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From Cropping and Farming Systems Research to Ecoregional Approaches for Integrated Natural Resources Management: Developing the Agricultural System Concept

G. Trébuil [1/] and S.P. Kam [2/]

ABSTRACT

This is a framework paper proposing a conceptual and methodological approach for INRM at the agricultural system level. After a definition of the natural resources management (NRM) and agricultural system (AS) concepts, the authors argue that a key issue in NRM research is to identify dynamically the conditions for a co-viability of bio-physical changes and socio-economic as well as institutional transformations of agricultural systems. To achieve such a goal, they think that a new interdisciplinary, or even transdisciplinary, action-research paradigm and framework is essential to integrate knowledge across bio-physical sciences, ecology and social sciences at several pertinent and complementary levels of organization. Past experiences in systems research applied to agriculture and recent advances in science and technology can help to reach this goal. Following an assessment of the contemporary challenges and breakthrough in NRM research, the current trends in systems approaches applied to agroecosystem management at complementary scales are briefly presented. Then, a description of the principles of integrated natural resources management (INRM) with an ecoregional approach is followed by a discussion of the obstacles to the implementation of INRM research methodologies. Based on recent experiences, several propositions to avoid such obstacles are also proposed.

Introduction

What is natural resources management?

Generally, Natural resources management (NRM) is primarily dealing with the manipulation of human-dominated complex ecological systems to acquire a certain level of desired products corresponding to the local social needs. NRM forms an interface between the bio-physical environment and human intervention at different

[1/] Scientific delegation for agronomy, environment and resources management, Cirad, TA 179/01, avenue Agropolis 34398 Montpellier Cedex 5, France. Seconded to Crop, soil and water sciences division, IRRI. Guy.trebuil@cirad.fr

[2/] Social Sciences Division, International Rice Research Institute, MCPO Box 3127, 1271 Makati City, Philippines.S.Kam@cgiar.org

levels of organization of phenomena. Recently, IBSRAM, and ICRAF researchers proposed the following definition on the INRM list server[1]: "NRM can be defined as the management of natural capital to produce flows of desirable products and services at local, national, regional and global scales. Natural capital is the stock of environmentally derived assets that provide a flow of useful goods or services (e.g. land, water, biodiversity, wildlife, vegetation, etc.)".

NRM research involves the understanding and the management of interactions between three key sub-systems:

- Physical processes regarding flows of energy, materials, water and nutrients,
- Ecosystems, this concept underlining the importance of interactions among different species, as well as regulations and feedback effects resulting from the system dynamics more or less affected by human activities. These ecosystems provide functions (production, transport, regulation, etc.), which generate products (grains, animals, etc.) and services (recycling, soil erosion control, sediment traps, etc.),
- Human users benefiting from the ecosystems products and services, as well as their cultural and institutional systems regulating the management of ecosystem resources and land use.

NRM research needs to cover areas from the identification of the social demand for improvements in resource use and the understanding of key resource dynamics, down to the assessment of the measures and policies in place to regulate resource uses and the design and testing of potentially more effective new ones. This implies that NRM research needs to be carried out through an holistic, systems approach and is necessarily a long-term effort in which end-users, researchers and development officers need to work side by side.

This only implies that NRM is generally a site specific kind of research. Local experiences and knowledge, involving a wide range of stakeholders are of paramount importance in NRM research, but they can also have a wider relevance. Therefore, it is typically a kind of research for National Agricultural Research and Extension Systems (NARES), with international research centers supporting mainly the development of innovative approaches, methodologies and tools in close collaboration with NARES to make NRM research more effective and to increase its impact in the field and on the farms.

The importance of NRM research was recently emphasized by rapid environmental degradation (Trébuil 1995). More and more often, agricultural and environmental issues are now very linked, and innovative ecological approaches are needed to answer key questions like: how far the effects of the individual agricultural activities are aggregating to affect whole ecological systems at the landscape level? How far non-farm changes affecting the agroecosystem are influencing agricultural practices? How existing ecological services could be maintained and reinforced through better agricultural practices and technologies?

[1] <inrm@cgnet .com>

What is an agricultural system?

During the 80's, it was shown that, besides useful concepts at the field (cropping system) and the farm (farming system) levels, a more macro analysis was necessary to identify and to understand the key transformations and trends affecting the whole farms of a region at a larger scale and in the longer term (Trébuil and Dufumier 1993). Such an analysis is essential to assess the conditions, effects and consequences of key transformations and adaptations of the regional agriculture, as well as to appraise their economic and social implications. To carry out such an analysis, the embodying concept of agrarian system, or agricultural system (AS), was conceived at the interface between agroecology and economic and social sciences (Mazoyer and Roudart 1997). The four interdependent variables of an agricultural system are (Trébuil 1988):

- The cultivated ecosystem, produced, exploited and maintained by man starting from a former original natural ecosystem,
- The technical system, which is made of the whole set of instruments and means of production. The combination of these first two key variables produces a mode of exploitation of the ecosystem, specific to a given AS and that can be used to characterized it and to delimit its boundaries,
- The agrarian structures regulating the relations of ownership of the means of production, the division of labor among economic sectors and the exchange of products, then
- The institutional, cultural and policy set of conditions regulating the functioning of the agrarian structures. Theoretically, changes in those last two variables command the transformations of the first two ones and of the AS as a whole.

