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Synthesis of methodology development and case studies

Terminal Programme Report

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SysNet is a systems research network established to develop methodologies for determining land use options and to evaluate these methodologies for generating options for policy and technical changes in selected areas.

SysNet is co-ordinated by the International Rice Research Institute (IRRI). The following main NARS partner organizations participate in the SysNet project:

India:	Indian Agricultural Research Institute (IARI) of Indian Council for Agricultural Research (ICAR)
Malaysia:	Malaysian Agricultural Research and Development Institute (MARDI)
Philippines:	University of the Philippines at Los Baños (UPLB)
	Philippine Rice Research Institute (PhilRice)
	Mariano Marcos State University (MMSU)
Vietnam:	Cuu Long Delta Rice Research Institute (CLRRI)

Collaborating institutions within the Wageningen University and Research Centre (Wageningen UR), The Netherlands, include:

- Alterra
- Plant Research International
- Crop and Weed Ecology Group
- Plant Production Systems Group

Acronyms

AEU	agro-ecological unit
CERES	crop estimation through resource and environment synthesis
CLRRI	Cuu Long Delta Rice Research Institute
DSS	decision support system
FHM	farm household modelling
GIS	geographic information system
IARC	international agricultural research centre
IARI	Indian Agricultural Research Institute
ICAR	Indian Council for Agricultural Research
IMGLP	interactive multiple goal linear programming
IPM	integrated pest management
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
LGU	local government unit
LUPAS	land use planning and analysis system
MADA	Muda Agricultural Development Authority
MARDI	Malaysian Agricultural Research and Development Institute
MGLP	multiple goal linear programming
MMSU	Mariano Marcos State University
NARS	national agricultural research system
NGO	non-governmental organization
NRM	natural resource management
PA	participatory approach
PhilRice	Philippine Rice Research Institute
QUASI	quantitative analysis of agro-ecosystems
R&D	research and development
SARD	sustainable agriculture and rural development
SARP	simulation and systems analysis for rice production
SSNM	site-specific nutrient management
SUCROS	simple and universal crop growth simulator
UI	user interface
UPLB	University of the Philippines at Los Baños
WOFOST	crop growth simulation model for world food studies
WUR	Wageningen University and Research Centre

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Foreword

The change in the research agenda of international agricultural research centres such as the International Rice Research Institute during the past 20 years went unnoticed by many. The increased influence of stakeholders, the broadening of objectives, the nature of research and the mode of operation of these institutes were all part of a reorientation and reformulation of the position of the international centres.

The need to strengthen technology-pull instead of technology-push, the stronger influence of demand and the emphasis on higher aggregation levels and policy-oriented studies had a distinct effect on the priorities of the research agenda.

IRRI has become more and more a centre based on two main pillars: conservation, exploitation, exploration and management of genetic resources and management and exploration of (other) natural resources.

Especially the second pillar became a core business during the past decade. This makes IRRI more and more a hybrid centre that will continue to play an important and indispensable role in international agricultural research and innovation in the developing world, especially in Asia. It is the answer to important questions raised in the 21st century. An instrument in these activities is the ecoregional programmes IRRI started in South and Southeast Asia.

Building on experiences with systems research programmes such as SARP in various countries of Asia, the new approaches implemented with the SysNet project became successful in a very short time. In a period of less than four years, methods and tools integrating socioeconomic and biophysical information for ecoregional programmes were developed and implemented in different places. SysNet shows how these methods help to strengthen and deepen policy discussions and enable better decision making on land use and resource management. This report demonstrates that the required involvement of various stakeholders, the commitment of farmers and their representatives and the demand-oriented research of the scientific community all lead to an upgrading of ecoregional programmes.

Although the various contributions to this final report show work in progress that will be continued by IRRI and the national agricultural research systems (NARS), it is now already clear that the project has had more impact than expected. It illustrates convincingly that IRRI, with the support of Wageningen University and Research Centre, has played its role as a strong partner of the NARS and other users in developing and facilitating dissemination of the newly attained insights, knowledge and expertise.

Ronald P. Cantrell	Rudy Rabbinge
Director General, IRRI	Wageningen UR

Preface

The 'Systems Research Network for Ecoregional Land Use Planning in Support of Natural Resource Management in Tropical Asia (SysNet)' was financed under the Ecoregional Fund, administered by the International Service for National Agricultural Research (ISNAR). The objective of the project was to develop and evaluate methodologies and tools for land use analysis, and apply them at the subnational scale to support agricultural and environmental policy formulation.

In late 1999, when the financial support from the Ecoregional Fund formally ended, IRRI organized an international symposium, in which the project's achievements were presented, with active participation of scientists, (representatives of) stakeholders of the four study regions (Haryana State, India; Kedah-Perlis Region, Malaysia; Can Tho Province, Vietnam; and Ilocos Norte Province, Philippines) and parties interested in land use analysis and planning. The proceedings of this symposium has been published as SysNet Research Paper Series No. 2, 'Systems research for optimizing future land use in South and Southeast Asia'. In this proceedings, the land use planning and analysis system (LUPAS) and its component models, developed in the framework of SysNet, are extensively described, as well as various scenario studies for the four case study regions.

The Ecoregional Fund approved a budget-neutral extension of the project until June 2000 and both the International Rice Research Institute (IRRI) and Wageningen University and Research Centre (Wageningen UR) committed additional funding to allow the project teams to properly finalize the project through additional improvements in the methodology and adequate reporting.

In the external project review that was carried out parallel to the symposium, one of the recommendations was 'Give higher priority to ensuring that planners and policymakers actually use the methods developed. (...) Involvement of intended users in development and testing of methods should be intensified. Presentation of outputs should be simplified for the benefit of users'.

In response to this recommendation, the period between October 1999 and June 2000 has been used by the participating scientists to improve and extend the site-specific LUPASs, to carry out additional scenario studies, in consultation with key stakeholders, and to develop a user interface for Ilocos Norte and Kedah-Perlis that allows policymakers and other end-users to compile new scenarios, run the model and display the results. A CD-ROM has been prepared that contains all the tools developed within the project period.

In this volume, the highlights of the project period are illustrated through presentations of the results of the most recent scenario analyses for the four case study regions. Subsequently, special attention is paid to the developments in the extension period, focusing on the development and description of the user interface and interaction with the stakeholders in the case study areas. The volume concludes with a brief outline of the most important challenges ahead.

We would like to take this opportunity to thank the four national team leaders, Drs. Pramod Aggarwal (India), Felino Lansigan (Philippines), Ismail Abu Bakar (Malaysia) and Nguyen Xuan Lai (Vietnam), for their enthusiastic participation in the write-up of the scenario studies.

We also thank the national agricultural research systems, the Indian Agricultural Research Institute (IARI), Malaysian Agricultural Research and Development Institute (MARDI), University of the Philippines at Los Baños (UPLB), Philippine Rice Research Institute (PhilRice), Mariano Marcos State University (MMSU) and Cuu Long Delta Rice Research Institute (CLRRI) for their unwavering support for the activities of the teams.

The International Rice Research Institute and Wageningen UR, in particular Alterra, Plant Research International and the Plant Production Systems and Crop and Weed Ecology groups of Wageningen University, are gratefully acknowledged for their willingness to make funds and capacity available for these final stages of the project.

A special word of thanks is extended to Alice Laborte, Peewee Cabrera, Benjie Nunez, Cecilia Lopez and Arlene de la Cruz from the IRRI SysNet staff for their untiring support at all times.

The Ecoregional Fund, its International Scientific Advisory Committee (ISAC) and its managing agency, ISNAR, are acknowledged for their financial support and counsel. Deserving of special mention are the former and present Chairman of ISAC, Prof. Dr. Rudy Rabbinge and Prof. Dr. Johan Bouma, and Drs. Christian Bonte Friedheim and Stein Bie, Directors-General of ISNAR during the project period. We also would like to thank Dr. Miguel Vatter, the ISAC Executive Secretary, for his support.

Finally, we sincerely hope that research and development with respect to interactive land use planning and analysis, as part of ongoing efforts in integrated natural resource management, a key factor in improving the livelihood of a majority of the rural population in developing countries, will have received a major boost through SysNet efforts and will continue to be in the forefront of interest for investors and research organizations.

Los Baños, October 2000 The Editors

Executive summary

Background

Currently, methodologies and tools for land use systems analysis at various levels of integration are under development. This has been stimulated by the United Nations Earth Summit on 'Environment and Development', the introduction of new concepts in land use planning during the 1990s and, last but not least, the establishment of 'Ecoregional Initiatives' worldwide.

The Ecoregional Fund was founded in 1995 with the explicit objective of supporting research on the development of methodologies required by initiatives aiming at sustainable agriculture and integrated rural development.

In late 1996, the SysNet project was launched as the first methodology development project under the umbrella of the IRRI coordinated Ecoregional Initiative for the Humid and Subhumid Tropics and Subtropics of Asia. The project is also a major component of IRRI's core project on 'Implementing ecoregional approaches to improve natural resource management in Asia' (CE6).

Growing populations and urbanization, and expanding economies are characteristic of the situation in South and Southeast Asia. Agricultural systems are being challenged by the requirements of increased productivity, more diversified products and reduced environmental impact. This leads to potential conflicts in land use objectives and resource use among the various stakeholders. In many parts of South and Southeast Asia simultaneously, trends to further intensify and diversify can be observed. The gains in productivity and consequences for environmental impacts of these developments are unknown. Effective land-use planning and (future-oriented) resource analysis at different scales can help to make the issues transparent in the search for feasible solutions.

SysNet is a systems research network established to develop methodologies and tools for exploring future land use options in selected areas of South and Southeast Asia with emphasis on the subnational scale (provinces, states). Case study areas include Haryana State in India, Kedah-Perlis Region in Malaysia, Ilocos Norte Province in the Philippines and Can Tho Province in Vietnam. SysNet is based on the premise that planners and policymakers need systems analysis methodologies and tools, since the complexity of the problems is such that it is no longer sufficient to evaluate land-use options at the field or farm level.

Objectives and expected outputs

- *Objective 1*: To develop a scientific-technical methodology for exploring future options for land use, using crop models and expert systems at the regional (subnational) scale.
- *Objective 2:* To develop an operational methodology and corresponding

system for supporting a network of sites, representing various ecoregions in tropical Asia.

Expected outputs:

- A general methodology for land use planning, models and expert systems for estimating yield at the subnational level.
- Various options for agricultural land use, explored at four representative domains.
- Teams of trained scientists who can apply systems analysis techniques at the regional level, to identify development potentials, opportunities and constraints.

Major accomplishments

In less than four years, significant achievements under each of the expected outputs listed above were made. The project has developed and operationalized a common modelling framework for land use planning and analysis system (LUPAS), including comprehensive databases and modelling components (tools), tailored to the specific situation of the individual (four) case study areas. The tools developed include database management systems, crop models to estimate yields, expert systems, geographic information systems (GIS) for quantitative description of production activities, and for land evaluation and assessment of resources, and linear programming models for regional optimization of land use under multiple objectives. These components plus databases on biophysical and socioeconomic conditions and policy views were integrated to form LUPAS. Development and evaluation of LUPAS for the four study regions were carried out by country teams, each comprising scientists from 7-8 disciplines, supported by an IRRI team and scientists from Wageningen UR, The Netherlands. The 'highlights', i.e., LUPAS land use scenario analyses, are presented in this report.

Evaluation of LUPAS and its further development as a decision support system (DSS) for strategic planning for the agricultural sector were done in close interaction with key stakeholders from the study regions. The aim of the DSS (recently realized for two case studies) is to provide policymakers and planners with quantitative information that enables them to examine different land-use scenarios, and the probable consequences of their decisions on agricultural production and land use in the region. All tools developed under the SysNet umbrella have been compiled on CD-ROM. A short description of the tools and a list of SysNet publications are given in Annexes 1 and 2.

Scientific-technical innovations realized during 1996-99 include

- SysNet's integrative approach to the development of a generic land use planning and analysis system (LUPAS).
- Progressive involvement of local scientists and stakeholders in developing and evaluating specific modelling systems and tools, tailored to the information needs in four study regions.

During its 8 months' extension (Nov. 1999 - June 2000) the project concentrated on

- Documenting tools developed and presenting project results to a wider scientific and non-scientific audience,
- Fine-tuning and tailoring its tools to the specific questions and needs of users, and making tools and scenario analysis results widely accessible (via SysNet Web-site and CD-ROM) and, finally,
- Discussing results with key policymakers and planners of the study regions.

The latter activity led SysNet teams into new terrain. It initiated an exciting process of interactive policy design with key stakeholders and planners in the various regions.

Lessons learned

1. There is a need for new land-use planning methodologies and applications in Asia.
2. A better definition and identification of stakeholders and end users are needed at the inception of projects aiming at development and/or implementation of a DSS for land-use planning.
3. It is of utmost importance to involve stakeholders/end-users from the beginning in the design and to have frequent interactions between research teams and other stakeholders during development of the DSS.
4. Once a prototype DSS (LUPAS) was developed, it served as a vehicle to exchange information and knowledge and stimulate discussion among different stakeholder groups on land use and related policy issues.
5. In SysNet, LUPAS also functioned in building systems research capacity and fostering interdisciplinarity within research institutions (e.g., the newly formed multidisciplinary teams were later institutionalized at IARI and MARDI). The capacity to transfer the methodology to local planning agencies has been created. But the effective project time span (of 3½ years) was too short to start the process of methodology transfer – which now rests with the individual NARS partners.
6. Only a handful of the stakeholders involved in each case study were identified as direct end-users of the methods and tools. In one case this referred to the officers from the Department for Planning and Investment (e.g., Vietnam), in another case principal officers from the provincial planning and development office or key advisors for agricultural programmes (e.g., Philippines).
7. Considerable investment in training, planning and establishment of partnership is required before fruitful synergies in methodology development by a network fully come to the fore.
8. Initiation of a fruitful process of interactive design of future land use options and policies requires confidence of stakeholders in a well-tested methodology and tools.

SysNet has developed its methods in the context of practical application and, hence, contributed to the mutual understanding of scientists developing such methods and planners and policymakers that could benefit from their use and the information generated. The various project stages and milestones that led to the various outputs, presented in this report, are depicted in Figure 1.

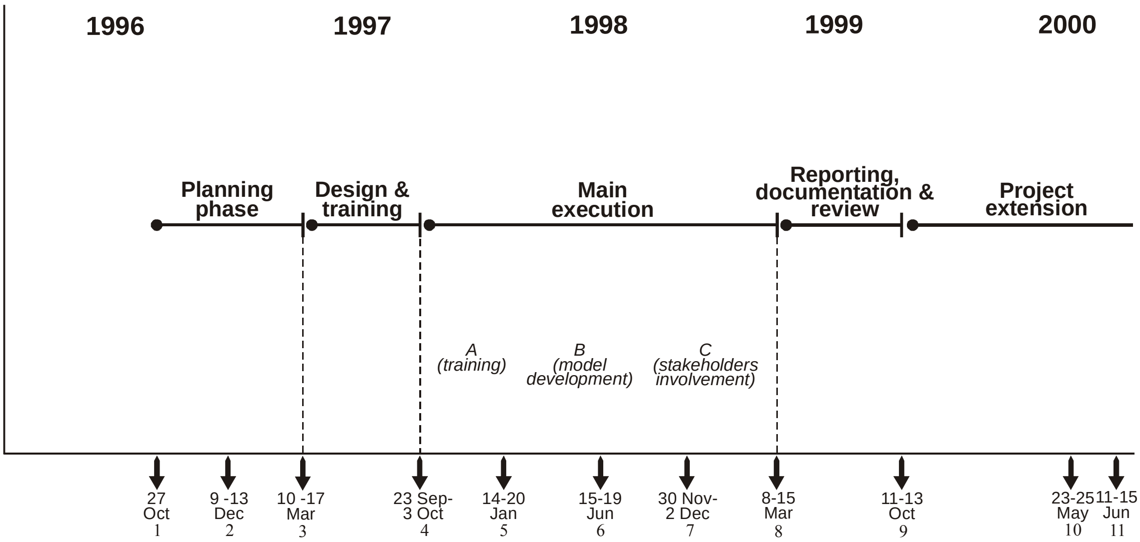

Figure 1. SysNet project stages, October 1996 – June 2000.

Keys to Figure 1:

1 SysNet Agreement between IRRI and ISNAR signed in Washington, D.C., USA (27 October 1996).
2 Systems Approaches Planning Meetings at IRRI, with 37 participants from 8 countries, 9-13 December 1996.
3 Start of SysNet partner country training workshops (4) on simulation models, GIS and linear programming, at IARI, New Delhi, India, 10-17 March 1997.
4 End of first training cycle with a joint workshop on multiple goal linear programming (MGLP) at IRRI, Los Baños; four NARS SysNet teams, IRRI and Wageningen experts, October 1997.
5 Start of first round of interactive stakeholder-scientist workshops (4) at Batac, Ilocos Norte; 70 participants, January 1998.
6 SysNet International Workshop on Methodology Exchange in Land Use Planning in Can Tho Province; 180 participants from 7 countries, 15-19 June 1998.
7 SysNet Technical Review Workshop, 30 participants from 7 countries, Bangkok, Thailand, 30 November-2 December 1998.
8 Start of second round of stakeholder-scientist workshops (4) at Delhi, India, March 1999.
9 SysNet International Symposium on 'Systems Research for Optimizing Future Land Use' (SysNet'99) plus project Phase I review and planning for year 2000 and beyond, IRRI, Los Baños, Philippines.
10 Final stakeholder meetings for Ilocos Norte Province, Philippines.
11 Final stakeholder meetings for Kedah-Perlis Region, Malaysia, and Can Tho Province, Vietnam.

Project overview and highlights 1996-1999

Challenges, project strategy and major accomplishments

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Background and challenges

South and Southeast Asia are characterized by growing populations and increasing urbanization. Rapid population growth coupled with economic expansion is increasing the demands on land not only for agriculture but also for housing, infrastructure, recreation and industry. This is accompanied by increasing and competing demands on water supplies and other natural resources. The agricultural sector is being challenged by the requirements for increased (land and labour) productivity, more diversified products and reduced environmental impact. These developments create conditions for potential conflicts in land use objectives among various interest groups (or stakeholders). This calls for effective tools for resource use analysis to support decision making with respect to land use. These tools should have the capabilities to

- Identify potential conflicts in rural development goals, land use objectives and resource use,
- Identify technically feasible, environmentally sound and economically viable land use options that best meet a well-defined set of rural development goals, and
- Widen perspectives of stakeholders through learning about possibilities and limitations within the agricultural land use system, thus contributing to a more transparent policy-making process.

The big challenge for agricultural research and development is thus to find solutions that best match the multiple development objectives of rural societies (e.g., increased income, employment, improved natural resource quality, food security) with the multiple functions of agricultural land use and production systems. Finding such solutions has numerous dimensions.

