchers consult with stakeholders (national and regional agricultural planning and management agencies, local government agencies) at various stages of model development and interpretation of results, as shown in Figure 7.

Stakeholders in the case study regions are already using the results to review their resources and revise their regional land use plans.

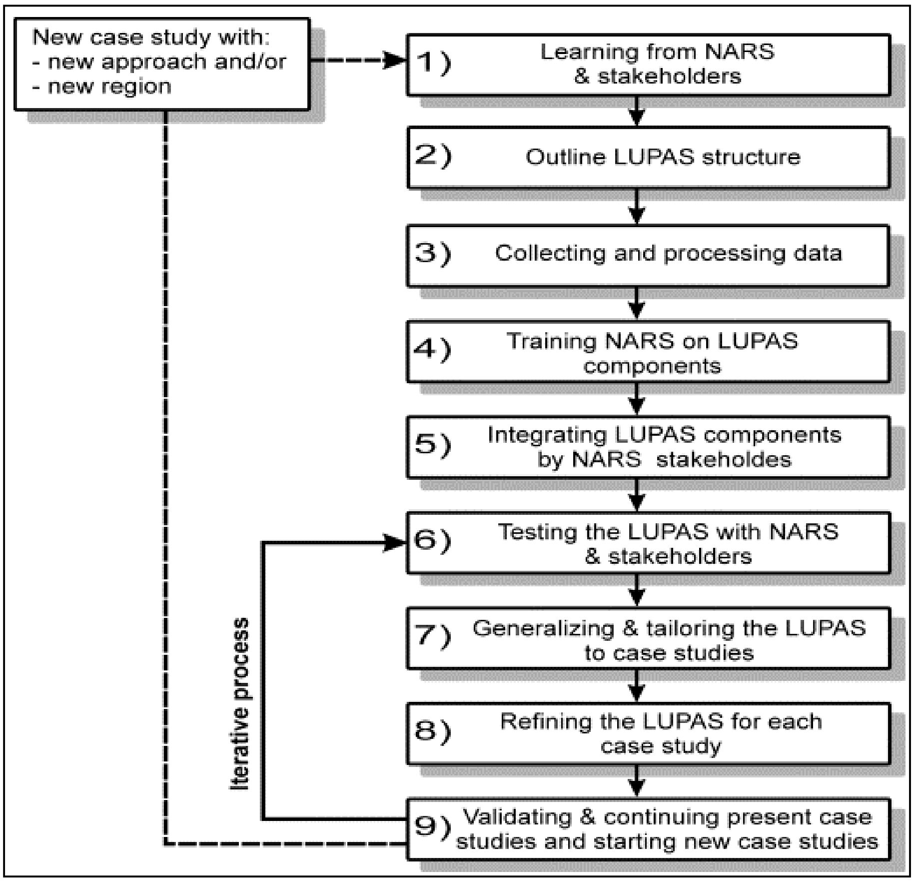

Figure 7. *The scheme of stakeholder involvement in LUPAS methodology development.*

2.3 Methodology integration

The major outputs from the above three examples are (a) tools that facilitate integrative analyses and exploration of options on the use and management of natural resources, and (b) operational methodologies to enable stakeholders to use these tools. Although Ecor(I)Asia started by developing a "basket" of methodologies for INRM, we are now moving toward using these methodologies in a complementary manner, recognizing that no single methodology can solve complex NRM problems.

Figure 8 illustrates the prospect of complementing the LUPAS and SAM methodologies in the northern uplands province in Vietnam. LUPAS is used to explore existing and future development scenarios at the regional level, making explicit the trade-offs, implications and consequences on land and resource allocation. It provides a rational basis for policymakers to make informed choices of various development options. This is one way of influencing policy and governance decisions that are supportive of the diverse needs of stakeholders yet protective of the long-term productive capacity of the natural resources.