Figure 1 summarizes the relationships between these four key variables. The characterization of a given major type of agrarian system consists in the identification of a state of coherence between these four variables, produced by the local agrarian history and allowing the AS to meet the local social needs, for food and other products, at a given time. The history of a given regional agriculture can be interpreted through the construction of an evolutionary succession of several main types of AS, which are permanently under transition. At any time, farms corresponding to the previous type of AS can be identified, while others displaying the key characteristics of the forthcoming new kind of AS can also be observed. Along the process of agricultural development, the emergence of a new organization of agriculture, through a major qualitative transformation (such as the use of new source of energy, of irrigation, etc.), accompanies the recession of the older order of things that has reached its capacity for production and response to social needs.

Because the adoption of the means of production of new AS are costly, a contradictory process of "development-elimination" or "accumulation-degradation" among farmers who can, or cannot, afford them to remain competitive is taking place (Trébuil 1996). For each successive round, this process repeats itself for a decreasing number of farmers while the less favored ones have to move out from agricultural production. More or less rapid advances in production techniques and the kind of policies in place can accelerate or slow down this process.

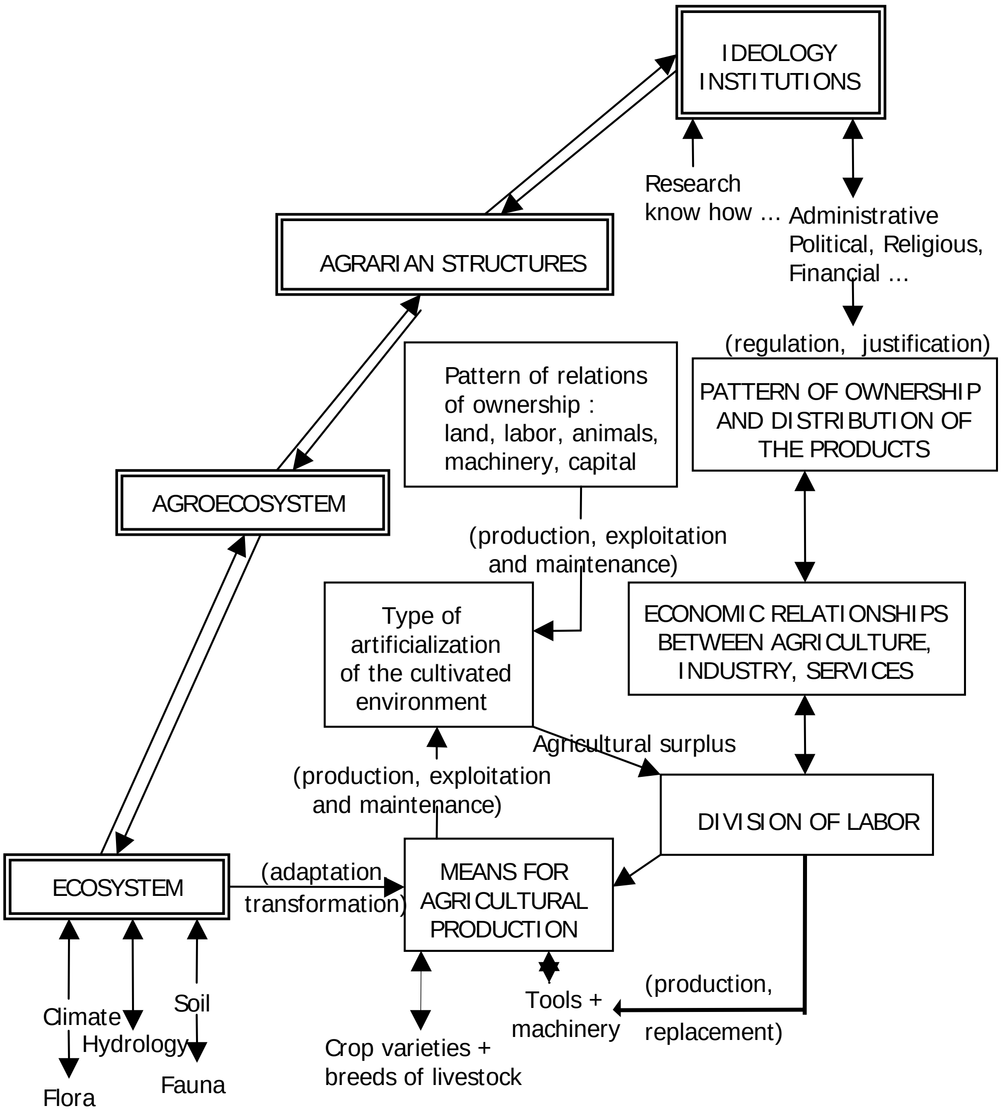

Figure 1. The concept of agrarian system: The four variables and their relationships.

Source : Adapted from Mazoer (1978).

In this article, the authors argue that a key issue in NRM research is to identify dynamically the conditions for a co-viability of bio-physical changes and socio-economic as well as institutional transformations of agricultural systems. To achieve such a goal, they think that a new interdisciplinary, or even transdisciplinary, action-research paradigm and framework is essential to integrate knowledge across bio-physical sciences, ecology and social sciences at several pertinent and complementary levels of organization. Past experiences in systems research applied to agriculture and recent advances in science and technology can help to reach this goal. Following an assessment of the contemporary challenges and breakthrough in NRM research, the current trends in systems approaches applied to agroecosystem management at complementary scales are briefly presented. Then, a description of the principles of integrated natural resources management (INRM) with an ecoregional approach is followed by a discussion of the obstacles to the implementation of INRM research methodologies. Based on recent experiences, several propositions to avoid such obstacles are also proposed.