Many of the agricultural regions in South and Southeast Asia characterized by (intensive) rice-based agro-ecosystems provide striking examples of conflicts in agricultural land use objectives. The need for crop diversification to increase labour productivity and farmers' income and prevent migration to the (rapidly expanding) mega-cities is often in direct conflict with the necessary increase in (staple) food production and maintenance or improvement of the quality of the natural resource base (soil, water, air). The introduction of technically feasible and socially acceptable improved (resource-use efficient) management practices (technologies), supported by adequate policies, might considerably reduce these conflicts. The sooner such practices are adopted, stimulated by appropriate policies, the greater the (potential) benefits to both farmers and local governments.

Land use systems analysis, directed to the question of how to match the quality of the natural resources with the various societal demands placed on them, can provide quantitative information on optimum (agricultural) development goal achievements and associated land use options under a given set of (multiple) objectives and constraints, and on trade-offs between various land use objectives. For such research activities to be effective, they need to be dovetailed with (and, ideally, be part of) processes of policy design, decision making and negotiation on resource management at different levels, and prioritization of agricultural research activities. The primary tasks for (interdisciplinary) land use systems research teams remain, however, to generate scientifically sound information on feasible land use options and facilitate exchange of this among the various stakeholders (scientists from various disciplines, planners, policymakers at different levels, farmers – to name a few important interest groups/actors) in the rural development process.

This defines the important issues in (sustainable) land use and food security for South and Southeast Asia and the big challenges. But how do these issues unfold in the local context and how can the challenges be met under different biophysical, economic and socio-cultural conditions?

In late 1996, the 'Systems research network for ecoregional land use planning in tropical Asia' (SysNet) was launched as a methodology development project in support of the IRRI coordinated Ecoregional Initiative for the Humid and Subhumid Tropics of Asia (EcoR(I)). The project was expected to contribute to the design, exploration and evaluation of land use options at higher integration levels. Specifically, its objectives were to develop methodologies and tools for exploratory land use analysis, and to evaluate these for generating options for policy and technical changes. To realize these objectives, SysNet set up four case studies at a subnational scale: Haryana State in India, Kedah-Perlis Region in Malaysia, Ilocos Norte Province in the Philippines and Can Tho Province in Vietnam (Figure 1).

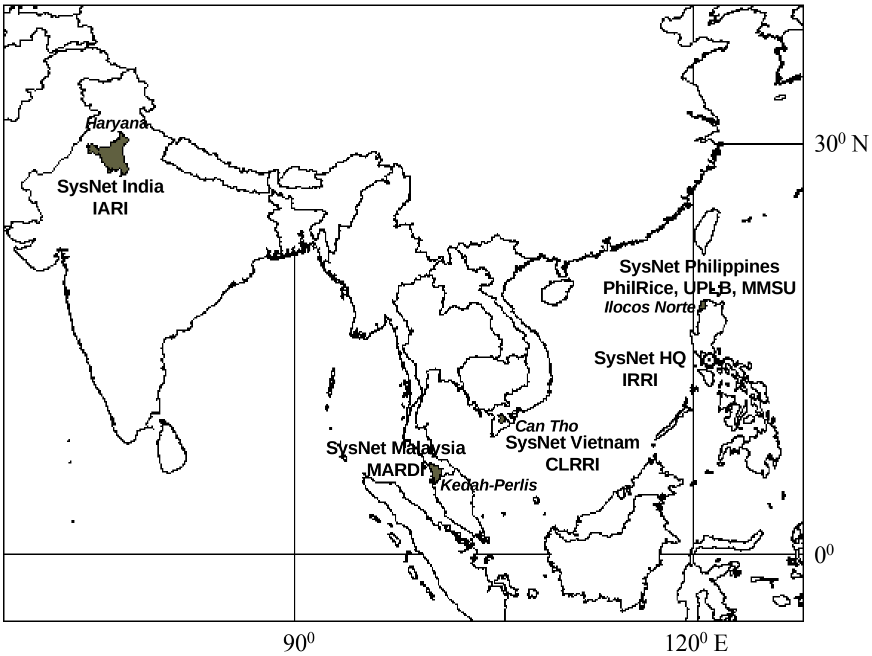

Figure 1. SysNet research partners and study regions.

Project design, strategy and major accomplishments

Initial project design

The project's original design is outlined in the proposal submitted by IRRI to the Ecoregional Fund dated 20 September 1996. In the project's logical framework, the stated goal is to support decision making at the regional (subnational) level on sustainable agricultural development, natural resource management (NRM) and land use in the humid and subhumid tropics of Asia. The *purpose* is to develop, exchange and apply systems methodologies for improving the scientific basis for land use planning aimed at sustainable NRM and agricultural development in the same area. To achieve these higher-order objectives, two lines of work are proposed:

- Development of a 'scientific-technical methodology' to explore land use options using crop models developed for different scale levels; and
- Development of an 'operational methodology' to support the cooperation needed in a network to address issues at multiple sites, representative of the humid and subhumid ecoregions of tropical Asia.

For the first line of work, the logical framework identified two expected outputs: (*i*) crop models evaluated for yield estimation at different scale levels and (*ii*) options for agricultural land use explored at four representative sites in Asia. A single expected output was identified for the second line of work: teams of scientists that could apply techniques of systems analysis at the regional level.

The programme design assumed that available methodology was suitable for providing quantitative estimates on alternative land uses. It also assumed that national or regional decision makers would participate in goal definition and would use outputs of the modelling exercise in decision making.

Important adjustments in project design

Crucial to the planning of the project's agenda was a December 1996 workshop in which IRRI and NARS scientists met with Wageningen collaborators. During this meeting, the project design was modified in some important ways. SysNet scientists realized that the two crucial assumptions outlined above were questionable. Available quantitative methodology was not, in fact, adequate to achieve the program's objectives. Furthermore, planners and policymakers could not be expected to use the outputs of land use models unless they developed confidence in the modelling tools, understood the outputs and were able to incorporate them in their decision-making process.

Three distinct design changes were introduced into the project over time. Early in project implementation, the SysNet team shifted its scientific-technical focus from application and refinement of crop simulation models and their integration at cropping-system and regional levels to the development of an integrated land use planning and analysis system (LUPAS) at the subnational (province or state) level. The consequence of this change was that SysNet embarked on a *much more complex, ambitious and innovative process* of methodological development.

The second major design change involved SysNet's training strategy. Originally, training was viewed as a means of transferring knowledge from scientists based in IRRI and Wageningen to their counterparts at the study sites in Asia. But, during implementation of the project, it evolved into a means of mutual learning and joint development and testing of LUPAS methodologies. When the scheduled sequence of training courses (March – October 1997) started, team coordinators and participants soon realized that these events would need to go beyond training and include hands-on work in model building and data estimation. Team coordinators responded by adding development workshops, in which scientists from IRRI and the national groups worked together to develop LUPAS models adapted to the specific conditions of each of the study sites. As a result, the training events evolved into venues for mutual learning and development of the LUPAS methodologies.

The third design change involved broadening the networking strategy to involve stakeholders in the development and adaptation of the LUPAS models. Initially, stakeholders were informed about the project activities in their region. Gradually, however, they were increasingly involved in identifying priorities for model development, gathering relevant data and evaluating the models' outputs (Figure 2). As a result of stakeholder involvement, SysNet was confronted with the practical concerns and interests of land use planners and policymakers much earlier in the process of methodology development than otherwise would have been the case.

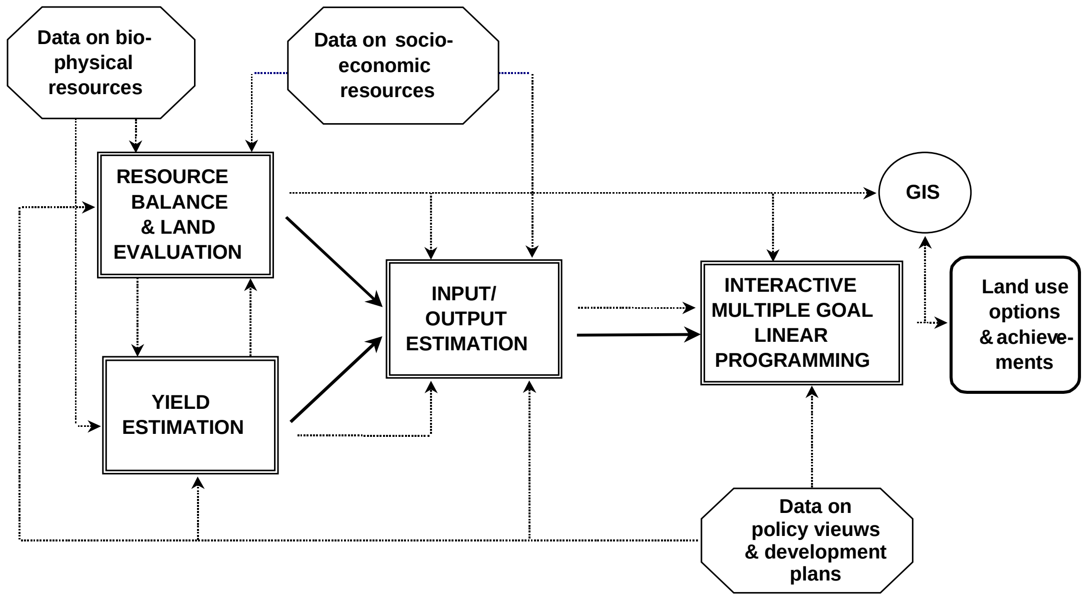

Figure 2. Structure of the LUPAS modelling framework.

Consequently, during the first year of project implementation, SysNet objectives, strategies and expected outputs were revised as follows:

- *Principal objective*: To develop and apply methodologies to analyse future options for land use and NRM at the regional scale to guide policy changes and to assess the scope for agricultural development beyond the constraints of current agricultural and environmental policies.
- *Strategy*: To present an operational methodology and corresponding system for quantitative land use planning at the regional level, and to elaborate and apply the methodology in close interaction with stakeholders in four representative regions.
- *Expected outputs*:
    - A general methodology for land use planning, models and expert systems for estimating yield at the subnational level.
    - Various options for agricultural land use, explored at four representative domains.
    - Teams of trained scientists that can apply systems analysis techniques at the regional level, to identify development potentials, opportunities and constraints.

Major accomplishments

In less than four years, significant achievements under each of the expected outputs listed above were realized:

(1) Methodology and tools:

- Estimates of actual and potential yields for 60 annual and perennial crops in diverse environments (MGLP databases).

- WOFOST (version 7): an improved generic crop growth model with documentation and users' manual.
- Progress in developing a general methodology for land use planning, using ultiple goal linear programming (MGLP) techniques for exploring land use options (LUPAS); and in developing the component modules to make the operation of the system easier and more flexible, e.g., AGROTECH, CASS, TECHNOGIN, three technical coefficient generators (for case studies in Can Tho, Haryana and Ilocos Norte, respectively); MAPLINK, a component linking model outputs and inputs to GIS; and user interface (Web application) for interactive land use scenario analysis (realized for case studies in Ilocos Norte and Kedah-Perlis).
  (http://irriwww.irri.cgiar.org/IRRIIntra/sysnet/mglp/SysNetMGLP.htm)
- A significant scientific contribution in the form of high-quality publications.

(2) Exploration of land use options:

- Exploratory land use studies have been executed for four case study areas.
- Results of scenario analyses for the four case study areas have been presented and discussed with stakeholders.
- Reports on the four regional case studies were presented during the SysNet symposium in October 1999, proceedings were published and various detailed case study reports are in preparation.
- Numerous scenario analyses results for Ilocos Norte and Kedah-Perlis are accessible via the Internet (see URL address above); for these two case studies, a user interface is available (at the moment restricted to local a Web server; CD-ROM available to SysNet collaborators) that allows policymakers and other end-users to compile new scenarios, run the model and display the results.

(3) Trained scientists:

- Teams of trained scientists in the collaborating NARS (SysNet) as well as scientists/scholars from IRRI and Wageningen UR able to apply regional systems analysis tools to identify development potentials, opportunities and constraints.

Important means and milestones for realizing these achievements were three international meetings: a training workshop on the interactive MGLP (IMGLP) technique, October 1997; a workshop on exchange of methodologies in land use planning, June 1998; and a symposium on methodology and case study presentation in conjunction with external project review, October 1999. Additionally, an in-country training cycle in modelling components for each

SysNet team (March – August 1997) and three cycles of stakeholder-scientist meetings for each case study (in 1998, 1999 and 2000) ensured timely delivery of project outputs.

Development of SysNet LUPAS

The land use planning and analysis system (LUPAS, Figure 2) developed in SysNet is based on the IMGLP technique (De Wit *et al.*, 1988). Agricultural systems are characterized through

- Databases on biophysical and socio-economic resources and development targets.
- Input-output model for all promising production activities and technologies.
- Multiple criteria decision method (MGLP model).
- Sets of goal variables (representing specific objectives and constraints).

In an iterative approach, modelling components and databases were developed and integrated in LUPAS for exploring alternative land use options for Haryana State (India), the Kedah-Perlis Region (Malaysia), Ilocos Norte Province (Philippines) and Can Tho Province (Vietnam) (Roetter *et al.*, 2000).

In consultations with local stakeholders, agricultural development objectives and constraints related to production, income, employment and environmental impact were identified and translated into scenarios combining multiple objectives; one objective is optimized while minimum requirements are set for others. In successive iterations, goal restrictions are tightened to quantify trade-offs between conflicting goals. The choice and degree of tightening of goal restrictions reflect the specific priorities for sustainable land use. To reach a consensus on feasible options, scenario analyses need to be conducted interactively with different interest groups. To facilitate this negotiation and learning process, SysNet developed the IMGLP user interface (see Laborte *et al.*, this volume and URL mentioned above).

The process (sequence of steps) followed in SysNet for integrating data, information, models and expert systems into a common decision support system for strategic land use planning for the agricultural sector in South and Southeast Asia is illustrated in Figure 3.

The fruits of developing LUPAS, tailoring it to specific local biophysical and socioeconomic settings and policy issues, are presented as case study results in the following four chapters – ‘the highlights’ of SysNet 1996-99.

Contribution to ecoregional R & D

With its advances in quantitative methods for land use planning and analysis in the context of practical application, its interdisciplinary approach and due consideration of economic, technical, ecological and social aspects of land use and the agricultural production process, the project is in full compliance with the

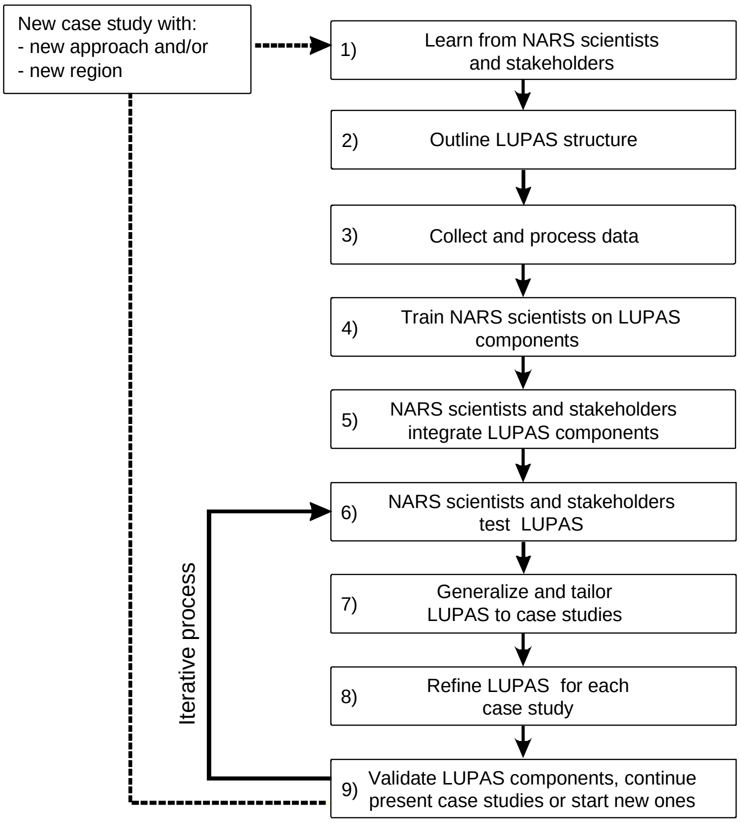

Figure 3. Steps in developing a decision support system for strategic land use planning and analysis.

principles of sustainable agricultural development. Examples are the principles contained in the Rio Declaration on Environment and Development and Agenda 21: Programme of Action for Sustainable Development, in particular with chapter 14 on ‘Promoting Sustainable Agriculture and Rural Development – based on the 1991 Den Bosch Declaration on Sustainable Agriculture and Rural Development (SARD).

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Haryana State case study: Trade-off between cereal production and environmental impact

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Introduction

While in 1965 food grain imports in India reached 10 million tons, during the last three decades due to a quantum leap in production there has hardly been any significant import of food grains. But again, the country is at a crossroads facing tremendous new challenges since food supply grows slower than demand. While the population continues to grow rapidly, stagnation in farm-level productivity is observed, especially in the intensively cultivated irrigated areas. Moreover, withdrawal of agricultural lands for urban uses and declining profitability of (staple) food production relative to other, competing agricultural activities are diminishing the scope for substantial increases in food production. Recent evidence of degradation of the quality of the agricultural resource base (water, soil) is further compounding the problem. In particular, concerns have been raised about a decline in soil fertility, change in water table, rising salinity and degradation of irrigation water quality (Sinha *et al*., 1998). Along with this, an increase in the number of pest species and a greater resistance of these pests to many pesticides have been observed.

To address these multifarious challenges, agricultural planning has to propose solutions that do ensure sufficient food, employment generation and rural income without degrading natural resource quality or increasing the risk of environmental pollution. It is generally difficult to define the best solution when there are so many potentially conflicting objectives. Information therefore needs to be generated to determine the consequences and trade-offs of different sets of policy aims for agriculture. The economically viable optimal solutions should be based on considerations of biophysical potentials, resource limitations and socioeconomic constraints. Thus, a systems approach is needed that translates policy goals into objective functions integrated into a bioeconomic land evaluation model.

In this paper, we summarize the results of our study focused on developing a decision support framework to explore future options for land use based on our present technical knowledge and anticipated future agricultural development goals and constraints. The major objective was the resultant modelling framework to be capable to determine the magnitude of production possibilities, associated environmental risks and the inputs required to attain the targeted production levels. Model results are illustrated for the state of Haryana in northern India, which has contributed tremendously to the success of the Green Revolution in India. Rice and wheat, commonly grown in a double-cropping rotation, are the major food crops of the region and their current total production is 10.5 million tons. Regional stakeholders of Haryana are interested in finding optimal agricultural land use plans that can meet this goal as well as maximize employment and income from agriculture, while minimizing pesticide residues, nutrient losses and groundwater withdrawal.