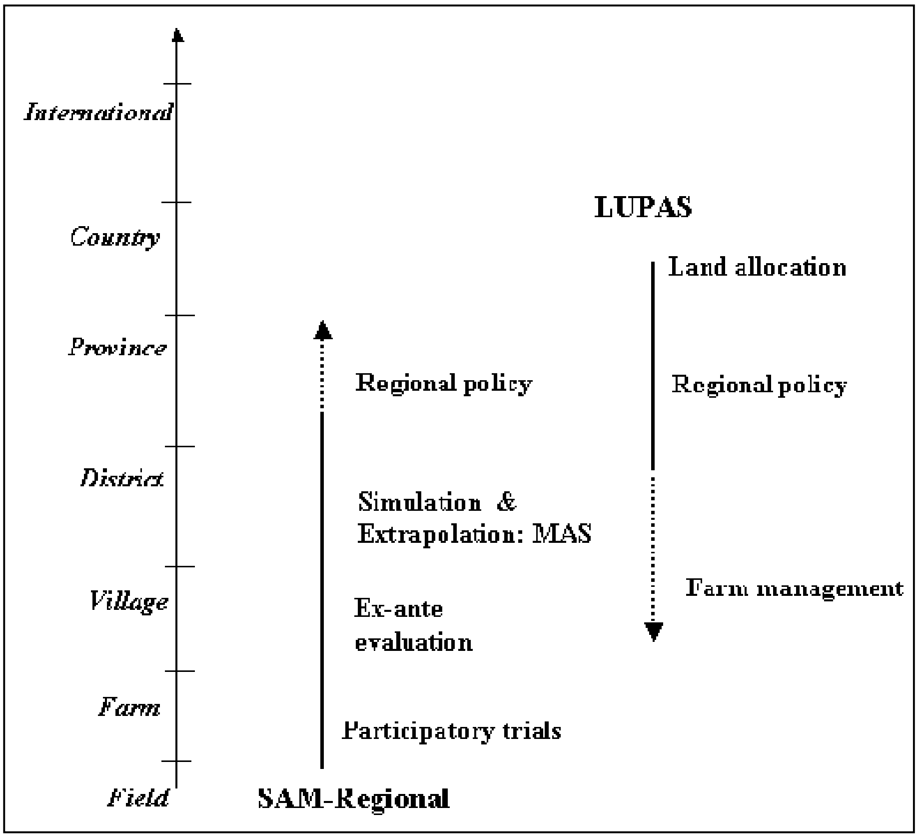

Figure 8. *Multi-scale integration in methodology development in Ecor(I)Asia.*

The question remains as to how to steer changes along the development pathway from the existing to a preferred scenario, such as one that is more sustainable in the long term. The goals of resource conservation and environmental protection are not likely to be realized by adopting solely top-down measures that are not reconciled with farmers' livelihood concerns and are therefore not acceptable to them. The bottom-up approach of INRM, such as that adopted in the SAM project, helps strengthen community capacity to develop livelihood strategies that are more sustainable. Brought together, the LUPAS and SAM-R methodologies can potentially help bridge the gap between top-down and bottom-up approaches to INRM by improving communication and dialog among stakeholders at different levels of organization.

2.4 *Forging partnerships*

In developing and implementing these methodologies, we have made conscious efforts to establish strategic partnerships with research and development agencies, and to involve the relevant stakeholders. The SAM project involves partners from international and national research organizations working closely with the communities and local government units. It also works closely with other complementary projects under the umbrella of the host national institution (Figure 9). The introduction of LUPAS into the same geographical area adds new partners under the coordination of the National Institute of Soils and Fertilizers (NISF). In bringing together the LUPAS and SAM methodologies, we form a second level network of partnerships, linking national institutions that had tended to be exclusive of each other. Such a partnership network provides the crucial institutional support for tackling multi-scale, complex NRM issues in a holistic manner (Castella, et al., 1999c).

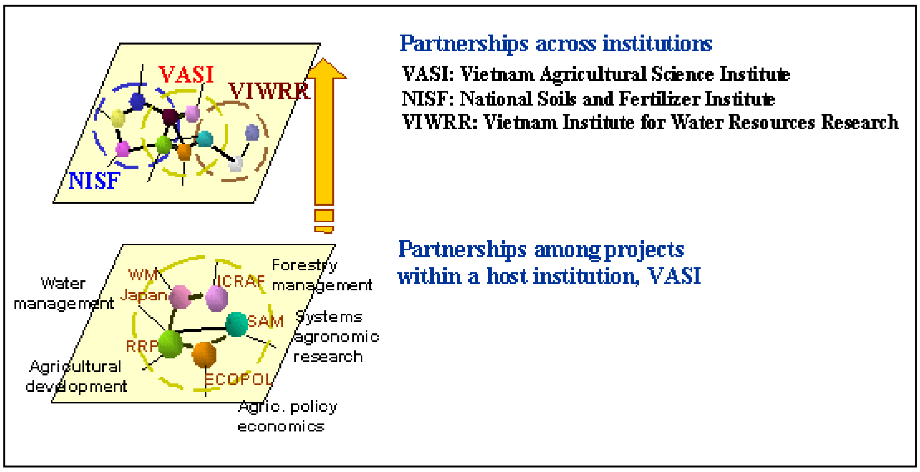

Figure 9. *Building the partnership hierarchy at the Red River Basin ecoregional site, Vietnam.*

3. Conclusions

The ecoregional programs of the CGIAR provide the geographical context for INRM. By carrying out INRM research within well-defined ecoregions, the methodologies developed and lessons learned can be extended to similar situations. In addition, the ecoregional programs are advanced in forging strategic partnerships among the CGIAR centers, advanced research institutes (ARIs), national agricultural research and extension systems

(NARES), and non-governmental organizations (NGOs) to tackle complex issues relating to agricultural production. Hence, these programs also provide the organizational and management context for developing integrative methodologies for managing natural resources.