The article is illustrated by the results of a multi-scale and interdisciplinary research on the relationships between soil erosion risk at the field level, agricultural diversification at the farm level and market integration at the local agricultural system level in Mae Chan area, Chiang Rai province, upper northern Thailand (Trébuil *et al.* 1997; Turkelboom and Trébuil 1998). At this study site, the Mae Salaep and Paka Sukjai watersheds farmed by Akhas highlanders are characterized by:

- An advanced stage of diversification of their upland agricultural system (800-1000 masl, 1600-2200 mm rainfall per year, some 65 inhabitants/km²) following 15 years of integration into the regional, national, and international market economy,
- Most of the cultivated fields located on steep slopes, with angles of 10-40 % and sometimes up to 60%,
- Already extremely short fallow periods (generally one or two years), while every year more fields become permanently cultivated.
- In this context, the research aimed at improving our understanding of the interactions between the risk of soil erosion by concentrated runoff and the rapid diversification of cropping systems and cultivation practices adopted by Akhas farmers (Trébuil *et al.* 2000).

Contemporary Challenges and Breakthrough Related to NRM

Environmental concerns and multifunctional agricultural systems

Table 1 shows that for the past decades, the challenges faced by agricultural production have evolved from predominantly technical aspects to encompass economic, social and cultural ones, as well as environmental concerns. In many places, like at our research site in upper northern Thailand, agricultural production issues (crop diversification and market integration) cannot be considered separately from environmental ones (land degradation, soil erosion, water quality, reservoir siltation). The importance of environmental issues is fast increasing, all of them having an ecological dimension, particularly when they deal with improved production associated with better maintenance and conservation of natural resources. This evolution leads to the adoption of more holistic approaches to “multi-functional” agricultural systems. The fact that the goals of food security, poverty eradication and environmental conservation are highly interdependent is also now widely recognized. If measures to improve crops and livestock performances are not based on an adequate understanding of the needs and options of poor farmers and do not take into account the ecological, economic and institutional context of the systems being addressed, rural poverty will not be eradicated (CGIAR 1999).

Key recent advances in several scientific areas have the potential to improve systems research applied to agriculture and the environment, but they could also generate new challenges. One of them being the difficulty faced by small farmers to have access, without external assistance, to the benefits of advanced technologies, such as biotechnology, remote sensing and spatial analysis, computer-based modeling and simulation and up-to-date information systems to assist them in making their decisions. The danger exists of seeing them even more marginalized relative to larger and more commercial producers.

Table 1. Past and current challenges, research objects and priorities in the field of NRM and agricultural systems development in developing countries.

Period	**80's**	**90's**	**Towards 2010**
Context and megatrends	Population increase / Closing of the land frontier / Strong Public aid / Foreign investment / Exports-led economic growth	Globalization of trade / Decline in public aid / Liberalization / Privatization / Price decline / Environment / Land-population pressure / Population growth and urbanization	Decentralization / Regional specialization / Industrial concentration / Population growth, movements and urbanization / Access to scarce resources / International conventions / Private – public sectors relationships / Information and communication technology / Biotechnology and property rights/ Part time agriculture / Land, farm consolidation / Climate variability
Agricultural development key challenges and issues	Increase in crop, animal productivity / Food self-sufficiency / Expanding the "green revolution"	Competitiveness / Food security / Resource conservation / Poverty eradication	Food security and safety / Poverty eradication / Durable, multi-functional agriculture / Added value increase of productions / Increased use of competitive advantages

Table 1. (Continued).

Period	80's	90's	Towards 2010
Dominating paradigms	Produce more / Technology transfer / Systems analysis	Produce better, in sustainable ways / People-centered approach / Diversity of stakeholders and objectives-strategies / Environmental assessment of practices	Stakeholder co-ordination and negotiation / Multiple-use approaches to NRM / Development-research continuum / Focus on high priority problems / Ecology / Informatics, Artificial Intelligence / Integrative sciences / Networking / Institutional density
Main research themes	Yield maximization with increasing use of inputs, irrigation, machinery / Standard technical recommend-ations for increased physical productivity / Economic evaluation of technology packages / Development-oriented research on farming and agrarian systems: AE Zonation, RRA, farm typologies, etc. / Crop models / etc.	Optimization of physical productivity / increase efficiency of input use / Labor productivity increase / Quality aspects / Crop x Environment models / Farm modeling / Conditions of adoption of innovations / Gender issues / Organization of producers / Spatial analysis of agricultural activities / Integrated modeling of renewable resources management / etc.	Decision support systems for crop, animal population management under varying conditions / Integrated models for crop-environment management / Control of product quality parameters, branding / Modeling of farm/non-farm interactions / Local development, territoriality / Landscape dynamics, spatial analysis, land-use conflicts / Resource dynamics with multiple uses and users / "Intervention research" / Coordination and negotiation processes and platforms / Scaling up adoption of innovations / GMO management / Climate change mitigation measures / Innovation processes / Social learning processes / Knowledge bases / New extension and communication methods / etc.