Methodology

The implications of various conflicting scenarios relating to multiple goals of maximizing food production and income and minimizing environmental degradation are evaluated by symphonic use of simulation models, geographic information systems (GIS) and optimization techniques. Resource characterization is done using a GIS and spatial databases. Modelling of crops and livestock is used to estimate primary productivity and milk. Multiple goal linear programming is used for optimization.

Resource characterization

Agro-ecological units These are developed based on considerations of soil and weather properties. The basic soil map of Haryana was reclassified into 17 homogeneous soil units based on particle size, organic carbon, sodicity and salinity, considered as critical characteristics for this study. Annual rainfall in the state varies from 300 mm in the western region and to 1200 mm in northeastern regions. A rainfall map was prepared based on data of 58 stations in and around Haryana. Overlaying this on the reclassified soil map yielded 59 homogeneous units. Rainfed area, which occurs mainly in western parts of Haryana, was mapped indirectly through satellite scans (IRS 1C- and 1D-images) and other conventional resource inventory. Addition of this layer consisting of irrigated and rainfed areas resulted in 87 agro-ecological units.

Land units The boundaries of the 16 districts in the state were overlaid on these agro-ecological units to determine the size and number of unique land units. The process resulted in 257 land units. Assuming that the area under settlements and barren land will not be available for cultivation, the non-agricultural area in these units was excluded. The demarcation of the latter was based on a recent satellite-based inventory.

Databases Databases relating to seasonal ground and surface water availability, labour, pesticides, fertilizers, transport facilities and costs and prices of main farm inputs and outputs were developed on a district basis.

Yield estimation and input-output tables

Land use types Major land use types (LUT) in Haryana are cereal-based. In irrigated areas, rice-wheat is the dominant cropping pattern, whereas in rainfed areas pearl millet-fallow or fallow-wheat are the dominant land use types. Based on the current cropping pattern in different parts of the state, 14 crop-based LUTs were selected for this analysis. Livestock is an integral part of Haryana's agriculture. Most farmers keep cattle for milk production, which is used for home consumption as well as for marketing. Three major dairy cattle types – crossbred cows, buffalo and local cows – were considered for this analysis.

Technology levels A major goal of our study is to explore options for increasing production. Considering this, we have used five technology levels: current yield (technology 1), potential yield (technology 5) and three levels between the two (technologies 2 - 4) for irrigated areas. The techniques for these levels were assumed to become more and more site-specific and capital-intensive (Aggarwal *et al*., 2000). In the absence of good data, only the current level of technology used is considered for rainfed areas and for livestock.

Estimation of yield Yields were estimated for different technology levels of each LUT and each of the 257 land units. Estimates were based on crop simulation modelling and empirical reduction factors for salinity/sodicity and other production losses (Aggarwal *et al*., 2000). The current yields of different crops were obtained from the state average (Anon., 1998). Target yields were set at bridging 25%, 50% and 75% of the gap between potential and actual yield – representing three different technology levels. Since rainfed areas are resource-poor as well, only the current level of technology was considered feasible for such areas.

Input-output tables Required inputs and other ancillary resultant outputs of various LUTs were calculated for the specified yields as described earlier by Aggarwal *et al*. (2000). Various approaches and tools including simulation models, a technical coefficient generator, surveys and rules of thumb were used for the estimation. The basic data for these were collected from a literature survey. It was assumed that the current level of input use would intensify in technologies 2 and 3. Technology levels 4 and 5 were assumed to be knowledge-based, precise and mechanized. Costs of fertilizers and farmyard manure (FYM), human and animal labour, hiring of tractor and procurement price of produce as well as residues were derived from the government statistics. The total cost of production included costs of seeds, human labour, machine labour, irrigation, fertilizers, FYM, Zn sulfate, biocides, fixed costs and miscellaneous (10% of operational costs) costs. Gross income is the value of the main product (grain/cane) and residue. Net income of the farmers was calculated as the difference between gross return and total costs.

Optimization

The constraints set The constraints set for the optimization exercise under current resource availability and production technology included land, water, capital and labour. Adoption of different, alternative technologies is at present mostly prohibited by the small size of landholdings, which indirectly reflects the capital base of most farmers. Farmers with small landholdings are generally not able to adopt capital-intensive technologies. Since this resource constraint had not yet been operationalized in the model, a land-based constraint was built in to restrict the use of capital-intensive technologies in Haryana: technology 4 to 19.1% area (large and very large farms) and technology 5 to 6.3% of the land area (very large farms only). Technologies 1 and 2 could be used by all four farm types (small to very large), whereas technology 3 could only be applied on medium and large farms (occupying 80% of the area). Another similar subconstraint of land-water was built into the model to restrict the amount of water used by area under various technologies.

Land and water constraints were specified per district and per land unit. Labour constraint was specified for each district on a monthly basis, whereas capital constraint was operational on a district basis only.

Scenario settings and results

During the March 1999 stakeholder-scientist workshop for Haryana, various scenarios were formulated and analysed. Stakeholders had given the following objectives priority:

- Doubling of food production for Haryana (tentative goal based on a recent policy statement).
- Maximizing agricultural production while setting limits on labour migration – in the future, the supply of labour from outside Haryana may become more restricted.
- Minimizing nitrogen loss.
- Minimizing pesticide residues.
- Improving water management/intervention measures to reduce groundwater depletion.
- Maximizing income from agriculture.

Table 1. Extreme values of the optimized food (rice + wheat) production (bold) in Haryana and the associated values of other variables. The values in each column are the results of separate optimizations with progressive inclusion of the constraints. In each case, the production of other crops was not allowed to be lower than the current level.

Objective variable	Unit	Constraint				
		Land	Land + tech	Land + tech + water	Land + tech + water + capital	Land + tech + water + capital + labour
Food	10^6 tons	**39.1**	**28.0**	**11.4**	**11.4**	**11.1**
Milk	10^6 tons	6.76	5.54	5.39	4.54	4.63
Income	10^9 rupees	109.9	77.8	54.3	56.3	54.9
Irrigation	10^9 m^3	56.4	51.2	16.3	16.2	15.5
N fertilizer	10^6 tons	1.51	1.25	0.64	0.64	0.61
Employment	10^9 labour days	666	674	364	361	347
Capital	10^9 rupees	114.2	92.1	54.1	53.7	52.0
N loss	10^6 tons	0.061	0.063	0.040	0.039	0.037
Biocide index	-	95	97	132	129	125

Based on these, we have done preliminary runs for the objective functions – 'maximize food grain production', 'maximize income for the agricultural sector', and 'minimize water use'. The results showed that Haryana has a capability of producing 39.1 million tons of food (rice and wheat) provided there are no constraints. This also assumes that all farmers would be capable of adopting the best technologies. In this scenario, the water required is more than three times what is currently available (Table 1). The scenario also indicates that this situation would need more than twice the capital currently used. The production of milk, employment generation and overall income are also considerably higher than at present.

Since constraints to technology adoption are likely to remain for some time to come, in the next optimization round, this aspect was introduced as a goal restriction. The results show that in such a case, the food production possibility is reduced to 28 million tons (Table 1). Resource requirements are nevertheless still very high. When the water constraint was introduced to restrict its use to the current level of availability, the results changed drastically. Food production came down to 11.4 million tons only. At the same time, income, milk production and employment as well became much lower. The introduction of capital and labour as additional constraints had a relatively small effect on food production. Irrespective of scenario, the biocide index was always within permissible limits (< 200 is considered as permissible), although it increased when water was

Table 2. Extreme values of the optimized income (bold) in Haryana and the associated values of other variables. The values in each column are the results of separate optimizations with progressive inclusion of the constraints. In each case, the production of other crops was not allowed to be lower than the current level.

Objective variable	Unit	Constraint				
		Land	Land + tech	Land + tech + water	Land + tech + water + capital	Land + tech + water + capital + labour
Food	10^6 tons	13.5	11.4	10.7	10.6	10.6
Milk	10^6 tons	6.17	5.05	4.68	4.63	4.62
Income	10^9 rupees	**236.7**	**145.9**	**58.7**	**57.6**	**56.3**
Land used	%	100.0	100.0	100.0	100.0	100.0
Irrigation	10^9 m^3	41.7	30.8	15.2	15.0	14.8
N fertilizer	10^6 tons	2.17	1.57	0.64	0.62	0.60
Employment	10^9 labour days	663	661	370	364	354
Capital	10^9 rupees	162.0	116.9	55.9	54.8	53.3
N loss	10^6 tons	0.041	0.043	0.037	0.037	0.037
Biocide index	-	739	459	133	127	121

imposed as an additional constraint (Table 1). In contrast, nitrogen loss was very high when land and technology were the only constraints.

The objective of most farmers is to earn sufficient income from their farm enterprise and not necessarily food production. In the next scenario, we have therefore focused on this objective function keeping current food production (10.5 million tons of rice and wheat) as the minimum food to be produced. The results indicated that income could be tremendously increased provided irrigation water was available. This type of production at the same time can result in a large environmental problem of biocide residues since there is heavy dependence on growing of cash crops such as cotton, sugarcane and potato. Since opportunities for an increase in water resources in Haryana are limited, income has to be restricted to 56 billion rupees only. At this stage, food production was only 10.6 million tons, indicating that some increase in income is possible through diversification of area to cash crops (Table 2).

In the next scenario, we focused on minimizing water use because the current use of water (particularly groundwater) is causing water tables to decline in many parts of the state. The results show that it is possible to produce the current amount of food with almost half the irrigation water. This can be realized by allocating more area to higher technologies, which produce more food at higher water use efficiencies. Since the minimum target for food can be produced on a smaller area, in the model, which was set to use all agricultural area, the

Table 3. Extreme values of the optimized water use (bold) in Haryana and the associated values of other variables. The values in each column are the results of separate optimizations with progressive inclusion of the constraints. In each case, the production of other crops was not allowed to be lower than the current level.

Objective variable	Unit	Constraint				
		Land	Land + tech	Land + tech + water	Land + tech + water + capital	Land + tech + water + capital + labour
Food	10^6 tons	10.5	10.5	10.5	10.5	10.5
Milk	10^6 tons	4.89	4.93	4.99	4.32	4.44
Income	10^9 rupees	58.5	55.0	50.1	51.8	51.6
Land used	%	100.0	100.0	100.0	100.0	100.0
Irrigation	10^9 m^3	**9.9**	**11.4**	**13.7**	**13.7**	**13.8**
N fertilizer	10^6 tons	0.56	0.59	0.57	0.57	0.57
Employment	10^9 labour days	236	301	341	341	341
Capital	10^9 rupees	46.0	47.7	50.3	50.4	50.4
N loss	10^6 tons	0.032	0.033.	0.035	0.035	0.035
Biocide index	-	31	77	122	122	121

remaining area is allocated to the fallow-wheat system, which does not require any irrigation water and yet produces food. The biocide index is very low when land is the only constraint. When other constraints are gradually introduced into the model, the biocide index increases, while food production can still be maintained at the same level – corresponding to current production (Table 3).

Conclusions and future work

The methodology described here provides a useful tool for exploring the 'window of opportunities' for future land use. The key advantage is that it integrates the knowledge base of several scientists from different disciplinary backgrounds and attempts to address some real issues put forward by the stakeholders. It also helps us in analysing scientifically whether many of our ambitious development goals are feasible and at what costs.

Our preliminary results point out that current availability of water is a major constraint to increasing food production in Haryana. Since we considered availability of water resources at today's level, the analysis needs to be expanded and possible changes have to be examined in total water availability in the future. Data for projecting future water resources are not easily available at the land unit or even district level. Therefore, the availability of good-quality data at the desired scale is an important limitation to making progress.

Based on the concepts of production ecology, a technical coefficient generator (TCG) for describing the input-output relations of the various production activities/technologies has been developed. Input-output tables, required for optimization, are generated by relating basic soil and weather characteristics and inputs used to economic yields and environmental impacts for all land use systems that are currently known and deemed relevant to the study region. While the TCG is easy to use, it is still based on a semi-empirical approach. This means that it cannot dynamically describe effects of critical daily events and integrate them into seasonal and annual results. This also limits its capability in extending current knowledge for determining input-output relationships for innovative future production activities. Simple yet robust simulation models are needed to facilitate this.

The results of the multiple goal linear programming (MGLP) model are exploratory and only a single (higher) level of stakeholders is considered while the interests of the other stakeholders in the region (e.g., farmers, village-level managers) have been ignored. Consequently, although the model illustrates the opportunities at the regional level, the changes in land use required for achieving this may not be implementable by the primary land manager – the farmer. There will be a large capital requirement at the state level to finance the equipment needed for implementing capital-intensive technologies 4 and 5. Such considerations need to be included in future analyses.

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Kedah-Perlis Region case study: Income from agricultural activities versus rice production

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Introduction

Malaysia has witnessed a steady increase in population and in recent years, a spectacular economic growth. The latter has prompted intensive urbanization and industrialization, which has resulted in an ever-increasing urban population at the expense of the rural area. This trend is expected to continue and will result in half of the population staying in urban areas by 2020. This means more people to feed and fewer people involved in food production. Agricultural systems in the country are therefore being challenged by the requirement for increased productivity, more diversified products and due consideration for environmental impact. At the same time, multiple claims by several sectors on commonly scarce natural resources are becoming more acute. Hence, an analysis of land use and natural resource management options at a regional scale is needed to guide policy changes and to assess the scope for agricultural systems beyond the constraints of current policies. Land use planning, however, is complex and planners need special tools, such as models and expert systems, to help simplify the related issues.

A study was carried out to develop, evaluate and put into operation methodologies for exploring land use options at a regional scale in Malaysia. The expected outputs from the study were to

- Identify/develop and evaluate models/expert systems for estimating agricultural inputs/outputs and environmental effects.
- Explore options for agricultural land use in the study area.
- Create a team of trained scientists capable of applying systems analysis techniques at a regional level to identify development potential and opportunities.

The Kedah-Perlis Region was selected as a case study area. The region is located in northwest Peninsular Malaysia, covering the states of Kedah (930,000 ha) and Perlis (79,500 ha). This agriculture-based region contributes about 10% of the national agricultural GDP and 17% of the national agricultural employment. The region is noted as the main producer of rice and sugarcane and is among the major producers of rubber, tobacco and fruits (especially mango). The region is also among the poorest in the country, with a per capita income of only 60% of the national average. The choice of the region had several reasons. There is strong competition for land resources, between food and non-food production and between agriculture and non-agricultural activities. Moreover, the supply of farm labour is deteriorating, farm wages are increasing rapidly, landholdings are small and fragmented and concerns are increasing about inefficient water use. In addition, there are also distinct disparities in natural resource endowments within the region.

These conditions were considered to provide a good ‘testing ground’ for evaluating the methodology for land use planning.

Methodology

As in the other case studies of the ‘Systems Research Network for Ecoregional Land Use Planning in Support of Natural Resource Management in Tropical Asia’ (SysNet), an explorative land use study was carried out, employing the interactive multiple goal linear programming (IMGLP) technique (De Wit *et al*., 1988), integrated in the land use planning and analysis system (LUPAS) (Hoanh *et al*., 2000). Only a brief summary of methodology components is given here, as these have been reported in detail before by Tawang *et al*. (1998, 2000).

Policy scenarios and development of objective functions

The assessment of policy views was based on various policy documents, formal discussions with stakeholders and farm surveys. Four major policy goals, or objective functions, were identified:

- Increased food production (e.g., maximizing rice production).
- Increased income (e.g., maximizing farm income).
- Environmental protection (e.g., minimizing fertilizer/chemical use).
- Increased efficiency in resource use (e.g., maximizing water/labour use efficiency).

Water, labour and capital availability, markets, mechanization support and policy on production quotas were considered as major constraints to attaining these development goals.

Delineation of land units and land evaluation

A land unit (LU) is defined as an area of land possessing specific characteristics and qualities that are considered homogeneous and can be mapped. It is a unique combination of an administrative subregion with an agro-ecological unit (AEU) and is the smallest calculation unit for which the input-output relationships for various production activities are quantified. Considered in the delineation of LUs were district and the Muda Agricultural Development Authority (MADA) boundaries. An AEU results from the combination of agro-ecological zones (AEZ) with other characteristics such as topography, and the soil’s parent material, texture and special features. Each LU was then evaluated for its agricultural potential (including its suitability for agricultural activities), input requirements and yield. From originally 87 LUs, only 60 were considered suitable for agriculture.

Promising activities and land use types

Based on land suitability and policy views, 18 promising production activities were selected to represent a group of similar or individual agricultural activities. The promising land use types (LUT) selected include either major existing activities or activities with a future potential mentioned in the policy guidelines or quota specifications.

Resource availability (land, water and labour)

The availability of land in each LU was based on land use maps and statistics. Labour availability in each district was translated from the population census. Water resources for double-crop rice in MADA were based on rainfall and supply from reservoirs, rivers and drainage recycling. The monthly cumulative water balance in each AEZ was used to estimate irrigation water requirements for various crops. Resource availability (land, labour and water) was estimated for the years 2000, 2010 and 2020.

Production technology

A production technology is defined as the agricultural activity in a particular environment that is specified by its inputs and outputs. Three production technologies are specified:

- Level 1 – as practised by a majority of farmers.
- Level 2 – as practised by some advanced farmers or estates.
- Level 3 – as practised in experimental plots or advanced estates.

Generally, it was assumed that production levels would increase with time as new technologies became available and farmers were likely to be ‘pressed’ to produce more.

Estimation of agricultural input and output

The study adopted the ‘input-target’ approach for quantifying input-output relationships. This assumes that, with similar inputs, the performance of a particular activity varies with the suitability of the various LUs. The establishment of the input-output relationships involved three technology levels, 18 LUTs and 19 AEUs. The inputs considered were fertilizers, pesticides, labour and irrigation water, while the outputs included yield (crop model and PARAEVAL), potential soil loss (USLE) and income. The input and output parameters for the various LUTs were standardized into unit/ha/year. The input prices are based on retail prices and output (yields) prices are based on farm-gate prices. The study considers the present prices for all the production activities, with the assumption that future changes in input and output prices will compensate for each other.

Local demand and targets for agricultural products

Local demand for various products was estimated by multiplying the national per capita consumption with the local population (Table 1). A second set of production limits was targeted or planned by the federal and state authorities as given in various planning documents. Estimates for the short-term (2000), and projections for mid-term (2010) and long-term (2020) were made.

Multiple goal linear programming (MGLP) model and user interface

An MGLP model was developed using the Visual XPRESS optimization software, with links to the Microsoft Excel spreadsheet for data retrieval and storage of the output, and the Geomedia GIS module for spatial display of the results. Recently, a user-friendly interface was completed providing the capabilities of interactive data input, model runs and immediate display of goal achievements and associated land use allocations (figures, charts and maps) (Laborte *et al.*, this volume). The modelling framework accommodates different scenario settings in terms of different production activities, resource availability, demands and production targets for different time periods, as well as for changes in policy directions and market situations.