Specifically, the research activities undertaken by Ecor(I)Asia already embody the salient features of INRM: (a) employing a holistic and systems perspective in understanding the main NRM issues within a defined region; (b) identifying the key intervention points for addressing these issues; (c) developing integrated approaches, methodologies, and tools and implementing strategies to influence and bring about the desired changes; and (d) evaluating and adapting INRM approaches and strategies to cope with changes.

We draw a few major lessons from our Ecor(I)Asia experience.

1. It is important to first develop a coherent research framework for INRM. Within the framework, methodologies developed should be adaptive in order to tackle NRM issues specific to the region of interest. It is then important to distill the key elements of the INRM approach and the generic elements of the methodologies, to be validated and applied to larger geographical areas.
2. With a coherent INRM framework in place, methodologies developed should be strategically targeted at specific NRM issues, with emphasis on augmenting single discipline-based research through integrative approaches. Using these methodologies in a complementary manner would further enhance integration along the three dimensions as shown in Figure 1.
3. It is not enough to focus on finding scientific and technical solutions when broader organizational, institutional and policy factors, often considered as externalities, do not support well-intended INRM efforts. The most difficult challenge for effective INRM is to "internalize" these factors, that is, to include within the scope of INRM research the development of operational approaches to deal with these constraints.
4. The new role of research in INRM requires a change in outlook of scientists from being expert givers of knowledge to facilitators in an interactive learning and knowledge development process. This requires new skills, perhaps even a new breed of researchers, for social interactions with a broader spectrum of partners to foster the emergence of a committed INRM community.

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Appendix 1

The application of Multi-Agent Systems for addressing multi-scale INRM issues

Multi-Agent Systems (MAS) modeling is based on recent developments in the field of distributed artificial intelligence (Ferber, 1999). It provides a means of representing knowledge and interactions among agents. In a MAS model, agents are computerized autonomous entities that are able to act locally in response to stimuli from the environment or in communication with other agents by sending messages and forming representations of the world as they perceive it (Bousquet et al. 1999). MAS models construct such agents and put them in realistic circumstances of interactions such as coordination of actors exploiting a given resource.

For the past ten years, MAS applications have been developed in the field of natural resources and environmental management (Barreteau and Bousquet, 2000; Janssen et al., 2000). Applied to INRM research, MAS focuses on the interactions between agroecological dynamics (i.e., the status and dynamics of the resources of concern) and socioeconomic changes, based on the hypothesis that the system dynamics depends on interactions between the resources and uses by both individual and collective agents (in this case, users) having different management strategies. MAS allows for construction of generic models to mitigate the site specificity of the more conventional approach to NRM research. MAS can incorporate into the same application or model spatial entities defined at different hierarchical levels, and can simulate their behavior or changes with time. Therefore, it is possible to take into account the spatial hierarchy and the temporal dimension in representing and simulating system dynamics. Closely articulated with fieldwork, MAS is employed to provide a companion-modeling tool for researchers to work with diverse stakeholders.

MAS is now implemented on the Common-Pool Resources and Multi-Agent Systems (Cormas) platform, which is a multi-agent simulation toolkit running under the *VisualWorks* software, and is specially designed for applications in renewable resource management (Bousquet et al., 1998). MAS is presented in two applications in this paper: as SAMBA in the Red River Basin, and as the Mae Salaep model in North Thailand. The Mae Salaep model is described below to illustrate how MAS simulation is applied to the soil erosion case study in North Thailand.

The spatial environment and land resources of the study area are depicted by GIS maps of topography and time-series, plot-wise land use, which are transferred into the MAS environment. Two interrelated spatial entities are considered in the model: homogeneous zones (with homogeneous slopes) and farmers' fields, with corresponding attributes such as area, owner, slope characteristics (orientation, angle, length), and crops grown.

The model has two different classes of agents: the communicating agents and the passive situated agents. Two main categories of communicating agents are included:

1. The farming systems present in the area; there are three main types with attributes such as the amount of (land) resources (quantity and quality) and strategies for crop combinations.
2. The village; regulating the beginning and end of the crop year, farmers' actions in their fields, and pooling the results of the daily assessment of erosion risk in each field throughout the rainy season.

The passive situated agents are the crops in farmers' fields. Their attributes are crop calendars (early-late sowing dates, duration of the crop cycle), duration of their respective periods of susceptibility to erosion, sequences of cultivation practices, and minimum and maximum size of their fields.

The model simulates the dynamics of land-use changes. Young farmers inherit from old ones, and the farm type can change with the creation of new farms depending on the amount of resources they yield. Results of cash-cropping activities in one year influence the crop allocation to the fields the next year, or a move to off-farm activities in the case of negative results or indebtedness.

The control of the simulation can be set according to a daily or yearly time scale. Historical daily rainfall data are used in the MAS model to assess soil erosion risk. The simulation results are depicted in land-use change and corresponding erosion risk maps, as shown in Figure 4 of the main text.

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