Major breakthroughs and changes affecting the context of NRM research

The current revolution in information and communication technologies (ICT) is demultiplying our capacity to process, store, and circulate information. As a consequence, there is a need to better structure information in organized systems based on theoretical representations of agricultural systems and their dynamics. Technological and organizational innovations could play a more and more crucial role. Better multimedia techniques for delivering and exchanging knowledge and for keeping information available and accessible for longer periods of time are now available. But there are challenges in finding ways that could minimize the impact of the "digital divide", the knowledge gap that is already occurring between those who have access to the Internet and those that do not. New information technologies can allow the improvement of information flows for NRM and environmental management. This should facilitate progress in the real participation of concerned stakeholders and a better integration of their knowledge in the research process. Potentially, it could also lead to a better dissemination and use of knowledge in agriculture and NRM, thanks to more easy networking and improved modes of collaboration between R & D partners. Then the capacity of partners along the Research-Development continuum to develop innovative INRM approaches, thanks to better information sharing, participatory monitoring and evaluation processes, could also be significantly improved.

More and more, the social demands to researchers and development workers are less technical in contents than before and deal more with more complex quality of life aspects. Beyond the (often still needed) increase in physical production, we assist to the broadening of the relevant performance criteria to be assessed during the monitoring and evaluation phase of a R & D project or program. Such suitable indicators are needed to monitor the system performance, as tools for adaptive management, as well as appropriate measurement of the impact of research and development efforts. Very often, they now need to include indicators on ecological sustainability and resource conservation, economic profitability, social equity, food security, etc.

It is also necessary to adapt working methodologies to the increased number of different stakeholders (starting with different types of farmers), often displaying conflicting interests and strategies, in situations characterized by multiple use and multiple users of common resources such as land, water, trees, etc. Because of this increasing complexity of phenomena and situations to be addressed, and because of the impossibility to operate through direct experiments, modeling seems to be the most appropriate way to test hypotheses on interactions between society, resources and the land. The complexity, chaotic nature, and lack of bounding in NRM at the agricultural system level require new breakthroughs in the application to NRM problems of various research domains such as artificial intelligence, scaling, evolutionary and viability approaches, etc.

System-scale simulation models linked to decision support systems (in the case of cropping or farming systems) or communication and negotiation platforms (in the case of complex NRM issues) are becoming more widely available and more user friendly. To be useful, these models must be easy to use and be conceived with a better understanding of the reality as the key objective in mind, and not just to verify if a given model is really describing what we already know about the real world. Such models and simulation platforms also need to offer an improved capacity to integrate social and economic information with bio-physical one, to provide the basis for a more adaptive management of NRM in agricultural systems. They also need to manage in a relevant way information on important phenomena occurring at different complementary scales (field, farm, watershed, region, etc.). As improvements occur in such tools for integrating knowledge across scales, sectors and between farmers and scientists knowledge, they become more effective to help unraveling the complexities of NRM issues to be addressed in close collaboration with all key stakeholders.

It is only quite recently that the importance of understanding community processes for managing resources was recognized and that devolved management systems were accepted as efficient solutions for a range of NRM problems. This led to emphasize social organization and social capital in projects, as well as research on finding ways for indigenous knowledge to complement scientific approaches. Methods and tools improving our ability to integrate diverse sources of knowledge and to match science to farming and NRM realities are essential and need to be developed.

A large adoption of such integrative methodologies in problem-oriented, interdisciplinary and participatory research could yield major improvements in NRM. In comparison with past research practices, there is a need to better balance efforts in the field of bio-physical research with those in socio-economic sciences, as well as to strengthen policy research at relevant levels of intervention to improve our understanding of the complex interactions among resources, people and their environment at different spatial and temporal scales. Improvements in the integration of NRM research with institutional and organizational issues are also required. This could now be better achieved by using truly ecological approaches to agricultural activities relying on modeling. The diversity of modeling and simulation approaches which is now available allow the application of a theory in a given discipline to specific conditions and according to the wishes and objectives of their users. The rapid emergence of computer-based simulation games for professional training illustrates very well how such models and simulators can stimulate thinking about options and scenarios and are becoming innovative NRM tools (Bousquet 1998; Ferber 1999).

We consider that the concept of agricultural system is a very pertinent one to build dynamic representations of the key interdependent features of a given regional agriculture in order to address its major NRM issues and to deal with the above-mentioned current challenges.

Trends in Systems Research in Agriculture

Cropping systems research

Pioneer applications of systems approaches to agricultural production started in the early 70's, and were very much linked to the spreading of the green revolution technologies, particularly the increased adoption of multiple cropping systems in favorable rice growing environments of Asia (Gomez and Gomez, 1980). By the early 80's, a standard on-farm cropping systems research methodology was disseminated in Asia (Zandstra, 1981), that somewhat limited the refinement of the cropping system concept.

In France, the concept of cropping system, defined as a set of crop management procedures (including varietal choice and the crop succession) applied to a given area, is still considered as a central and operational one for agronomists (Sebillotte 1990). Considered as sequential and spatial combinations of crops and their corresponding sequences of crop management techniques, cropping systems are components of household-based farming systems. This important concept is still being refined (Papy 1994; 2000), and nowadays it is even used to structure the interface between research and post graduate studies in agronomy.