Table 1. Local demand for food crops and production targets for selected commodities in the Kedah-Perlis Region (t ha^{-1}).

Product	2000			2010			2020		
	Local demand	Production target		Local demand	Production target		Local demand	Production target	
		Lower limit	Upper limit		Lower limit	Upper limit		Lower limit	Upper limit
Rice	126,483	750,000	no limit	133,311	860,000	no limit	135,769	990,000	no limit
Tobacco	-	-	18,000	-	-	18,000	-	-	18,000
Leafy veg.*	37,658	700	42,000	46,647	42,000	50,400	55,758	50,000	60,000
Trellis veg.*	30,556	700	34,000	37,853	33,600	40,800	45,245	40,000	49,000
Chili	2,724	100	3,800	4,267	3,120	4,560	6,122	3,700	5,500
Durian	8,952	5,300	85,500	13,845	10,800	111,000	19,922	14,000	144,000
Mango	1,642	2,000	14,000	2,543	2,600	18,200	3,653	3,380	23,700
Rubber	-	300,000	no limit	-	300,000	no limit	-	300,000	no limit
Oilpalm	-	850,000	no limit	-	1,045,000	no limit	-	1,400,000	no limit
Sugarcane	88,703	16,000	no limit	110,751	820,000	no limit	133,301	820,000	no limit
Star fruit	1,003	100	2,250	1,558	1,300	2,900	2,245	1,700	3,900
Banana	9,627	3,600	108,700	14,892	13,000	140,000	21,404	17,000	180,000
Cattle	6,291	-	no limit	9,721	-	no limit	13,996	-	no limit

* Leafy vegetables can be defined as group of vegetables which are harvested for their edible leafy parts, e.g., brassicas (cabbage, cauliflower, broccoli, chinese cabbage), Lactuca, Amaranthus, Ipomoea, etc. Most are annual but there are some perennials plants (e.g., Sauropus, Sesbania).

Trellis vegetables are a group of vegetables, which need the support of a trellis system in their economic production. They are from the fruity vegetable type such as Phaseolus and Vigna spp, Psophorcarpus, Pisum spp, Luffa, Cucumis, Momordica, Trichosanthes.

Description and discussion of relevant scenario analyses

Two types of post-optimization analyses were carried out. The first type was meant to provide indications on the 'window of opportunities' for the study area, based on the different objective functions, considering only the identified major resource constraints. The outputs, however, were of little interest to the stakeholders, since several other constraints to realizing these goals were not considered. The second type of analyses, the so-called 'expanded scenarios', included several 'what-if' questions considered relevant by policymakers and land use planners (scenarios 1-4, below). These included assessment of effects of likely (near-future) changes in policies, market prices, resource availability, demands and targets. The integration of these analyses would provide a clearer picture of the possibilities for land use options in the next 5 - 10 years. Theoretically, a whole range of possible scenarios could have been analysed given all the possible combinations of objectives and constraining factors identified. However, only a few selected scenarios, which were of greatest interest to the stakeholders, were analysed in greater depth.

The two objective functions of greatest interest were the maximization of income and of rice production. Results of the optimization are presented for the year 2000 only. In the 'trade-off' scenario between these conflicting objective functions, the minimum level of income and rice (from MADA) to be maintained was at RM1.4 billion[1] and 1.1 million tons of rice, respectively. The other objective functions – the environmental and efficiency goals – have not been taken into account, since they were considered less relevant for the 'short-term' development agenda compared with income and rice production.

Scenario 1: Income maximization – rice at 1.1 million tons in MADA; current technology; different constraining factors

The scenario was considered to reflect changes in income and pesticide and fertilizer use with successive increases in the number of goal restrictions (constraining factors). In the first run, the only constraint imposed was land; successively more constraining factors were added. The corresponding optimization results (Table 2) show a general decrease in values as more constraints were imposed. Income decreased by 78% from run 1 to run 4, while pesticide and fertilizer use decreased by 83% and 53%, respectively. Obviously the imposition of regional production targets, which were based on those set by the government (largely in view of existing market potential), drastically reduced potential income compared with the imposition of other constraints. In terms of land used, the percentage was reduced marginally (by 3%), while labour and water use in MADA were reduced by 60% and 33%, respectively, between run 1 and run 4. The top three production systems allocated in run 4 were rubber (38%), double rice (19%) and hardwood (sentang) at 16% of the agricultural land.

[1] Malaysian ringgit (1 US$ ~ 3.8 RM, January 2000)

Table 2. Income maximization: effects of imposing different constraints on goal achievements and resource use.

Run	Constraints	Income (10^9 RM)	Rice (10^6 t)	Pesticide use (10^3 t)	Fertilizer use (10^6 t)	Resource use (% of available)		
						Land	Labour	Water
1	Land	8.6	1.1	6.5	727	100	119	79
2	Land, labour, water	6.9	1.1	4.3	383	97	72	66
3	Land, labour, water, local demand	6.3	1.1	4.1	437	97	74	62
4	Land, labour, water, local demand, production targets	1.9	1.1	1.1	345	97	48	53

Table 3. Rice maximization: effects of different constraints on goal achievements and resource use with current technology.

Run	Constraints	Income (10^9 RM)	Rice (10^6 t)	Pesticide use (10^3 t)	Fertilizer use (10^6 t)	Resource use (% of available)		
						Land	Labour	Water
1	Land	1.4	1.3	1.5	0.1	32	26	70
2	Land, labour, and local demand	1.8	1.3	2.0	0.2	41	39	68

Scenario 2: Rice maximization – effects of changes in constraining factors on other objective functions and resource use; current technology

The maximum rice production under the current technology was 1.3 million tons for the two runs presented (Table 3). This is an increase of about 300,000 tons compared with that attainable under the income maximization scenarios. However, the impact on incomes was very significant. Under similar constraining factors (land, labour and local demand) for income maximization, the optimum income was RM6.3 billion, 3.5 times higher than in the maximization of rice production. Apparently, with the increase in the constraining factors, incomes for the region also increased correspondingly. This was because of the requirement to maintain certain production levels of non-rice agricultural commodities to fulfil the local demand. By comparing run 3 in Table 2 and run 2 in Table 3, there was a higher level of water use (in MADA) to

Table 4. Maximize income: under alternative constraints and technology levels with minimum requirement for rice production of at least 1.1 million tons.

Run	Technology level	Constraints[*]			Income (10^9 RM)	Rice (10^6 t)	Pesticide use (10^3 t)	Fertilizer use (10^6 t)	Resource use (% of available)		
		All	D/De-mand	Target					Land	Labour	Water
1	Current	✔	✔	✔	1.9	1.1	1.1	0.3	97	48	53
2	Improved	✔	✔	✔	2.3	1.2	1.2	0.4	98	49	54
3	Current	✔	✔	✕	6.3	1.1	4.1	0.4	97	74	62
4	Improved	✔	✔	✕	8.6	1.2	4.2	0.5	98	73	64
5	Current	✔	✕	✕	6.9	1.1	4.3	0.4	97	72	66
6	Improved	✔	✕	✕	8.6	1.2	4.2	0.5	98	73	64

[*] All : land, water, labour (✔ imposed, ✕ not imposed)
D/Demand : set minimum production at local/domestic demand for food crops
Target : set minimum and maximum production at specified targets for selected commodities

support rice production (68%) compared with that under the income maximization objective (62%), while the use of other resources (land and labour) declined from 97% to 41% and from 74% to 39%, respectively.

Scenario 3: Maximize income – rice at least 1.1 million tons; alternative technology levels

This scenario was set up to examine the possible contribution of improved production technology to income and other objectives, as well as its implications for resource use. The summary of the outcomes, at different constraining levels, is as indicated in Table 4. Generally, for all runs, improved technology was able to contribute an additional 10% to rice (at about 100,000 tons) and an average of about 25% to income. Such productivity improvement, brought about by the improved technology, was very substantial, and this represents an option that the government needs to pursue. Furthermore, such increases did not require additional resources, as reflected by an insignificant change in resource use.

Scenario 4: Maximize income – options for alternative land use in MADA, under different technology levels and constraints

In all the earlier analyses, the MADA irrigated areas were solely devoted to rice production, in line with the current government policy. However, the MADA

Table 5. Maximize income: options for alternative land use patterns in MADA under different technology levels and constraints.

Run	Land use in MADA	Technology level	Constraints*			Income (10^9 RM)	Rice (10^6 t)	Pesticide use (10^3 t)	Fert. use (10^6 t)	Resource use (% of available)		
			All	D/De-mand	Target					Land	Labour	Water
1	Rice	Current	✔	✔	✔	6.3	1.2	4.1	0.4	97	74	62
2	Rice	Improved	✔	✔	✔	8.6	1.2	4.1	0.5	98	73	64
3	Rice-based	Current	✔	✔	✕	10.0	0.3	3.6	0.4	87	79	24
4	Rice-based	Improved	✔	✔	✕	10.9	0.3	3.8	0.5	87	82	22
5	Rice-based	Current	✔	✕	✕	10.7	0.3	3.9	0.4	87	78	28
6	Rice-based	Improved	✔	✕	✕	11.7	0.3	4.0	0.4	86	81	25

* All : land, water, labour (✔ imposed, ✕ not imposed)
D/Demand : set minimum production at local/domestic demand for food crops
Target : set minimum and maximum production at specified targets for selected commodities

area, with its excellent irrigation facilities and strategic location, is also very suitable for the production of non-rice crops, notably vegetables, fruits and tobacco, which could form the basis for new rice-based farming systems. These commodities definitely yield higher returns than rice, assuming favourable market conditions.

As expected, the liberalization of the MADA area for other commodities resulted in a drastic change in the allocation of land, income and rice production. Under the current technology level, the opening up of the MADA area for other crops resulted in an increase in income of about 50% (from RM6.3 billion in run 1 to RM10 billion in run 3). This was at the expense of land devoted to rice production, which was reflected by a drastic decrease in rice production from 1.2 million tons to 300,000 tons. A similar trend was observed for all runs (Table 5). It is worthwhile to mention that the opening up of the MADA area for non-rice activities led to a reduction in land and water resource use, accompanied by a slight increase in required labour.

General discussion

The above findings represent some of the outputs from the various optimization runs. As a whole, the current planning guidelines aiming at integrating income (as the overriding development goal) and food security are sound. Although further increases in income are possible through the use of the MADA area for other commodities, the significant reduction in rice production is not in line with the current food security policy of the country. Similarly, further income generation is hampered very much by the current targets set by the state government, which are mainly dictated by current market considerations. Further relaxation of these targets, as in the setting of a higher target for non-rice agricultural commodities while the current price structure is maintained, will result in a corresponding increase in regional income. This is especially true for vegetables and fruits (especially mango).

Conclusions

Accomplishments

- A user-friendly model for explorative land use planning has been developed, evaluated and tested in the Kedah-Perlis Region. The model and data sets were designed to help policymakers and land use planners to deal with future uncertainties and important 'what-if' questions.
- The various procedures required for model development have been completed for the study region. These include the formulation of objective functions from policy views, delineation of land units, land evaluation, resource balancing (land, water and labour), identification of promising land use types and production technologies, quantification of agricultural inputs and outputs, and estimation of demands and targets for various agricultural products.
- The study has resulted in a team of trained scientists who can apply systems analysis techniques at the regional level to identify development potentials and opportunities.
- The model results offer various development options to the region that can be considered for agricultural land use planning and policy formulation exercises. Additional development options can be easily formulated.
- Experiences gained in the involvement of stakeholders at various stages of the study have been very positive. Their perceptions, comments and suggestions together served as an important guide for the establishment of both the model and data sets. This approach and the tools can be used in other research activities.

Unfinished business

- The study was negatively affected by the lack of crop models for perennials, the main current/promising land use types in the study area. For the estimation of agricultural inputs/outputs, the study did adopt an 'input-target' approach, which was fairly rigid. Subsequently, the yield estimation mainly relied on a parametric, semi-quantitative approach of land evaluation. The procedure/

modules, however, have to be validated, which was only partly achieved.

- Some problems also occurred in estimating relations between agricultural inputs and outputs, especially related to the treatment of annual versus perennial crops. For example, vegetables could be planted and harvested, three times a year, while forest species could only be harvested after 15 years. In the current study, the outputs were standardized into unit/ha/year, regardless of the production age and life cycle of the crop. A more appropriate methodology or procedure is needed for dealing with these extreme activities.
- The current study also did not consider price sensitivity to production level (over- or under-production). A proper procedure to deal with this aspect is expected to result in better planning as well as in less reluctance from stakeholders to accept the results.
- A more effective approach in creating awareness of capabilities and promotion of the established model is required. The understanding and acceptance of the model were generally hampered by its complexity and exploratory nature.
- During the last two years, the project was negatively affected by a high staff turnover rate. The most significant negative effects were in the field of computer modelling and programming, which are currently the bottlenecks for further expanding the Kedah-Perlis model or transferring the methodology and tools to other regions (as requested by planning officers from other states).

Research challenges ahead

- The need to look into some of the above-mentioned scientific problems so that the model would be well accepted by scientists and stakeholders.
- To equip the model with the capability to cater to multi-level decision making, e.g., at the federal, state, district and farm levels.
- To develop procedures for the model to consider minimal land-based agricultural activities, e.g., aquaculture, poultry, feedlot animals, controlled-environment vegetables, etc., which are very important in the country, especially in relation to labour use and revenue generation.

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Ilocos Norte Province case study: Effects of future changes in nutrient management practices on agricultural development goals

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Introduction

Problems and new approaches to natural resource management (NRM)
In Asia, a further decrease in good land and water resources for agriculture is unavoidable due to growing urbanization and industrialization. At the same time, there will be more people to feed and less people involved in agricultural production. The negative environmental effects of injudicious nitrogen and pesticide use are well-documented (Pingali & Roger, 1995; Balasubramanian *et al*., 1999). A major challenge is to overcome the potential conflicts associated with the required increase in productivity, farmers' income and the conservation of water, soil and other natural resources by identifying production systems and technologies that make optimum use of external inputs and natural resources and policy measures supporting their adoption for sustainable agricultural development (Van Ittersum, 1998; Rabbinge, 1999).

The SysNet methodology aims at exploring alternatives for agricultural land use and development to assist in strategic planning aimed at identifying feasible development objectives and targets that respect the agro-ecological principles underlying agriculture (Meermann *et al*., 1996). For this, SysNet has developed the land use planning and analysis system (LUPAS) (Laborte *et al*., 1999). Future-oriented land use explorations for Southeast Asia need to address questions related to the agro-ecological and socioeconomic basis of sustainability. In Ilocos Norte, Philippines, recent research on intensive rice-cash crop cropping systems revealed a significant risk of groundwater pollution by nitrate leaching, raising questions about feasible and acceptable solutions with improved management (Lucas *et al*., 1999; Tripathi *et al*., 1997).

Objectives of this study

Based on an existing LUPAS for the Ilocos Norte case study area (Laborte *et al*., 1999), additional databases were prepared to examine the effects of changes in availability, use efficiency and costs of various production resources on productivity, income and environmental goals.

Assumptions made relate to anticipated policy interventions, gains in farmers' knowledge to choose from alternative production technologies and possible changes in socioeconomic boundary conditions. Scenario analyses carried out looked at the effects of (*i*) variations in water and labour availability, (*ii*) alternative, more/less resource-use efficient production technologies, and (*iii*) changes in fertilizer and labour costs on objectives related to food security, income and resource use. This was to answer several stakeholders' questions:

- To what extent is realization of development goals at the regional scale limited by current water and labour constraints?
- How could resource use be optimized?
- To what extent could adoption of new production technologies such as site-specific nutrient management contribute to goal achievements and how would changes in fertilizer costs and economic development affect the results?

The outcome of scenario (*i*), i.e., effects of variations in water and labour availability, has been presented elsewhere (Lansigan *et al*., 2000). In the following sections, results for scenarios (*ii*) and (*iii*) are presented.

Materials and methods

Ilocos Norte Province: Characterization of the region

Ilocos Norte Province in northwestern Luzon, Philippines, with a population of nearly 0.5 million people and a total land resource of nearly 0.34 million ha, is a region with a large area of forest resources (46% of total area). About 38% of the total area is classified as agricultural land. Agriculture in the province basically consists of rice-based production systems. While rice is cultivated in the wet season between June and October, during the dry season, diversified cropping is practised: tobacco, garlic, onion, maize, sweet pepper, and tomato, all supported by groundwater irrigation, are cultivated in the lowlands. Agricultural activities are most intensive in the central lowlands. The major environmental problems are soil erosion on hilly land in the eastern parts and groundwater pollution in the lowlands (Lansigan *et al*., 1998; Tripathi *et al*., 1997).

Mean annual rainfall in the province ranges between 1700 mm in the southwest and above 2400 mm in the eastern mountain ranges. The occurrence of typhoons, mostly between August and November, has considerable adverse effects on agricultural production. Soils are developed from very diverse parent

Table 1. Characteristics of the Ilocos Norte case study area.

Total area	340,000 ha
Available for agriculture (current)	129,650 ha
Available for agriculture (2010)	119,850 ha
Total population	
Current (projected)	0.50 million persons
2010 (projected)	0.56 million persons
Labour force available for agriculture (2010)	0.18 million persons
MGLP characteristics	
Land units	200
Agricultural products	17
Land use types	23
Technology levels	3

materials. In the lowlands, sandy loams developed from alluvial deposits are predominant.

Rice is the most common crop. In 1993, the province had a surplus of 100 000 Mt above demand (113,000 Mt). A well-developed marketing system has facilitated the establishment of intensive rice-cash crop production systems (Lucas *et al*., 1999). The main characteristics of the study region and the multiple goal linear programming (MGLP) model are summarized in Table 1.

Policy issues The Provincial Government of Ilocos Norte (1999) formulated the Sustainable Food Security Action Plan (SFSAP) and Agro-Fishery-Industrial Modernization Framework (AGRIMODE). The document, released in February 1999, outlines the market, technological and policy directions and action plans to be taken in the next 3-6 years. The current major constraint to agricultural development is the low level of agro-fishery productivity and income. Some of its major causes are relatively low cropping intensity, underdeveloped irrigation systems and small average farm size.

Public awareness of current and possible future negative environmental effects resulting from further intensification of agricultural systems, especially in the lowlands, was only created recently through research on groundwater pollution by the RLRRC, the Rainfed Lowland Rice Research Consortium, coordinated by IRRI (Lucas *et al*., 1999; Tripathi *et al*., 1997). In SysNet meetings with local stakeholders since 1997, an assessment of trade-offs among food security, farmers' income and, to a lesser extent, environmental objectives was identified as the major issue to be addressed in exploratory land use analysis for the province.