The role of agronomy, seen as an integrative discipline at the field level, is also changing from the establishment of technical rules and recommendations for crop management to a more decision-making support function. In the current NRM context, the contribution from agronomists has to be adapted to variable circumstances and needs to incorporate up to date information, as well as a wider range of performance assessment criteria. This is necessary to allow a faster adaptation of farming practices to today needs and a greater flexibility in cropping systems choice and implementation. Cropping or animal rearing systems are linked to specific farmer decision-making processes. Today, production objectives and crop or animal rearing management practices cannot be defined by the producer and the agronomist alone. Nowadays, the following three complementary points of view need to be considered simultaneously in a kind of "integrated pattern of innovation" (Boiffin *et al.* 2000):

- at the farmer and farm level : what is the yield objective?
- at the commodity chain level : what type of product quality is expected and what kinds of relationships with the market need to be taken into account?
- at the society level : what environmental risks and constraints should be taken into account and evaluated?

Farmers' decisions integrate external factors and conditions regarding the farm economic, social, technological and environmental context, but also the objectives and needs of the farmer and his family members, as well as the land, labor and machinery resources available on the farm and to be allocated to various activities at a given time, etc. It is in fact a knowledge and information system that farmers use to manage their farms. And it is essential for the on-farm researcher or extensionist to understand the decision rules used by farmers and the way they are assembled and activated to regulate field level operations and to co-ordinate and to prioritize resource allocation at the whole farm level. Thanks to advances in information science and technology, effective models of action and decision support systems representing such sets of decision rules are now being proposed. They can complement field testing and be used to improve their protocols and their implementation, and can also help to study changes in existing cropping systems or emerging ones.

Towards the development of such an information, communication and knowledge-based "decision agriculture" (Boiffin *et al.* 2000), there is still a lot of work to be done in cropping systems research to produce user-friendly dynamic agro-ecological models, based on the integration of all key interactions and behavioral patterns. They should be able to be connected to decision-making rules and to provide economic and environmental evaluations of sets of crop management practices. To avoid a greater "digital divide", such approaches should be developed in developing as well as industrialized countries and be used to encourage a more extensive and fast sharing of agronomic knowledge.

- Examples of upland rice cropping systems in Mae Haeng (Van Keer *et al.* 2000) and cabbage systems in Paka Sukjai (Turkelboom *et al.* 1998).

Farming systems research and development (FSRD)

Changes in cropping or farming systems are always linked to more global changes in the farm functioning or in its environment that need to be understood. This is why a whole agricultural system analysis needs to be undertaken. In the current context, such kind of research has three main scientific objectives:

  - to generate new knowledge about the diversity of farmers and other stakeholders, on their specific practices and decision-making processes as well as their relationships,
  - to improve our understanding of the interactions between bio-physical processes and socio-economic dynamics at the farm level,
  - to design and to implement decision-support approaches, systems and tools to assist farmers and other stakeholders in taking into account the effects of their decisions on resources and other agents when managing their complex production systems.

- Examples: Farming system diversity (Trébuil 1996), in Mae Salaep, degree of integration into market (Thong-Ngam *et al.* 1997), and relationships between farm types and erosion risk at cropping system/field level (Turkelboom and Trébuil 1998).

Manuals are available in Thai language to explain how to analyze the recent transformations of a given regional agriculture and the origin of the diversity of farming systems (Traimongkonkool *et al.* 1994), as well as for the analysis of the functioning of household-based agricultural production systems to characterize and to classify them (Naritum *et al.* 1994). In the recent past, such methods were also applied to explain the succession of cotton production crises in Thailand (Castella *et al.* 1999).

Recently, a broadening of the scope of FSRD can be observed. This was reflected in the main themes selected for the last International Farming Systems Association (IFSA) Symposium in Chile in November 2000 which addresses the issues of the relationships between globalization and local dynamics, and of the conflicts between local needs and global environmental services. Generally, FSRD practitioners consider that diverse, multi-activity and multi-function farming systems will help minimizing risks to the poor farmers.

At the same time, for the past years, one can also observe a renewed interest of agronomists in agroecology as a scientific discipline that uses ecological theory to study, design, manage and evaluate agro-ecosystems that are productive but also aim at minimizing the negative environmental and socio-economic impacts of new technologies (Altieri 1998). This is particularly the case in the European Initiative (EIARD 1999) and Global Forum on Agricultural Research for Development (GFAR). As pressures on land grow, this renewed interest in agro-ecological approaches can be linked to the increasing negative impacts, on environmental degradation and producers and consumers health, of yield maximizing and high-input practices of intensive agriculture that have bypassed the needs and specific circumstances of large numbers of resource-poor farmers. When the agro-ecological approach adopted considers the interactions between bio-physical, technical and socio-economic components of farming systems as a whole to be studied in an interdisciplinary fashion, in practice, as it is also sensitive to the complexities of local agriculture, it becomes very close to FSRD (Collinson 1999).

In Europe, FSRD practitioners are also often involved in research on "territorial" approaches to local development and management of resources at the small regional level (a watershed, a valley, a province, etc.). Their "territory" is a complex and structured research object made of different sub-systems, in which they look at individual and collective behaviors and actions and their effects on the interactions between agro-ecological and socio-economic dynamics. A lot of similarities between FSRD and action-research, intervention-research and social learning approaches (Röling *et al.* 1998), in which the on-farm researcher takes part in the action himself as a mean to produce knowledge.

Ecoregional research

The point of departure of the "ecoregional research" approach can be traced to the Rio conference and Agenda 21 of the United Nations Conference on Environment and Development (UNCED). Agenda 21 emphasized the relationships between natural resources and ecological, economic and social sustainability, as well as development policy. In many parts of rural Southeast Asia, and particularly in Thailand, one can observe rapidly growing an competing demands for land, water, labor. Urbanization is increasing and residential and industrial areas are expanding, eating up (very often best quality) farm land, while consumer demands for more diversified products increase. The quality of the natural capital (such as land, water, etc.) needs to be maintained, but farmers' incomes must also increase and enough employment be created. Conflicts among economic, social and environmental goals set for the agricultural sector must be better analyzed and dealt with. To achieve this, not only must the scope of research be extended beyond the bio-physical aspects of production but, at the same time, problems must be analyzed in terms of their, interdependent, technical and human dimensions.

The very objective of the ecoregional approach to research is to contribute to the sustainable development of a given geographical region, an agricultural system, with its diversity of agricultural situations requiring a diversity of options and "solutions". But, like in the case of soil and water conservation techniques in the uplands/highlands of Thailand and other neighboring countries, many experiences have shown that to be accepted and disseminate, new knowledge must be in harmony with the needs and strategies of the people for whom these technical or organizational innovations are destined and must take into account the set of constraints (and opportunities) to which they are subject.

The ecoregional approach to research can be defined as the integrated study of bio-physical, socio-economic and policy factors of sustainable development in the context of a regional agricultural system (Manichon and Trébuil 1999). It is an inter-sectoral, actor-centered kind of R & D approach to deliver action plans at the regional level. The ecoregional approach to agricultural research on agricultural systems considers the land, its people and their activities, as a real research objects. Its integrated analysis aims to identify realistic margins for future progress benefiting the less-favored majority of farmers and the means to achieve them. To do so, the initial diagnostic approach should be carried out in a way so that scientists should not impose their own vision of the agricultural system state, dynamics and needs upon farmers, economic managers, policy makers and other key stakeholders. To ensure relevance and efficiency of ecoregional research, the preliminary overall diagnosis needs to be gradually constructed with stakeholders through a dialogue and a negotiation between a social demand and a supply of research activities. This process is to be established as early as possible in the design of the research program and must lead to a common vision of the agricultural system structure, its current dynamics and of its desirable future state at medium to long term. This will guide the programming, implementation and monitoring-evaluation of subsequent activities combining knowledge generation and its utilization in an action-research, long-term iterative process leading to strong partnership between research scientists and local key stakeholders. During such a process of integrated approach to development-oriented research, the classic boundaries between strategic, applied and adaptive research categories can also be removed.

To avoid some shortcomings of previous ways to implement regional diagnosis on agricultural systems (Trébuil and Dufumier 1993), it has been proposed to build up the picture of regional agricultural realities by combining several complementary, but partially redundant "points of views". These points of view integrate the different perceptions and patterns of reasoning of key stakeholders. They can be wholly included in the analysis without necessarily associating them with a single level of organization. Three key points of views can constitute the foundation of such a regional agricultural system diagnosis:

- The understanding of the structure and the mode of operation of the key commodity chains, from producers to consumers (vertical approach) by using various tools to analyze and to model their functioning,
- The land, its variability, natural and human organization and the mechanisms regulating its uses. The « territory » and territoriality is here a key research object in an integrated analysis in which GIS and other kinds of models based on spatial representations are playing an important role (horizontal approach),
- The various policies (prices, credit, land ownership, labor migration, etc.) influencing the behavior of stakeholders and affecting their reactions to uncertainty.

For each point of view, the analysis can concentrate on the current situation, however, past events are also taken into account to understand the causal mechanisms that let to it. The integration of the findings from these three points of view guarantees that the main stakeholders involved in the dynamics of the agricultural system and the interactions among them are accounted for. By giving importance to the social demand and the stakeholder expression at the regional/territorial level, the research process tends to switch from a supply-driven (or top-down) to a demand-driven (or bottom-up) one. The overall diagnosis leads to a model of the region's current mode of operation that can be used to build scenarios about its possible evolutionary trends according to various changes in its technical, social, economic and policy contexts. Depending on the common vision and agreement among stakeholders about the future desirable state of the agricultural system, key sub-systems are identified for improvements through research and development activities. They usually lead to new knowledge (several disciplines are highlighted such as geography, cognitive sciences, modeling and simulation of complex systems, etc.) and modes of organization for the exploitation of natural resources with multiple uses.

Past experiences have shown that one of the broad questions that an ecoregional research program has to answer is often: what appropriate coordination mechanisms should be put in place among the increasing number of different stakeholders affecting the functioning of the agricultural system to bend some of the current practices toward a more productive but also sustainable use of natural resources? The linkage between ecoregional research and the need for "doubly green revolutions" (Conway 1995; Weber and Griffon 1995) is here clear. If such "doubly green revolutions" need to be even more productive than the previous "green revolution" to cope with demographic, economic and social challenges, they also aim at contributing to sustainable food security and alleviation of poverty in developing countries through increasing the productivity of scarce resources and conserving the natural resource base. So they should also be "evergreen" by better conserving natural resources and the environment. To emerge and disseminate, they require both technical innovations and innovative partnership mechanisms.

- Example: Use of multiple diagnoses at different scales in upper northern Thailand (Trébuil *et al.* 1997).

Programs and initiatives with an ecoregional approach to research can serve as vehicles for the development of problem-based Integrated Natural Resources Management research and be strengthened by such association of activities.