LUPAS methodology

The interactive MGLP (IMGLP) technique (De Wit *et al*., 1988) is used to determine optimal options for agricultural development and deal with conflicts in land use objectives of stakeholders in the region. The three main methodology parts of LUPAS are

(i) Land evaluation, including assessment of resource availability, land suitability, yield estimation and input-output estimation;
(ii) Formulation of scenarios, based on policy views and development plans; and
(iii) Land use optimization in the form of an MGLP model (Laborte *et al*., 1999).

The system draws data from three databases: (*i*) data on biophysical resources such as characteristics of agro-ecological units, available land and water resources and observed yields and inputs, (*ii*) socioeconomic data such as available labour force and capital and prices of inputs and outputs of production, and (*iii*) data drawn from policy views and development plans (Hoanh *et al*., 2000).

Database for basic MGLP model A total of 200 land units were defined by overlaying biophysical characteristics: irrigated areas, annual rainfall and distribution, slope and soil texture; and administrative units comprising 23 municipalities (Lansigan *et al*., 1998). The total area available for agriculture for the year 2010 was identified to be 119,850 ha. This was derived by taking out severely eroded areas, areas with steep slopes (>30%), soils unsuitable for agriculture (mountainous soils, river wash, dune land, barren sand and coral beds, and rock land), areas currently under forest, water bodies (rivers, lake) and built-up areas (based on the proposed land use plan). In Lansigan *et al*. (1998), land identified as suitable for agriculture was 109,000 ha. The difference in agricultural areas derived is due to the difference in the base map used for slope. In Lansigan *et al.* (1998), slope was derived from the 1-km digital elevation model (DEM), whereas, in the new classification, the base is an actual slope map.

Seventeen different agricultural products were considered (Table 2), and 23 land use types (LUTs), which are currently practised in the province, were included in this study: rice-white maize, rice-yellow maize, rice-garlic, rice-mungbean, rice-peanuts, rice-tomato, rice-tobacco, rice-fallow, rice-rice, rice-cotton, rice-potato, rice-onion, rice-sweet pepper, rice-eggplant, rice-vegetables, sugarcane, rice-rice-rice, rice-garlic-mungbean, rice-white maize-mungbean, rice-yellow maize-mungbean, rice-watermelon, mungbean and root crops. The data for the input-output tables were derived from farm surveys in the province consisting of 1,957 farms in the wet season and 2,523 farms in the dry season.

Scenario formulation The SysNet methodology can be used to explore land use options by looking at different scenarios and identifying which of the goals can or cannot be achieved, which resources are insufficient, and the mix of land use types and production techniques that will result in the corresponding goal achievements. The specific 'what-if' question we pose in this study is: How does

Table 2. Provincial demand for agricultural products, Ilocos Norte Province, Philippines. (Source: Provincial Planning Office, Ilocos Norte, Philippines.)

Agricultural product	Demand (t)	Agricultural product	Demand (t)
Rice	112,610	Sweet potato	11,172
White maize	229	Onion	223
Yellow maize	-	Sweet pepper	559
Garlic	223	Eggplant	2,793
Mungbean	1,397	Vegetables	16,759
Peanut	1,117	Sugarcane	-
Tomato	3,352	Watermelon	1,117
Tobacco	-	Cotton	-
Root crops	22,903		

achievement of the objectives and land use allocation change, if for given production activities the technologies change?

Future production technologies and macro-economic conditions Three production technology levels were considered: (1) average farmers' practice, (2) 'best farmers' yield/high input', and (3) 'improved practice'. The data for the input-output tables were derived from farm surveys in the province. The values for the input-output relations for the average farmers' practice were derived from the average values for these farms.

For the 'best farmers' yield/high input', data were derived by taking the mean of the values with a yield level between the 90th and 95th percentile of the survey data. Fertilizer and pesticide use were assumed to increase by 100% and labour by 70% and other inputs were the same as in the average practice. This is based on survey data indicating that one group of farmers approaching 'best farmers' yield' achieves this by almost doubling fertilizer and pesticide inputs, while labour input increases less.

For the 'improved practice', the same inputs as in the average farmers' practice were used, but fertilizer use efficiency was improved. Average applications of N, P and K decreased by 20% for non-rice. For rice, N application decreased by 40%, P application decreased by 15% and K application increased by 20%. This is partly based on survey data suggesting that another group of farmers achieves 'best farmers' yield' with about the same input as in the average farmers' practice. We further assume that by better balancing nutrient supply with crop demands the efficiency of fertilizer (macro-nutrients N, P, K) can be further improved as demonstrated elsewhere by the efficiency increases in rice. The nine model runs for analysing effects of changes in production technologies and fertilizer and labour cost on land use objectives are defined in Table 3. Assumptions on technology change with increases in resource use efficiency

Table 3. Definition of production technologies and scenarios.

Technology	Description
Technology 1 (average farmers' practice)	
A	Average farmers' yields and average input use based on recent farm surveys
B	Same inputs and outputs as A, plus 25% increase in fertilizer price
C	Same inputs and outputs as A, plus 25% increase in fertilizer price and 35% increase in labour cost
Technology 2 (best farmers' yield/high input)	
A	90^{th}-95^{th} percentile yield of average practice and higher input (100% more fertilizer and pesticide, 70% more labour) compared with Technology 1
B	Same inputs and outputs as A, plus 25% increase in fertilizer price
C	Same inputs and outputs as A, plus 25% increase in fertilizer price and 35% increase in labour cost
Technology 3 (improved practice)	
A	Different fertilizer levels (rice: ×0.6 N, ×0.85 P, ×1.2 K; other crops: ×0.8); same yield as in Technology 2 and other inputs as in Technology 1
B	Same inputs and outputs as A, plus 25% increase in fertilizer price
C	Same inputs and outputs as A, plus 25% increase in fertilizer price and 35% increase in labour cost

(Technology 3) are based on farm surveys, crop statistics and reports for the Philippines and Ilocos Norte and recent experimental data for various rice systems from different sites in the tropical lowlands of Asia.

Fertilizer, pesticides and labour and their use efficiencies

Fertilizer, pesticide and labour use Farm survey data in the province for 1994-97 by the Rainfed Lowland Rice Research Consortium (Lucas *et al.*, 1999; RLRRC, 1998) and a more comprehensive farm survey conducted by SysNet during 1998-99 (Francisco *et al.*, unpublished) were used to establish relations between N, P and K fertilizer input, pesticide use and labour use on the one hand and yield levels of the various crops under current farmers' practices on the other.

Nutrient and labour use efficiencies in rice-based systems Currently, in the IRRI coordinated RTDP (Reversing Trends of Declining Productivity) Project, much research is done on the optimum balance for nutrient uptake for rice, depending on target yield (Witt *et al.*, 1999). To determine optimal N, P and K fertilizer applications in given physical environments, this model requires as input the indigenous soil supply of these three macro-nutrients and a potential yield estimate for the season. For Ilocos Norte, soil and plant data are too scarce to apply the model QUEFTS (Janssen *et al.*, 1990) for all land units. Instead, we screened several farm survey and experimental data to assess fertilizer application rates and indicators for current and possible future nutrient use efficiencies for the major rice-based systems in Ilocos Norte. Moreover, we applied QUEFTS concepts to estimate nitrogen surplus (fertilizer applied minus nitrogen taken up and allocated to harvestable products). The calculated average nitrogen surplus was about 40 kg ha^{-1} for rice, 23 kg ha^{-1} for garlic and 121 kg ha^{-1} for sweet pepper.

Data from the two farm surveys are consistent in showing that even farmers' average nitrogen application rates to sweet pepper (250 kg N ha^{-1}) far exceed the recommended rate of 170 kg N ha^{-1} (Pascua *et al.*, 1998).

Fertilizer experiments at Mariano Marcos State University (MMSU), Batac, Ilocos Norte (Pascua *et al.*, 1998), at IRRI's long-term continuous cropping experiment (LTCCE), and other pluri-annual and multi-site experiments on rice in the framework of the RTDP Project (Dobermann & White, 1999; Dobermann *et al.*, 2000a), were examined to compare current with possible future labour and nutrient use efficiencies for rice in Ilocos Norte. Modern rice varieties are cultivated. At the LTCCE, it is IR72, while in Ilocos Norte these are IR64, IR42, IR66, IR5 and BPI Ri10 (Cosio *et al.*, 1998).

Agronomic efficiency (AE) of fertilizer N is defined as the ratio kg increase in rice produced per kg fertilizer applied. For an experiment conducted during 1995-97 at MMSU, Batac, Ilocos Norte, AE at 120 kg N ha^{-1} applied was 18.4. AE was also calculated for the LTCCE (1993-99). In the dry season, AE ranged between 20 and 25 at moderate to high nitrogen application rates (130 - 210 kg N ha^{-1}). For the early wet season, AE was 11 at 90 - 110 kg N ha^{-1} applied (Roetter *et al.*, 2001). Further comparison on AE was done with data from the IRRI coordinated RTDP Project (206 sites in Asia). Under current farmers' fertilizer practices, mean AE was 9.6 versus 13.8 when applying site-specific nutrient management (SSNM) (Dobermann *et al.*, 2000b). At the LTCCE, the world's most intensive rice field: (*i*) labour use efficiency increases with yield and (*ii*) pesticide use efficiency is higher under integrated pest management (IPM) than under full protection, but also increases with yield (Roetter *et al.*, 2001). Comparison to the farm survey data from Ilocos Norte shows that there is considerable scope for improving nitrogen use efficiency at moderate to high doses. Striking is a high pesticide use efficiency in Ilocos Norte. In recent years, farmers widely adopted IPM (Cosio *et al.*, 1998), since rice is mostly cultivated only once per year (during the wet season). In such systems, IPM is much more effective than in double or triple rice (Litsinger, 1989). This co-determines the high labour use efficiency in the province.

Past and possible future trends in labour and fertilizer costs

In the analysis for the year 2010, three price scenarios were considered: (A) the baseline scenario uses current prices for all production inputs and output, (B) fertilizer price increases by 25% over current levels, and (C) in addition to the increase in fertilizer price, the farm wage rate increases by 35% (Table 3).

From 1961 to 1980, the nominal farm wage rate in the Philippines increased by 7.1% annually, but the real farm wage rate was declining by 2.1%. The declining trend was reversed from 1980 to 1992, during which the real farm wage rate increased by 2% annually (source of basic data: World Rice Statistics for 1999, IRRI). For the next 10 - 20 years, we therefore consider two variants:

- In scenarios A and B, there is no change in labour costs, which would reflect the past long-term trend.
- In scenario C, there is a 35% increase in labour costs over the next 10 years, reflecting an optimistic view on economic development.

The real price of urea in the Philippines decreased annually by an average of 4% from 1990 to 1997. Despite this trend, we also considered the possibility of real fertilizer price increases in the next 10 - 20 years (scenarios B, C). This reflects the pessimistic view of geologists who expect that oil supplies will start to decline steadily in about 15 years. This would have considerable implications for oil prices and consequently for energy costs ("The next oil crisis looms large – and perhaps close"; *Science* (1998), Vol. 281, 1128-1130). Fertilizer price strongly depends on energy costs and would increase accordingly. But even when taking this pessimistic view, we would not expect the fertilizer price increase by more than 25% in the next 10 years.

Results

When current land, labour and water constraints as well as provincial demand for rice and other crops were considered in the optimizations, the maximum attainable rice production under the average farmers' practice was 295,000 tons. This allocation resulted in a total non-rice production of 62,400 tons, used up to 11,000 tons of N fertilizer and generated an income of 1.9 billion pesos. In contrast, when N fertilizer use was minimized, fertilizer use declined by 72% as a result of the reduction in rice production by more than half. The maximum income, on the other hand, was eight times more than the income that will be generated when rice production is maximized. This optimal income can be achieved by shifting to more profitable land use types (root crops, mungbean, rice-tomato) rather than the double and triple rice systems.

If all farmers would adopt Technology 2 or 3, then optimal rice production would increase by 67% and 74%, respectively. Under Technology 2, land use systems will require considerably more inputs; hence, when N fertilizer use is minimized, the use of this input will increase by 25% over fertilizer use levels under Technology 1. Technology 3, however, employs more resource-use-efficient techniques than Technology 1. N fertilizer use will decline by 30% over usage levels under Technology 1.

Although more production inputs are required for Technology 2 than for

Technology 1, using only the former technology will lead to a doubling of regional income. If all farmers would adopt Technology 3, this would result in a further increase of 40% in optimal income.

Anticipated changes in fertilizer and labour costs had negligible effects on the values of income. Values were reduced by 1 - 3% for all technology levels.

Figures 1a-c show modelling results for three different optimizations: (a) to maximize rice production (Technologies 1, 2 and 3), (b) to minimize fertilizer use (Technologies 1, 2 and 3), and (c) to maximize income (Technologies 1A, 1B, 1C, 2A and 3A).

Discussion

Assumptions on 'improved practice' are made for what is considered feasible in the not too distant future. While in the next 10 years new semi-dwarf rice varieties with 13 - 15 t ha^{-1} yield potential in the tropical lowlands and resistance to major pests might be fully developed (Peng *et al*., 1994; 1999), it is unknown when and to what extent this will lead to productivity gains, since crop and soil management practices still need to be tailored to these new plant types. For this reason, we do not assume that in the foreseeable future productivity gains will exceed the level of current 'best farmers' yields' (Technology 2), but that considerable gains in resource use efficiency are possible with current plant types (Technology 3).

Current research on NRM in agricultural systems in Asia is designing and testing knowledge-intensive, innovative crop production technologies to optimize resource use efficiency. These are based on the concepts of integrated crop management (ICM) (Meermann *et al*., 1996), including knowledge-intensive, SSNM and IPM (Peng *et al*., 1996; Dobermann & White, 1999; Rabbinge, 1999). For instance, at average yield levels of 5 - 5.5 t ha^{-1} in irrigated rice systems, IPM has proven to be effective and nutrient use efficiency could be increased between 20% and 40% through SSNM (Dobermann *et al*., 2000b).

For intensive, irrigated rice systems, attempts are being made to optimize resource use efficiency (Cassman *et al*., 1998; Dobermann *et al*., 2000a; Roetter *et al*., 2001) based on the principles of the law of the optimum (Liebscher, 1895; De Wit, 1994).

De Wit (1994) stated that a production factor which is in minimum supply contributes more to production the closer other factors are to their optimum. Haverkort *et al*. (1997) suggest that strategic research on NRM should seek to identify the minimum of each production factor needed to allow maximum use of all other resources. Research in intensive, irrigated rice systems, in which nitrogen is the factor in minimum supply, has shown that indeed the law of the optimum applies and that resource use efficiency can be improved considerably even at yields of > 6 t ha^{-1} (Peng *et al*., 1996; Dobermann *et al*., 2000a). In Ilocos Norte, the expansion of the irrigated area is estimated at 13,434 ha by 2010 (25%

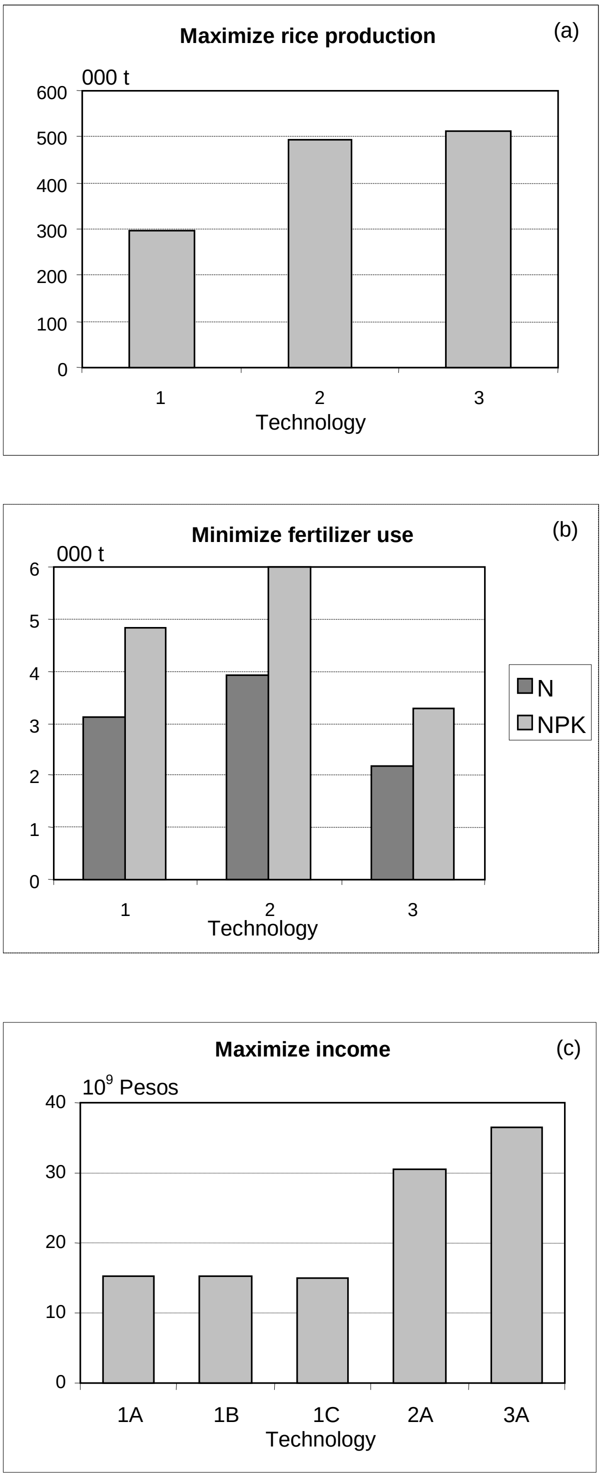

Figure 1a-c. Results of optimizations to (a) maximize rice production, (b) minimize fertilizer use and (c) maximize income.

increase) and there is scope for considerable efficiency increases (Provincial Government of Ilocos Norte, 1999). Still, about 40% of the agricultural area will depend on rainfall, which means that at times water will be the factor in short supply. Consequently, in years of low rainfall, the area under cultivation is less and farmers use less nitrogen than in years with favourable rainfall (RLRRC, 1998). This clearly hampers optimization of resource use efficiency. Another constraint to improvement is related to land tenure. According to Cosio *et al.* (1998), less than 50% of the rice farmers in Ilocos Norte own the land they cultivate. This limits to some extent the scope for implementing knowledge-intensive and site-specific production technologies.

When income is maximized, the corresponding land use allocation shows that a few cropping systems (root crops, rice-tomato and mungbean) would cover about 90% of the agricultural land. This applies to all scenarios. The local demand for root crops and for mungbean would be far exceeded. This would have consequences for the product price. This has not been accounted for in the current model. When we introduced some very optimistic future market ceilings for mungbean, root crops and tomato, total farmers' income in the province as well as the area under cultivation decreased considerably. In large parts of Ilocos Norte, water is not sufficient to cultivate a crop in the dry season, except for crops with low water requirements such as root crops and mungbean. In future work, price elasticities will be incorporated in LUPAS according to Schipper *et al.* (1998), so that the operational system will be able to capture the changes in prices resulting from changes in the supply and demand of agricultural products and production inputs.

Conclusions and outlook

Population density in many Asian countries is already very high and will increase further, which implies the need for tremendous productivity increases. In some provinces of China (Rabbinge, 1999), the limits of the carrying capacity seem to be in sight (Smil, 1998). It is only through judicious use of external inputs and natural resources and supportive policies within the limits set by agricultural production potential and socioeconomic conditions that sustainable productivity increases can be achieved.

For Ilocos Norte Province, the medium- to long-term prospects are as follows:

- If 'best farmers' practices' were applied by all farmers, crop yields would increase by 70 - 120%.
- Productivity increases and substantial income increases (up to 140%) at reduced environmental costs are possible by adopting knowledge-intensive management practices.
- Probable changes in fertilizer and labour costs will have negligible effects on goal achievements.

Model results for Ilocos Norte based on farm surveys and field experimental data indicate that the law of the optimum (Liebscher, 1895) on resource use applies at both the field and regional scale. Some prevailing socioeconomic constraints such as low investments for expanding/improving irrigation systems currently prevent the optimization of resource use. Apart from incorporating price elasticities in LUPAS, in future studies for Ilocos Norte, it will also be necessary to take into account multi-decision-level conflicts in land use objectives and resource use (farm, municipality and province) and to have a closer look at the behaviour of farmers, which is decisive for the adoption of new production technologies. There is still plenty of scope to improve studies on policy design by better links between on-farm and operational research.

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Can Tho Province case study: Land use planning under the economic reform

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Introduction

Can Tho Province is located in the central part of the Mekong Delta of Vietnam. The province's economy is mainly based on the agricultural sector. Total area of the province is about 0.30 million ha, of which 82.7% is under arable farming with rice-based cropping systems as the predominant land use type. The population of Can Tho in 1997 was 1.92 million, with 80% living in rural areas.

The economic reform of Can Tho was successfully implemented between 1991 and 1996, resulting in an annual economic growth rate of 9.3%. This increased slightly in 1997 to 9.5%, before the financial crisis in Asia. Development in all sectors led to an average gross domestic product (GDP) per capita of US$473 in 1997 versus US$369 in 1995. The contribution of agriculture to the total economy of the province decreased from 53.9% in 1995 to 39.7% in 1997 (Luy, 1998), but agriculture and fisheries contributed 78.7% to total export value.

Economic development of the province continues to be based on agriculture. The objectives of agricultural development are (*i*) to assure food security, (*ii*) to increase the value of agricultural production and (*iii*) to increase the total value of exports. Realization of these objectives requires more efficient use of agricultural land, with higher yields and improved quality of agricultural products, especially rice.

Rice production in Can Tho is not only to assure food security of the province, but also for the country. Vietnam has decided to strictly maintain its present rice area, about 4 million ha, until at least 2010. One goal is to ensure a stable annual output of 33 million tons of unhusked rice, of which 25 million tons will be earmarked for domestic consumption and the country's food reserve, and the remaining 8 million tons for export. In 2000, however, the country exported only around 2 million tons of rice in the first seven months of the year, a 40% decrease compared with the same period one year earlier. Concurrently, the decline in rice price in the international market caused the domestic rice price to fall. Such a situation requires a change in the policy for rice production, in particular in the provinces, such as Can Tho, where rice is the major product.

Because of chronic difficulties in marketing of agricultural products, particularly rice, in recent years, policymakers have been forced to reconsider their plans for restructuring the agricultural sector. The process of restructuring agricultural production and increasing farmers' income has been too slow. The process needs to be accelerated to encourage many individuals to continue farming. Therefore, besides analysing trade-offs among different land use objectives as identified at the beginning of the SysNet case, an important additional 'what-if' question needs to be considered: What are the consequences for land use if the policy view is changing from a scenario with priority for rice production to one that favours diversification for income generation? Such a scenario also challenges the operational capability of the land use planning and analysis system (LUPAS) that was developed for the Can Tho case study area. Adjustments of LUPAS were needed to be able to respond to rapid changes in policy views on agricultural land use.

Methodology and results

LUPAS for the Can Tho case study area

The LUPAS developed for the Can Tho case study area has the following functional components (Hoanh *et al*., 1998; Lai *et al*., 1998a):

- Land evaluation and resource assessment,
- Yield estimation,
- Input-output estimation, and
- An multiple goal linear programming (MGLP) model to analyse optimal possibilities in land use.

The purpose of land evaluation and resource assessment is to (*i*) identify land units and their characteristics, (*ii*) estimate available resources and (*iii*) identify promising land use types. Crop yields, at various technology levels, are extracted from farm survey data. For each yield level, corresponding input-output relations are estimated. A technical coefficient generator has been developed applying the LUST (land use system at a defined technology) concept (Jansen & Schipper, 1995; Jansen, 1998) to generate the input-output values of each crop for the different land units (Lai *et al*., 2000).

In the 1999 study (Lai *et al*., 2000), effects of differences in capital availability were introduced in the MGLP model. Capital is a constraint that limits the capacity of farmers to apply improved production technologies. Based on income per capita of farmers, as derived from survey data, farmers in each district of the province were classified into four groups: poor, medium, better-off and rich, with income per capita of < 1, 1 - 2, 2 - 3 and > 3 million VN dong[2] per year, respectively. The fraction of farmers in each group FG(g,d) was estimated per district. Average farm size, FS(g,d), for each group per district was estimated from the survey data. Subsequently, the fraction of the area that each farmer group occupies in the district, FA(g,d), was calculated as FG(g,d) × FS(g,d). The decision of

[2] VND = Vietnamese dong; 1 US$ = 14, 000 VND (September 1999).

each farmer group was considered valid only in the area that it managed. The optimal land use options in each land unit generated by the MGLP model were therefore calculated for each farmer group separately. It was assumed that, because of capital constraints, only better-off and rich farmers could apply improved technology due to higher input requirements and costs. A capital feasibility factor was introduced to reflect this assumption in the MGLP model.

At the beginning of the study, seven objective functions were proposed (Lai *et al*, 1998a), of which three have been of major concern in the scenario analyses: (*i*) maximize total regional net farm income; (*ii*) maximize total rice production and (*iii*) maximize employment generation.

Application of LUPAS for scenario analysis under the economic reform

In 1998, on the basis of policy views, development plans and targets, two sets of scenarios were formulated:

- Scenarios for 2000 using current data on biophysical and socioeconomic resources and development targets for 2000 to examine by how much each goal could be improved with currently available resources, and what changes in land use would be required to achieve such improvement.
- Scenarios for 2010 using modified biophysical conditions and development targets for 2010. The objective of these scenarios is to explore more future-oriented options for development.

From the preliminary analysis of LUPAS results in 1998 (Lai *et al*., 1998b), conflicts in development objectives are clearly shown: maximizing income leads to lower rice production and lower employment, while maximizing rice production leads to lower income and higher employment (Table 1).

After the refinement of LUPAS in 1999, the scenario analysis more clearly showed these conflicts. For example, when income is maximized, rice production and employment decrease by 29% and 19%, respectively, compared with the maximum achievement of these two objectives. On the other hand, when employment is maximized, rice production decreases sharply (54%).

In the same year, 1999, a review of the economic reform concluded with

Table 1. Goal achievements under the conditions of 1997.

No.	Goal	Maximize rice production	Maximize income*	Maximize employment*
1	Rice production (million t)	1,876	1,800	1,800
2	Income (billion VN dong)	5,196	5,489	5,172
3	Labour use (million labour-days)	51.6	49.5	57.2

* with target for rice production = 1.8 million tons.

Table 2. Goal achievements under the conditions of 2000.

No.	Goal	Maximize rice production	Maximize income*	Maximize employment*
1	Rice production (million t)	2,567	1,821	1,195
2	Income (billion VN dong)	3,887	5,130	4,180
3	Labour use (million labour-days)	50.5	63.9	79.3

* no target for rice production.

recommendations for decentralization and shifting more distinctly to the free-market system. Under such conditions, skills and decisions of farmers with respect to resource management become more important than in the former centralized economy. To increase income of the rural population, improved technology is likely to be introduced faster and capital support provided more effectively to the farmers than before. Under such a scenario, it is assumed that all four farmer groups, including the poor, can apply the improved technology. With such capital availability, in the scenario of maximizing employment, employment, income and rice production could be improved by 3%, 12% and 13%, respectively (Lai *et al*., 2000).

However, rice production was still considered as the major target for the year 2000, with an (even higher) target of 2 million tons. The relevant 'what-if' question in that case is: What is the consequence for employment generation if rice production has to exceed 2 million tons as required by the central government? A multiple goal scenario is analysed by first maximizing income and setting a target of 2.0 million tons. The results show that employment decreases to 19% of the available rural labour force, while about a 5% improvement in income can be gained. Next, the scenario of maximizing employment shows that at most only 27% of the available labour force can be gainfully employed, while income as well as rice production are significantly lower than their respective maxima, i.e., by 19% and 35%.

Recently, input data and information for the LUPAS have been updated. As mentioned above, the price for exported rice has changed and the reduction in rice exports has led to a change in policy. Rice production is not as strictly fixed as it used to be and policy favours diversification to boost farmers' income. The stakeholders are looking for an optimal compromise scenario that gives priority to maximizing income rather than rice production. Results for this revised scenario show that, when income is maximized, a total rice production of about 1.8 million tons is achieved (Table 2).

Discussion

The development and application of LUPAS for land use planning in the Can Tho case study show that

- LUPAS can be applied to identify the optimal options in land use under the economic reform when the objectives for development are rapidly adjusted to accommodate for changes in production and consumption as a consequence of the country's active participation in international trade.
- Refinements of LUPAS to satisfy new requirements in the analysis of land use options can be rapidly and independently included by the NARS, which have developed the capacity during participation in SysNet. The LUPAS framework proved to be sufficiently flexible for being adjusted to new 'what-if' questions at reasonable requirements of manpower and time.
- Since no modelling system or methodology can cover all the changes/cases that are possible in reality, the strategy of SysNet has not been to develop and deliver a rigid system with its applicability limited to the conditions perceived important at the time of its development. On the contrary, LUPAS development has always been driven by the intention to train and transfer technology to national and local researchers. The project invested heavily in training of NARS scientists to enable them to handle the system and make refinements and adjustments on their own, when needed. For Can Tho, this strategy proved to be the right one.
- However, stakeholders involved in the Can Tho case study requested not only more refinements of LUPAS and further regional analyses but also more flexibility in the analysis that would require further expansion of the system. The issues raised include among others:
  - At the regional level, how to arrive at a compromise option from the multiple goal analysis that satisfies the majority of the stakeholders rather than only identifying the degree of the conflicts.
  - How to identify and analyse conflicts in resource management among different decision levels, i.e., regional, district and farm.
  - How to incorporate variations in certain factors at different levels in LUPAS, for example, variations in international rice prices.
  - Flexibility in generating land use plans in direct and prompt response to changes in the real world. This also relates to a request for dynamic (multi-period) analysis of optimal land use options.
  - To operationalize the LUPAS methodology, cooperation between research organizations and management agencies needs to be strengthened; this includes, for example, comprehensive training of the management staff (end-users) who eventually should be carrying out the planning exercises.

Conclusions

It has been demonstrated that the LUPAS developed for Can Tho is applicable to complicated land use problems and is sufficiently flexible to be adapted to new situations (e.g., the economic reform process).

Application of LUPAS in this case study has also shown that SysNet's mode of scientific collaboration (IRRI, Asian NARS and Wageningen University and Research Centre) in methodology development and technology transfer is successful in dealing with complex local issues in land use planning.

Many challenges remain, however, to bring the methodology to a fruitful and day-to-day operational phase.

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Recommendations by external reviewers

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Introduction

The following sections have been extracted from the external review report of 18 October 1999 (by Goldsworthy & Horton). This is to provide an objective, external assessment of the status of SysNet's major accomplishments after three years, as well as of the 'unfinished business' and recommendations for future activities. The excerpts presented in the following can therefore be taken as a starting point for appraising SysNet's activities during the project extension from November 1999 to June 2000 (see next chapters).

Programme contributions to ecoregional R&D

SysNet has made some important contributions in the area of ecoregional R&D. The first and perhaps most tangible contribution relates to the advancement of quantitative methods for land use planning and analysis in the context of practical application. The various reports and publications on LUPAS and its component models offer evidence of this contribution.

A less tangible, but no less important, contribution refers to enhanced mutual understanding on the part of scientists concerning the role of quantitative modelling in land use planning and policy making. As a result of their participation in the SysNet project, planners now understand better what kinds of information can be generated by land use planning models. Similarly, scientists (at IRRI and in Wageningen as well as at the four study sites) now understand better what information planners and policymakers would like to have in order to improve their decision making.

A third contribution is that at the study sites there has been progress toward improving the information available for land use planning and analysis. Stakeholders from Malaysia, Philippines and Vietnam indicated that their aim was to demonstrate the application of the system at a provincial level and, when that had been done, successfully make the system available to other states or to the central planning authorities. An important issue for the future is to consider whether the most effective propagation of the methods for wider use might best be done in this manner, rather than on the grander scale of the CGIAR ecoregional projects where the management issues are more complex.

Unfinished business

Improvements are to be made in the following areas:

- Increase the scope of the analysis to include different scales, including farm and household data.
- Add capability to examine future scenarios, including relative changes in the price of production inputs and outputs.
- Indicate the probable time frame for change from a present to desired situation (e.g., the shift from rubber to oilpalm production in Malaysia).
- Provide means to assist in resolving conflicts between goals at a single level, at different decision levels (e.g., regional *vs* municipal) and at different stages of development. Once this is done, it will be easier to attribute weights to objectives and optimize for several goals.
- Consider other novel scenarios and a wider range of 'what-if?' situations. This will involve generation of technical coefficients for alternative production technologies.
- Include area under forest in the resource analysis.
- Develop models for perennial crops or stimulate others to do so.

Global assessment and recommendations

The SysNet project can be characterized as ambitious, innovative and productive. Its objectives have been, and continue to be, highly relevant to the improvement of ecoregional R&D. Its results are abundant and of generally high quality. The project has made significant contributions to the development of methods for land use planning and analysis. It has achieved an integration of multidisciplinary efforts on important aspects of natural resource management.

In their future activities, it is recommended that SysNet managers and participants:

- Give high priority to ensuring the application of methods developed in planning and policy making. To this end, the planning processes actually used in the study areas and the information needs of planners and policymakers need to be better understood. Involvement of intended users in development and testing of methods should be intensified. Presentation of outputs should be simplified for the benefit of users.
- Expand the sources of knowledge and expertise drawn on in both the biophysical and social-science realms.
- Explore alternative sources of funding to support methodology development and testing in a networking mode, involving both national scientists and other intended users of the methods and of their results.
- Seek opportunities to convey the significance of this work to scientific and policy audiences, including those affiliated with the ecoregional programmes of the CGIAR.

Progress: November 1999 to June 2000

Development of a tool for interactive land use scenario analysis: IMGLP user interface

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Introduction

Tools for resolving conflicts

Potential conflicts between the required increase in land productivity and farmers' income and the conservation of water, soil and other natural resources represent major problems for agricultural systems and rural development in South and Southeast Asia. According to Van Ittersum (1998), identification and implementation of

- Production systems and technologies that make optimum use of external inputs and natural resources and avoid natural resource degradation, and
- Policy measures supporting their adoption for sustainable agricultural development

would be the keys to resolving such conflicts.

One of the research challenges in this context is to develop effective tools for land use planning and resource analysis that can make the issues transparent and identify required technical and policy changes.

Between 1997 and 2000, the SysNet project has developed methods and tools for identifying options for agricultural land use at the subnational scale (provinces, states) and has tested these in four selected regions in South and Southeast Asia. Data and tools have been integrated into the so-called land use planning and analysis system (LUPAS) (Hoanh *et al.*, 2000), which is now operational for the four case study regions: Haryana State (India), Kedah-Perlis Region (Malaysia), Ilocos Norte Province (Philippines) and Can Tho Province (Vietnam) (Roetter *et al.*, 2000). LUPAS allows users to relate biophysical and technical opportunities of agricultural systems to societal objectives and priorities. This means that technically feasible solutions generated by 'hard systems' are confronted with the 'value- or preference-driven' objectives and targets and acceptance of technical solutions as expressed by different interest groups. With its specific features, LUPAS meets the much-proclaimed demand for novel tools for strategic land use planning (Bouma *et al.*, 1995; Rabbinge, 1995).

New tools for land use systems analysis

During the last decade, systems analysis methods and several new tools for decision support in strategic land use planning and rural resource management have become available – as reported by Van Keulen & Veeneklaas, 1992; Rabbinge, 1995; Schoute *et al*., 1995; Hoanh, 1996; Van Ittersum *et al*., 1998; Kuyvenhoven *et al*., 1998; Stein *et al*., 1998; Stoorvogel *et al*., 1998; Zander & Kächele, 1999; Laborte *et al*., 1999; Rossing *et al*., 2000.

A common denominator of these decision support tools is that they seek to provide sound information as a basis for improving the 'quality' of decision making with respect to key problems in rural development and resource management (Walker & Zhu, 2000; Van Keulen *et al*., 2000).

The demand for new land use planning tools has not only been emphasized by scientists, but also by a wide range of stakeholders in South and Southeast Asia. For example, in 1997, scientists from MARDI (Malaysian Agricultural Research and Development Institute) conducted a survey among state-level planners and 220 farmers in the Kedah-Perlis Region to assess perceptions of the specific agricultural development objectives in the region as well as on major obstacles (Tawang *et al*., 1998). The lack of flexible planning tools to assess the consequences of changes in policy views was identified as one such constraint. Other examples include various scientist-stakeholder meetings on ecoregional activities at pilot sites in Vietnam and Thailand during 1997-98, in which stakeholders stressed the need for tools to support integrated planning (e.g., Kinh *et al*., 1999). Finally, at the SysNet'99 symposium at IRRI, several key policymakers and planners from four Asian countries expressed the need for new planning tools and their willingness to evaluate and apply such tools (Roetter *et al*., 2000).

Does LUPAS qualify as a decision support system? There are 'information-technology oriented' and 'management-oriented' definitions of decision support systems (DSS) (Walker & Zhu, 2000). An example of the former category is given by Adelman (1991):

> "DSS is a diverse class of computer technology integrating data-base information and analytical modelling methods (artificial intelligence, decision analysis, optimization models, etc.) to support decision making".

For the category 'management-oriented' definitions, Cox (1996) points out that the term DSS is increasingly used

> "to indicate any kind of decision aid, whether computer-based or not, and whether the problem it purports to address is more or less well structured. It has become almost synonymous with 'extension'!"

LUPAS does qualify as a DSS according to both Adelman (1991) and Cox (1996).