Integrated Natural Resources Management (INRM)

Although no universally accepted definition of INRM exists, generally this term can be defined as the "responsible and broad-based management of the land, water, forest and biological resource base (including genes) needed to sustain agricultural productivity and avert degradation of potential productivity" (http://www.inrm.cgiar.org 2000). INRM research should be more integrated to achieve holistic understanding of agro-ecological systems and their dynamics (Kam *et al.* 2000). Ideally, INRM aims for increased output without resulting in greater environmental degradation and riskier livelihoods systems. This is often achieved by diversifying options and activities available to resource-poor farmers.

- Example: crop/activities diversification process in Mae Salaep watershed and their positive effects on erosion risk (Trébuil *et al.* 2000).

INRM research and development activities should provide a basis for the sustainable development of agriculture and other renewable natural resources and provide the context to help maximizing the impact of component research (such as soil and water conservation and watershed management policy in our example). But research concerned with NRM also needs to be set in a broader an more integrated context encompassing the social and environmental dimensions of agroecological systems. INRM research needs to propose new models to represent them and their dynamics, and to help monitoring changes in the interactions between society and its environment in order to point in a timely manner to potential crises in the management of renewable resources. INRM research should also involve all concerned stakeholders and be widened beyond agricultural issues to address the multi-functionality of the rural environment to better contribute to poverty eradication, food security and environmental sustainability. In the recent past, despite successful experiences in IPM and FSRD, progress in achieving this objective has generally been slow. Today, major advances in INRM science could help improving this situation as a number of emerging issues are making the need for a stronger INRM contribution even more urgent (Table 1).

Ideally, INRM also aims at better (in quantity, as well as quality terms) outputs without environmental degradation and riskier livelihoods. When successful, usually INRM research can achieve these objectives by diversifying the options available to farmers and by proposing multi-activity, multi-function farming systems. The complementary, and even sometimes similar, roles of the above-mentioned four types of agricultural research approaches is obvious. While all of them adopt a systems perspective, they are implemented at different levels in the systems hierarchy (Kam *et al.* 2000). As agricultural research institutions are increasingly conscious of the role they must play in responding to the social demand, all of them can still improve their partnership arrangements with development-oriented organizations. Nowadays, most of the time, such arrangements need to go beyond the classic NARS institutions to include the private sector and NGOs. Recent years have seen a growing recognition of the need for collective, interdisciplinary organization of research planning, implementation and monitoring-evaluation of activities that need to be based on the analysis of stakeholders needs and on jointly defined clear objectives.

Principles and Steps of INRM Research with an Ecoregional Approach

Some of the conceptual underpinnings of INRM research are:

- That ecological sustainability underpins economic and social sustainability, and is necessarily linked to the ability of the agroecosystem to adapt to change and to be resilient,
- That agroecosystems being dynamic systems, research cannot aim at identifying the set of conditions bringing them to an optimal equilibrium state, but should help stakeholders in managing the effects of their degradation, or even collapse, and in exploring ways to recovery and rejuvenation,
- The resilience of the agroecosystem is enhanced if the different users of the resource base and their organizations also have a high adaptive capacity (CGIAR 2000),

One can say that INRM research entails adaptive management in an integrative and truly participatory, social learning mode of operation. In that sense, and because this kind of research has to address multiple stakeholders’ interest, often with contrasting objectives and strategies, participation, coordination, negotiation and mediation are key words in INRM research.

INRM research projects with an ecoregional approach should satisfy several general criteria (CGIAR 1999):

- Be action research oriented and conceived in a truly collaborative and equitable manner,
- Be agent/actor-centered with all concerned stakeholders represented, and incorporate the inputs of all of them in the formulation of an initial common vision and diagnosis on the problem to be addressed,
- Generate new knowledge based on both indigenous and scientific knowledge from the diverse relevant disciplines,
- Be able to work at all appropriate intervention points along the research-development continuum,
- Effectively communicate results and conclusions to all concerned stakeholders,
- Strengthen institutions, from local to policy levels, to improve capacity to implement future INRM research and to disseminate research results.

INRM research and development programs should also meet several more specific criteria such as (CGIAR 1999):

- The research component must be people-centered and problem-oriented and address the links between natural resource degradation and its root causes, especially the understanding of the interactions between ecological/biophysical changes and socio-cultural and economic dynamics,
- It should utilize interdisciplinary and participatory research approaches that:
  - draw on the tools and methodologies of integrative sciences, particularly modelling and simulation of complex systems,
  - enhance a process of balanced, two-way, communication among scientists and concerned stakeholders to favor the integration of indigenous and scientific knowledge and experiences,
- Respect and strengthen the rights of the poor to natural resources and knowledge,
- Diagnose and characterize problems in terms of ecosystem functions and services across a range of relevant spatial and temporal scales, and develop management practices that integrate productive human action and environmental functions at ecosystem and landscape scales.
- Understand the interactions between biophysical properties and socio-economic processes that determine the agroecosystem function and viability, and bring this understanding to the attention of resource users and managers,
- Strive to strengthen the generalizability of research products, so that they may be extrapolated beyond specific sites and conditions to see their effects and impact multiplied,

- Lead to the development of economic and social systems and management practices that integrate farmers' production practices and environmental functions at agroecosystem and landscape levels through the appropriate use of biological, human and manufactured inputs to provide goods and environmental services.

These principles and criteria aim at providing an effective systems approach to the design of balanced programs and an appropriate framework for addressing natural resources management and agricultural systems issues, particularly poverty elimination, in complex agricultural settings. Such programs will need to set up an "integrated management system", based on multi-sector criteria and objectives and to provide adapted tools for its operation.

The possible steps of such an action-research and problem-focused approach along an R&D continuum could be as follows:

- Definition of the concrete, major, problem to be solved, and its translation into a workable research question,
- Diagnosis on constraints and opportunities for INRM linked to the social structure: identification of intervention points at any level of the systems hierarchy (field, farm, watershed, community, region, etc.) offering a chance to address this problem (including institutional and policy arrangements when needed to create desired changes in farmers and/or community behavior resulting in positive changes of bio-physical processes, system productivity, resource quality, etc.).
- Assembling of the local and scientific thematic knowledge and measurement tools needed (from natural resource dynamics and environmental processes to stakeholders' strategies regarding the exploitation of resources, etc.) to understand the cause and effect processes at all pertinent scale of analysis. Representation and modeling of these processes through back and forth process between the field and the computer.
- Tools and means to provide useful and efficient environmental information to stakeholders for them to be able to make informed decisions and to improve the coordination of their actions: modeling of complex systems, interfacing and information systems on the environment, tools for knowledge transfer, relevant indicators of sustainability for a monitoring and evaluation system, impact assessment, etc.

Obstacles to the Adoption of INRM Research Methodologies

Because it is dealing with complex systems and issues, some people are questioning whether research on INRM can deliver the goods. The fact that, beyond the site specificity of local experiences, INRM research is capable to benefit large numbers of resource-poor rural people across large areas and within sensible time frames needs to be reaffirmed. To facilitate the achievements of INRM research objectives, it is cautious for a given program to focus on a major and concrete issue. It is also necessary to strive to strengthen the generalizability of results, so that they may be extrapolated beyond specific sites and conditions.

R & D institutions will need to adapt their management style from a “commodity” or “disciplinary” culture build up over many years of operation to embrace the goal of INRM and of achieving sustainable productivity gains without the risks of negative social and environmental impacts. The skills mix of senior scientists and managers of most key agricultural R & D institutions is still biased toward the “hard” side of the land and productivity enhancement. Ecologists, social scientists and specialists in “integrative sciences” are still very much underrepresented. This is a pity as many current challenges and issues require the guidance of social scientists (see for example the on-going heated controversies about GMO, biodiversity, climate change, etc.). Innovative methodologies are urgently needed to conceive, to test and to adopt tools allowing the integration of social science with technical knowledge in the process of designing pertinent NRM methods with concerned stakeholders. More “open” research systems will also be needed as the complexity of the problems to be addressed will call for forming alliances with partner organizations with complementary skills and resources, including private sector and NGO institutions. Such alliances, can enable a leading institution to tap specialist expertise not available among their staff. But it is also true that such alliances implies increased transaction costs, competition for funding and tensions over the “ownership” and governance of the programs and projects.

INRM research needs to be organized and implemented by truly interdisciplinary teams, adopting participatory action research and collective learning as their main mode of operation. The activity evaluation system needs to be adapted to this mode of organization and operation. But to be recognized, participatory research activities in the context of multiple partnership should adhere to the same scientific standards than other kind of research. The recent review of the CGIAR ecoregional programs has shown that this objective could be better achieved if a clear scientific leadership is in place, as well as an efficient mechanism to facilitate collaborations in the planned research activities. Sometimes, it will be important to re-think and to precise the role of scientists intervening in decision making processes through interdisciplinary teams and in the context of multiple partnership. Quite often, “solutions” will be inspired by farmers’ initiatives and knowledge, the researcher playing mainly a supportive role to accompany stakeholders’ projects and to reinforce their capacity to manage complex situations and to facilitate their access to the relevant information complementing their own knowledge.

Conclusion

A key objective of INRM research is to identify dynamically the conditions for a co-viability of bio-physical dynamics and socio-economic and institutional transformations of agricultural systems that could help to eliminate poverty on one side while preserving the resource base on the other side. To achieve such a goal, innovative inter/transdisciplinary research frameworks are necessary to integrate knowledge across bio-physical sciences, ecology and social sciences at several pertinent and complementary levels of the systems hierarchy.

To go beyond the site specificity of INRM experiences, these new approaches should facilitate the emergence of networks and flexible collaborative systems, through communication facilitation. In the same way, scientific analysis based on new research tools that are now available could also help by identifying general trends, models and frameworks having extensive domains of application.

It is very important to fill the existing gap between the technical work regarding the conception and development of sophisticated integrated and explanatory models, the social demand concerning NRM major issues and the realities of policy decision making. One way toward achieving this objective could be the design and implementation of approaches, methodologies and tools facilitating a more evolutionary, adaptive and participatory kind of decision-making support than what could be observed in the recent past. Before to be implemented, these interdisciplinary system approaches need first to be negotiated with stakeholders.

Methodological questions remain to be solved regarding the feasibility and procedures on how to practically use modeling and simulation approaches with stakeholders. The kind of "ecological engineering" approach adopted by INRM researchers working at the interface between human and natural sciences will not be able to avoid fundamental questions such as: how decisions should be made and by whom? How to balance the adhesion to "quality science" and "quick and dirty" approaches, that are sometimes very efficient depending on the problem at hand?

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