SysNet-LUPAS is a computer-based decision support system for strategic land use planning with emphasis on the agricultural sector (at the state and provincial level). It aids decisions by integrating relevant data and information and by improving the 'quality' of the decision-making process (Roetter *et al*., 1998).

In response to stakeholders' and scientists' comments on LUPAS, more recently, a *user interface* has been created. Its aim is to widen accessibility of the information generated by SysNet, allow easy use of the LUPAS system and enhance interaction among stakeholders (scientists, planners, other stakeholders/end-users) in formulating scenario runs and interpreting results – as advocated, among others, by Bouma (2000).

This paper briefly addresses four aspects of the decision support tool: (*i*) information needs and relevance of the system, (*ii*) development of the IMGLP user interface, (*iii*) its major features, capabilities and applications, and (*iv*) accessibility of the information generated/potential bottlenecks to adoption.

Information needs and relevance of LUPAS and IMGLP user interface

LUPAS is based on the interactive multiple goal linear programming (IMGLP) technique (De Wit *et al*., 1988). Applying LUPAS to study alternative land use scenarios facilitates learning about the performance of agricultural systems at the regional (subnational) level. Scenario settings and model runs carefully selected and analysed by a mixed group of scientists and stakeholders can serve as a basis for negotiating alternative land use options among different stakeholders. Walker & Zhu (2000) list four reasons that would justify the development of research-based decision support systems for rural planning/resource management:

- Increasing information availability
- Increasingly complex decisions being required
- Professionalization of resource management systems
- Increasing requirements to demonstrate 'due process'

With respect to the four SysNet case studies, all these reasons apply, although not always to a full extent:

- With the rapid diffusion of computers and information technology into remote areas of South and Southeast Asia and the access to remote-sensing data, available information has increased exponentially – especially in the last five years. While this inundation of data has been absorbed by (SysNet) research groups, who combine a broad range of disciplines working on a well-defined subject, local resource managers are just being confronted or struggling with the question how to deal with this. In all cases, the multi-disciplinarity of the SysNet teams turned out to be right on time to enable local governments to better manage and use available information (not only for the purpose of the SysNet project).
- With the ascent of the 'second Green Revolution' in Asia, and the experience of negative (side-) effects and problems associated with the productivity increases during the 'first Green Revolution', there is wide awareness that only

progressive management practices that respect (agro-)ecological principles can help to increase production at reduced environmental cost. Finding solutions is more complex, since both production and environmental goals need to be taken into account.

- Inherent to the former point, management practices are becoming increasingly complex, which generally requires that knowledge-intensive and site-specific solutions need to be found to fine-tune/optimize resource use efficiency. Fine-tuning and optimizing resource use require more detailed information, on both the resource base and crop status ('matching demand with supply in time and space'). Such 'real-time' management practices are increasingly being introduced in the intensive irrigated rice and rice-wheat systems (e.g., in nitrogen management); such fine-tuning is meant by professionalization of management systems. Moreover, national governments are increasingly including the use of proper planning and management tools as one of the criteria for allocating funds to state and provincial governments.
- Demonstrating 'due process' is connected with keeping records of management. While this practice is common in Europe (even for the majority of farmers, sometimes under the influence of government legislation), it does not yet affect many farmers in Asia. However, resource managers at the catchment, provincial or state level increasingly face legislation related to environmental impact (more in Malaysia and the Philippines than in India and Vietnam).

Development of IMGLP user interface

Operationalizing LUPAS for land use scenario analysis required

- Databases on biophysical and socioeconomic resources and development targets.
- Models and expert systems for assessing resource availability and quality and describing input-output relations for all relevant production activities.
- Active stakeholders that translate and prioritize policy views into specific objectives and targets.
- Sets of goal variables (representing specific objectives and constraints).
- A multiple-criteria decision method (multiple goal linear programming, MGLP, models) to optimize land use under different sets of objectives and constraints.

As mentioned earlier, this has been done for four case study regions in South and Southeast Asia. However, the interactive part of IMGLP had not yet been well developed technically. A typical interactive scenario analysis starts with exploring the 'window of opportunities' for agricultural development in a given region. This is realized by first asking 'if-what' questions, such as 'If priority is given to maximizing food production, what will be the consequences for other development goals (such as farmers' income and employment), and what production technologies and resources would be required to achieve, for instance, a 50% increase in cereal production'. The first cycle of exploring the optimum for each development goal in turn is called 'zero-round', with only resource constraints imposed. In the next iteration, one development goal or policy view (e.g., increase in income) is given priority and optimized while minimum requirements are set for other goals (e.g., food production, employment). In subsequent iterations, anticipated future resource constraints may be introduced and, by consensus, certain goal restrictions may be tightened (more employment, less nitrogen fertilizer use) until the 'solution space' narrows to only a few acceptable solutions that are much closer to reality than the most desirable and technically feasible potential solutions. Through a stepwise approach, trade-offs between conflicting goals are quantified and the required resources and production technologies are made explicit. The whole procedure, from definition of scenarios for the various iterations to discussion of the consequences of possible interventions (e.g., what would be the effect on goal achievement if resource availability were increased), is (or, at least, in the ideal situation should be) a highly interactive process.

This *interactive part* of IMGLP is most critical, and especially in this area SysNet has made its most innovative contribution to ecoregional research and development. Our approach is in line with the leitmotiv of Walker & Zhu (2000, p. 8):

> "Only by being prepared to invest in developing systems responsive to the context of decision making and by finding novel ways of facilitating the uptake of products by decision makers can DSS developers hope to have a significant and consistent impact on practice."

In consultations with local stakeholders, agricultural development objectives and constraints related to production, income, employment and environmental protection were identified and translated into scenarios combining multiple objectives: choice and degree of tightening goal restrictions reflect the specific priorities for sustainable land use by the different stakeholders involved. Since different stakeholders express different opinions and preferences, usually a multitude of scenarios with various iterations ('what-if' questions) needs to be analysed and compared. To facilitate this negotiation and learning process, SysNet developed the IMGLP user interface (UI). Some years ago, the stepwise optimization procedure still required considerable computer time. SysNet has taken advantage of recent hard- and software developments to facilitate interaction with users.

Currently, the IMGLP user interface is operational for the case study regions Ilocos Norte Province, Philippines, and the Kedah-Perlis Region, Malaysia.

User interface: major features, capabilities and applications

The IMGLP user interface (UI) allows definition of scenarios through selection/editing of:

- Optimization settings (goal to be optimized, target region, accessible production technologies with variable input-output coefficients).
- Constraints (resource availability, environmental and economic goal restrictions).

The user request form (partly) illustrated in Figure 1 consists of four major sections:

- Objective to be optimized/optimization settings
- Resource constraints
- Goal restrictions
- Additional (production) constraints.

At the bottom of the request form, explanatory remarks on the specific model run can be included, and there are two buttons, 'Submit' and 'Reset input'.

In the first section, the user can select the 'objective' to be optimized, the target region and year. For Kedah-Perlis, there are 12 objectives to choose from (e.g., maximize income, maximize rice production, minimize labour use, etc.).

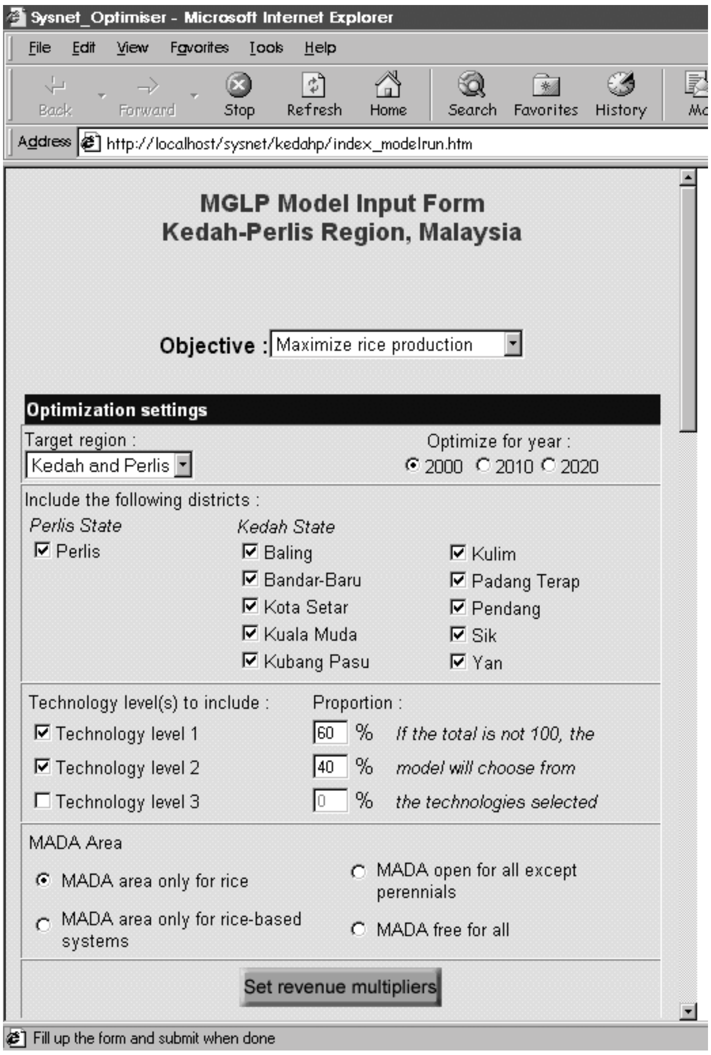

Figure 1. IMGLP model user request form (for Kedah-Perlis Region), first part. (View the complete form at URL: http://irriwww.irri.cgiar.org/IRRIIntra/sysnet/mglp/SysnetMGLP.htm).

The target region can be the Kedah-Perlis Region as a whole, Kedah and Perlis states separately or even individual districts within Kedah-Perlis. Note, however, that the spatial resolution of the underlying resource information will not change, but was chosen for modelling for the whole region. Target years are 2000, 2010 and 2020, for which projections on supply and demand of resources have been specified. Furthermore, the user can make assumptions on the proportion of production technologies accessible/available to the farmers of the region. For Kedah-Perlis, three technology levels are distinguished (Ismail *et al*., this volume).

As a special feature of the Kedah-Perlis case study, the user can express different future policy views about crop cultivation in the Muda irrigation scheme, which is managed by a regional management authority, MADA (Muda Agricultural Development Authority). Current policy is that only rice can be cultivated within the MADA-managed area.

The second section, 'resource constraints', enables the user to impose and modify actual labour and water constraints in different ways. Available land area suitable for agriculture (in a given target year) is always a constraint and cannot be modified. The third section on 'goal restrictions' allows the user to introduce (edit) or to change limits on the various goal values (e.g., on oilpalm production, labour or fertilizer use). Finally, the fourth section, 'additional constraints', allows the user to specify minimum production values for one or more crops, based on local demand for the product, or set minimum or maximum values based on either production target or target area per product.

The UI is compiled in HTML and allows to control/run optimization models externally (e.g., via the Internet) and provides the following features:

- View prepared model results (goal values, land use allocation maps).
- Compare results (pair-wise tables, graphs and maps).
- Generate a model run file by submitting a user request form.

The function 'Submit' generates data streams and converts them into model run files via CGI script. Results (graphs, maps, tables) can be displayed promptly. A detailed technical description will be given in Laborte *et al*. (IRRI Technical Bulletin, in preparation).

Examples of model output for Ilocos Norte Province are illustrated in Figures 2 and 3. Apart from viewing model results, e.g., on on 'land allocation' as pie charts (Figure 2) and maps (Figure 3), the user can also review the scenario description and look at individual goal achievements and production values of individual crops – both presented in the form of tables and charts. Most importantly, by using the 'COMPARE' function, outputs from two different scenarios can be viewed side by side. This applies to tables as well as to maps and charts.

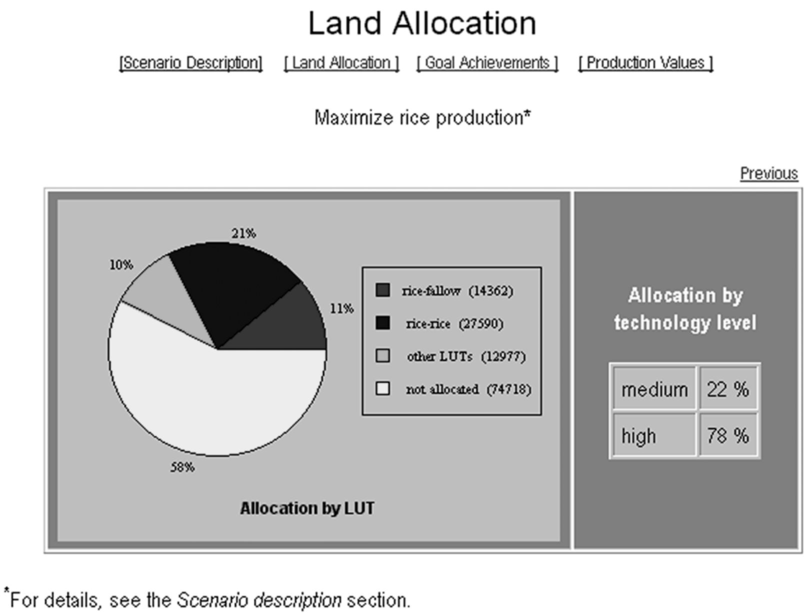

Figure 2. IMGLP model output for 'land allocation in percent' (for Ilocos Norte Province), prepared scenario, section A: no resource sharing, 'maximize rice production', without production limits.

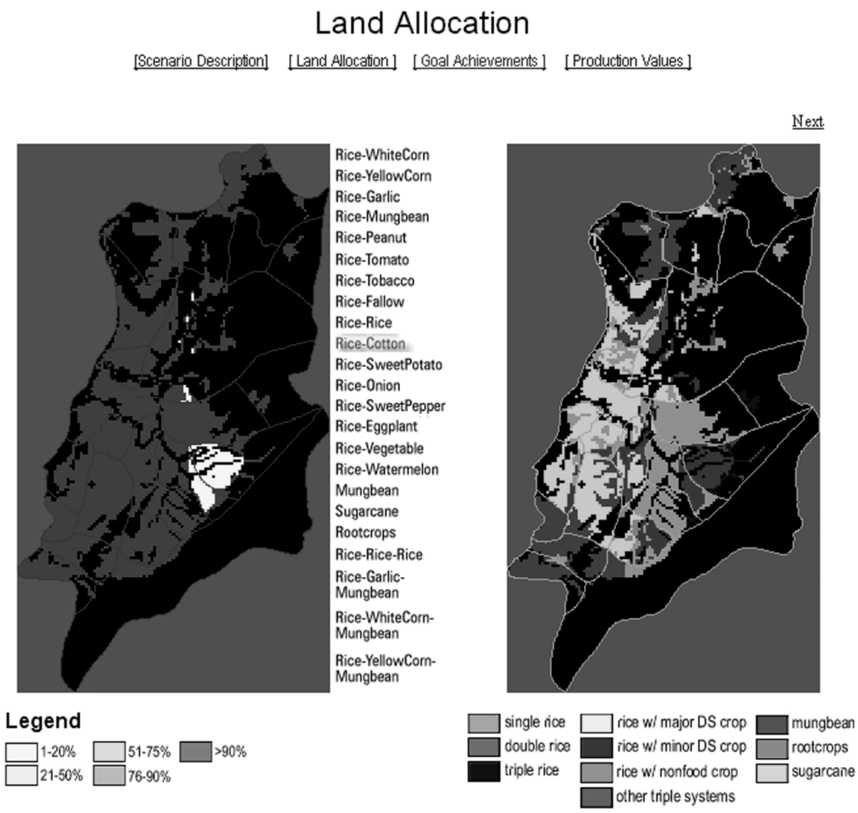

Figure 3. IMGLP model output for 'land use allocation' showing land use type and generalized map (for Ilocos Norte Province), prepared scenario, section 0. Land, labour and water constraints imposed, 'maximize rice production' – land use type map (left) shows percentage covered by the rice-cotton cropping system.

Accessibility of the information generated and potential bottlenecks to adoption of the system

Currently, the user interface, including supporting software plus numerous 'prepared scenario analysis results' for Ilocos Norte Province and the Kedah-Perlis Region, can be viewed on the IRRI intranet (see URL: irriwww.irri.cgiar.org/IRRIIntra/sysnet/mglp/SysnetMGLP.htm). Presently, users cannot submit a request for a new model run via Internet/email (SUBMIT function) – though conceptually the problem has been solved. However, since the SysNet project will terminate by the end of September 2000, no staff has been identified so far to provide the associated services. For the time being, we have resolved the problem by releasing a CD-ROM that contains the IMGLP user interface, supporting software and tools (MGLP models, GIS, technical coefficient generators, etc.) developed by the SysNet project during 1996-2000 (see Annex 1). Plans have been made to also develop the UI for the Can Tho Province case study region.

One bottleneck to making the system accessible to a wider user spectrum, in particular to local governments, is the high cost for a license of the commercial optimization software XPRESS-MP. This was one of the reasons for developing the user interface as a Web application (Dreiser & Laborte, 2000) and designing the specific model user request form (as outlined above). But we hope that the institutional personnel and minor technical problems to providing the UI service via the Internet can be resolved in the next few months.

However, a completely different type or complex of problems is associated with making the tools and information accessible to end-users. These difficulties mainly derive from the present lack of knowledge about concepts underlying the IMGLP technique, and the capacity and limitations of current regional MGLP models. This is more generally also connected to the lack of skills in many government planning and management institutions in managing large, complex and multi-disciplinary databases. This is, however, only a temporary bottleneck that can be overcome through assistance and knowledge transfer by the SysNet country teams. Another bottleneck is the lack of modelling features (a) to carry out multi-scale conflict analysis (from farm to region) and (b) to take into account price elasticities or climate-driven risks in the analysis (Roetter *et al.*, 2000). While the scientific challenges will be partly tackled in follow-up (PhD) studies (see Van Keulen *et al.*, this volume), it is beyond the scope of the current paper to deal with the question of accessibility of the information/bottlenecks to adoption of the system by local governments in greater detail.

Conclusions

- Through quantification of trade-offs between conflicting goals, the IMGLP user interface can improve strategic decision making on land and resource use for agriculture.

- The operational DSS enables integration of agronomic with ecological and socioeconomic information for exploring sustainable land use options at the regional level.
- The user interface allows varying input-output coefficients and resource availability in combination with different assumptions on technology level, economic conditions and policy, and facilitates learning processes of stakeholders on complex system behaviour.
- The future incorporation of methods and tools for multi-decision-level (field, farm, region) analysis in the user interface will result in a powerful and versatile DSS for integrated resource management and policy design.

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Stakeholder meetings in the Philippines, Malaysia and Vietnam

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Introduction

The ultimate goal of the SysNet project is to improve the quality of decision making on strategic planning related to agricultural land use at the subnational level. At the SysNet Symposium 'Systems research for optimizing future land use in South and Southeast Asia' (in October 1999), four NARS country teams demonstrated that they had developed the methods and tools and gained the skills to apply these in four case study regions. An external project review team concluded that the project had made remarkable progress in a short period of time with significant contributions to the development of methods and tools for land use planning and analysis. The reviewers recommended continuing funding of the project and give high priority to ensuring application of methods in planning and policy making. The Ecoregional Fund positively responded to a request for a budget-neutral extension that was granted till the end of June 2000.

To tackle the challenge and (still) meet the ultimate project goal, by the end of 1999, SysNet scientists opted for creating a user interface for interactive scenario analyses for those study regions (Ilocos Norte Province, Philippines and Kedah-Perlis Region, Malaysia) with good prospects for methodology transfer and implementation – while SysNet India and Vietnam concentrated on advancement /improvement of model components, their integration and documentation.

Through intensified interaction with stakeholders from Ilocos Norte and Kedah-Perlis (since November 1999), the planning processes and information needs in those regions were studied more closely, and, parallel to this, a user interface for SysNet's multiple goal linear programming (MGLP) models was designed and developed by IRRI scientists, transforming the models into user-friendly decision support systems that address the most relevant scenarios for a given region (Laborte *et al*., this volume). The main aim of the user interface is to allow fast model runs and immediate display and analysis of results, thus facilitating direct scientist-stakeholder interaction for policy design.

The question 'How well would these systems serve the information needs of local government unit (LGU) managers?' was to be examined at the SysNet final stakeholder meetings that were held in May and June 2000.

This development would not have been possible without informing and involving various stakeholder groups from the early stages of project implementation. The major objective of this contribution is to report on the project's progress made in developing a scientific-technical methodology for exploratory land use analysis in a networking mode. While emphasis will be on presenting the final outcome of this process, several related questions will be dealt with:

- Why were stakeholders involved in the process of methodology development?
- Which stakeholder groups have been involved at what stage of developing the land use planning and analysis system (LUPAS) methodology and how?
- What are the lessons learned, and how should stakeholders be involved in the future to ensure that the tools developed and the information generated can be successfully applied by the targeted end-users?

Why were stakeholders involved in the process of methodology development?

Stakeholders are individuals, communities or governments that have a traditional, current or future right to co-decide on the use of the land (FAO, 1995). In SysNet, we dealt in the first instance with provincial and state governments. However, over time a wider range of individuals and representatives of communities has been involved. Broadly, we distinguish two types of stakeholders: NARS scientists on the one hand and planners, policymakers and other community representatives from the study regions on the other. NARS scientists can be further grouped into members of the multi-disciplinary SysNet country teams and those that collaborated with the teams and/or the local governments.

In the initial project proposal, the role of stakeholders was not defined, while emphasis was given to innovations in the scientific-technical methodology for land use planning. During the project-planning workshop in December 1996, in which IRRI scientists met with collaborators from the four country sites and from Wageningen UR, the initial project design was reviewed. Based on the lessons learned from earlier projects applying IMGLP techniques in regional land use studies as reported by Veeneklaas *et al*. (1991) and later summarized by Rossing *et al*. (2000), SysNet scientists realized that planners and policymakers could not be expected to use the outputs of decision support systems for land use planning unless and until they developed confidence in the models, understood the outputs and considered them directly relevant for the decisions they needed to take.

Therefore, the SysNet teams agreed to re-direct the scientific-technical focus on developing a modelling system allowing interactive land use planning and analysis, and widen the scope of its training activities. While there was consensus on this, it was not yet clear how to realize this within the scheduled time span of the project and available resources.

Which stakeholder groups have been involved at what stage of developing the LUPAS methodology and how?

During the first year (between January and September 1997), local stakeholders were informed about the general methodology, workplans and data requirements. Some of them also participated in four in-country training workshops. Gradually (first during January to May 1998), they became involved in identifying priorities for model development, gathering relevant data and evaluating the models' outputs. Initial concerns by scientists that not enough farmers were represented in the stakeholder meetings were not justified. Over time, we learned that even most local scientists and research managers form an integral part of the farming community of Ilocos Norte. They shared their profound knowledge of management practices and constraints to farming with the SysNet team.

Figure 1 illustrates the involvement of stakeholder groups (the example applies to Ilocos Norte and Kedah-Perlis) at various stages of methodology development, from problem definition (point 1) to presentation of options (point 4). SysNet has not yet reached the implemenation stage (point 5) implementation. Within three years, 12 stakeholder-scientist workshops with participation of national and international teams were organized for the four case study regions. In January and February 1997, consultative meetings were held with researchers and stakeholders in the study regions and multidisciplinary teams. These meetings addressed points 1 and 2 of the five-point scheme. The meeting in Batac, Ilocos Norte (January 1997), had 70 participants representing (a) government planners and agriculturalists from the Department of Agriculture and Provincial Agricultural

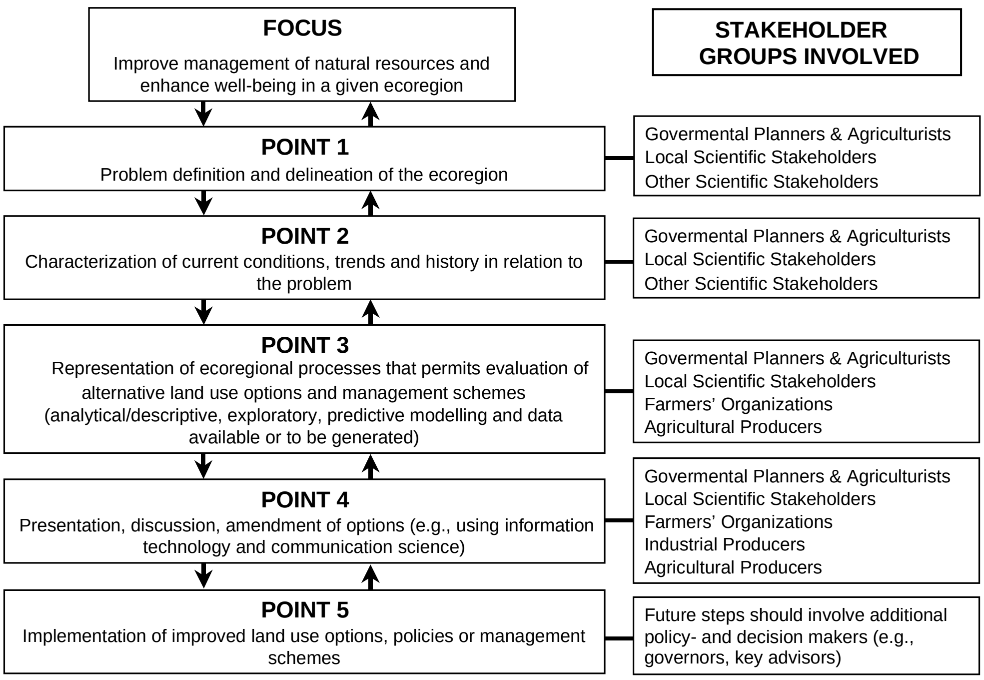

Figure 1. Stakeholder involvement in SysNet 1997-2000 related to the generalized 5-point scheme of ecoregional programmes (adapted from ISNAR, 1998, p. 150).

Office and planning and agricultural officers from 20 municipalities; and (b) local scientific stakeholders from Mariano Marcos State University (MMSU), the National Tobacco Administration and Cotton Development Authority, and (c) national scientific stakeholders (SysNet team members from PhilRice and the University of the Philippines at Los Baños). Point 3 of the scheme was addressed by the first series of four interactive stakeholder-scientist workshops between January and May 1998. These included intensive working sessions involving multidisciplinary teams at the study sites to integrate collected data and build component models for LUPAS. Local stakeholders were involved at the beginning and end of the one-week workshops to clarify land use objectives, assist in data gathering and review results of scenario analyses from the prototype LUPASs.

This series was followed by an international workshop at Can Tho City, Vietnam, in June 1998. The aim of this workshop, attended by 180 participants, was to exchange experiences and discuss results of scenario analyses for the four case study regions. A second round of in-country workshops was organized to allow scientists and stakeholders to review the updated models and databases. These events, held between March and May 1999, resulted in model improvements and filling of some data gaps (point 4 in scheme, Figure 1). The objectives of these interactive workshops were as follows:

- To present and discuss the SysNet methodology and the preliminary outputs from the LUPAS with stakeholders in the study region.
- To consult stakeholders on possible improvement of LUPAS and make necessary revisions.
- To consult stakeholders on alternative policy views and future directions of natural resource management for the study region – and associated definition of objectives for new sets of land use scenarios.
- To test the revised LUPAS with new sets of land use scenarios and present the outputs to stakeholders for discussion and suggestions for further work.

The four workshops followed a common structure and schedule: day 1 was devoted to a stakeholder-scientist meeting comprising two sessions: (*i*) review of LUPAS and its components, presented to stakeholders by SysNet scientists, and (*ii*) stakeholder consultation with comments by different stakeholders on the general approach, LUPAS components and relevant scenarios to be elaborated during days 2-5 by the NARS and IRRI SysNet teams. On day 6, there was a second meeting with stakeholders with presentation and discussion of new model outputs and a session on further work and interaction between stakeholders and scientists for improving LUPAS.

The revisions made in LUPAS, including the databases, formed the basis for generating land use options, documenting procedures and tools developed and presenting the results at the symposium on 'Systems Research for Optimizing Future Land Use' held at IRRI, 11-13 October 1999 (Roetter *et al*., 2000).

Outcome of the final stakeholder meetings

Programme for final stakeholder meetings: example for Ilocos Norte Province

- To discuss the most recent results from land use scenario analysis with provincial and municipal planners.
- To consult with planners regarding the most relevant land use planning decision-making issues at the provincial and municipality level (objectives, constraints, priorities/scenarios).
- To familiarize planners with the SysNet MGLP user interface for interactive scenario analysis for Ilocos Norte Province.
- To identify the required exchange of data and methodology improvement.
- To inform policymakers about the current capability of SysNet MGLP and scenario formulation.
- To perform and discuss new scenario runs and interpret results together with different stakeholders.
- To conduct a preliminary evaluation of the quality of SysNet LUPAS to meet decision support needs of policymakers, and decide on steps needed for methodology transfer.

Outcome of the stakeholder meetings at Laoag City, Ilocos Norte (May, 2000)

The SysNet team met with representatives of the Provincial Agricultural and Provincial Planning and Development Offices of Ilocos Norte to present the output of the SysNet project (i.e., MGLP user interface for interactive scenario analysis for Ilocos Norte). Several questions and issues were raised during the meeting. Unexpected for the SysNet team was the immediate, enthusiastic acceptance of the system and willingness of government advisors to test the tools for use in strategic agricultural planning.

First was the question, Who could avail of the software? SysNet scientists replied that the MGLP user interface still has to undergo testing and further refinement, and that afterwards it would ideally be made available through an Internet server to authorized persons (i.e., with a user name and password). As such, the tools may be installed at the MMSU server, or possibilities to install the system on the IRRI server could be explored. Finally, there is also the possibility to run the system on a local server (a powerful PC would need to be purchased). SysNet can provide user-interface and share-ware programs for running the interface locally (Annex 1); however, in the last option, the province would need to purchase the software XPRESS-MP, which is needed to run the optimization model.

On the second day, scientists met with representatives of the Provincial Agricultural and Provincial Planning and Development Offices and policymakers, including the governor of Ilocos Norte, several mayors and a consultant to the governor, responsible for agricultural programmes.

Scientists presented the modelling system for interactive land use scenario analysis and prepared scenario runs and interpretation of results for the province. Subsequently, hands-on exercises in applying the SysNet user interface for scenario analysis were done, with the participants practising scenario runs to test the capability of the model. A questionnaire was given to those who participated in the hands-on exercise to evaluate the model in five aspects: (1) information needs and relevance of the decision support system (DSS), (2) flexibility, (3) accessibility of information generated, (4) soundness of scientific methods applied and (5) degree of adoption and major bottlenecks perceived.

During the hands-on exercise, various questions and issues were raised by the stakeholders, such as

- Intercropping and relay-cropping systems should be included in the model.
- Livestock and fisheries should be included.
- Can the model be made to run for 'lower' levels (municipality and farm)?

Further questions on when and how the model would be made available (and by whom) to the province entail further institutional arrangements.

Finally, the governor of Ilocos Norte Province recommended that SysNet-IRRI and Philippine teams assist in rapid transfer and implementation of the system for planning (e.g., by providing hands-on training) and facilitate the required training.

Conclusions from the final stakeholder meetings

SysNet is and was based on the premise that planners and policymakers need systems analysis tools for strategic agricultural land use planning at the regional level, since the complexity of the problems (increased pressure on scarce resources and conflicts in land use/rural development objectives) is such that it is no longer sufficient to evaluate land use options at the field or farm level.

More complex issues also imply that a broader domain of information needs to be considered for decision making. Resource managers (whether farmers or government agency staff) currently often lack the capacity to make resource management decisions based on an integrated assessment of the range of issues that demand consideration.

At the first of a series of SysNet final meetings, stakeholders from Ilocos Norte expressed the need for the new tools, developed and tailored to their province. There was a consensus among all stakeholders that SysNet's LUPAS should be made available to provincial planning officers and advisors as soon as possible, since stakeholders expressed confidence that the system would improve the quality of decisions on land and resource use – in particular, the governor requested that provisions be made to transfer the system for further testing and give hands-on training for making full use of it.

Stakeholders present at the meetings for Kedah-Perlis (at Kangar) and for other states of Malaysia (at Kuala Lumpur) had diverse comments. One group responded that they did learn a lot about concepts and tools through the LUPAS methodology, others commented that the modelling system still did not address the most relevant questions, a third group requested immediate access to the tools developed and a last group requested the SysNet Malaysia team to inform it about requirements and conditions for developing LUPAS for other states of Malaysia. Since then, 48 stakeholders from Malaysia have been interviewed about their involvement in SysNet. Evaluation of this study is part of an on-going MSc study.

The more user-friendly modelling system had not yet been realized for Can Tho Province and Haryana. Nevertheless, a demonstration of the user interface at the final stakeholder meeting in Can Tho City created considerable interest. Moreover, key stakeholders from the province indicated that the results from LUPAS would be considered in future land use plans. No final stakeholder meeting was held for Haryana State, since scientists were not yet satisfied with available model results and were working on further refinement. Results will be presented to stakeholders in a special country report by the end of 2000.

With the *final results* for the Philippine and Malaysian case studies, SysNet has come very close to achieving its purpose: develop land use planning tools and provide these to the people who want them.

Lessons learned and future directions

The following lessons can be derived from the involvement of stakeholders:

1. There is a need for new land use planning methodologies and applications in Asia.
2. Improved definition and identification of stakeholders and end-users are needed at the inception of projects aiming at developing DSSs for land use analysis and planning.
3. It is of utmost importance to involve stakeholders/end-users from the beginning in the design and to have frequent interactions between research teams and other stakeholders during development of the DSS.
4. Once a prototype DSS (LUPAS) had been developed, it served as a vehicle to exchange information and knowledge and stimulate discussion among different stakeholder groups on land use and related policy issues.
5. In SysNet, LUPAS also served as a tool for building systems research capacity and fostering interdisciplinarity within participating research institutions (e.g., the multi-disciplinary teams formed in the framework of the project were subsequently institutionalized at IARI and MARDI). The capability to transfer the methodology to local planning agencies has been created. But the effective project time span (of 3½ years) was too short to start the process of methodology transfer – which now rests with the individual NARS partners.
6. Only a handful of the stakeholders involved in each case study were identified as direct end-users of the methods and tools. In one case, these were officers from the Department for Planning and Investment (e.g., Vietnam), in another,

principal officers from the provincial planning and development office or key advisors for agricultural programs (e.g., Philippines).
7. Considerable investment in training, planning and establishment of partnership is required before effective synergies in methodology development by a network fully come to the fore.

The process of interactive design of future land use options and policies requires availability of and confidence in a well-tested methodology and tools. In future ecoregional activities, building on the SysNet methodology, the following points should receive special attention:

- The current planning processes in the study areas need to be studied thoroughly.
- Ensure that planners and policymakers have access to the information generated and make use of the systems/methods developed.
- Participation of intended users in development and testing of methods should be intensified.
- Sources of knowledge and expertise (social and communication sciences) should be expanded.

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Scientific challenges

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Introduction

This final report of the SysNet project presents proof of considerable progress in the field of land use systems analysis, as a component of participatory land use planning. It would be an illusion to think that this presents the ultimate word on this issue, first of all because the issues and their relative importance continuously change as a result of autonomous developments. Secondly, technologies are continuously developing, leading to both increased possibilities for the use of data and improved methodologies for analysis and integration. Moreover, while scientists engaged in international agricultural research hope to find novel solutions with an impact on 'rural development', they frequently realize that the answer to one question leads to the formulation of at least two new questions.

In this contribution, major challenges are identified for research in the field of partcipatory land use analysis and land use planning, based on the SysNet-experience.

Description of production activities (technologies)

Analysis of the possibilities for regional development as a tool for identification of scope for improvement and attainment of various objectives strongly hinges on accurate quantitative description of agricultural production technologies. Current technologies, as practised in a region, generally do not represent the 'potential' situation, i.e., the production possibilities as dictated by factors that cannot be or can hardly be affected by land users, such as radiation and temperature. It often appears difficult to quantify the technical coefficients of these technologies, as in traditional farm surveys such information is not routinely collected. It would be necessary to include in farm survey handbooks guidelines for collecting the technical information required for accurate quantitative description of current production technologies.

For alternative production techniques that are not currently practised in a region, technical coefficients can, in principle, be generated by applying (crop growth) simulation models. Such models have been developed for various (major) crops, but, for many of the minor crops, for which subsistence and market-oriented systems in developing countries can be of critical importance, such tools are not available. This also holds true for most of the perennial crops that often represent an important component in agricultural production systems in tropical countries. It appears that, in agricultural research, development of such tools does not have a high priority (anymore). In many low-external-input farming systems, mixed cropping, i.e., the simultaneous growth of a mixture of crop species and/or varieties, is a common technology, to reduce risks, to profit from the spatial heterogeneity of the resource base or to make use of synergistic effects. Also, for these types of crop systems, adequate simulation models are not available. This lack of quantitative tools for generating accurate technical coefficients of alternative production technologies seriously hampers their inclusion in land use analysis.

Spatial analysis

The LUPAS methodology operates at the regional level and resource availability and quality are defined at that level, i.e., the total area of land of a certain quality, the total quantity of irrigation water, the total labour force, etc. However, the spatial distribution of these resources is of major importance for the way in which they are being, and can be used. This holds true for both the physical characteristics (i.e., the spatial distribution of the water resources determines to what extent they can be used for various purposes) and the socioeconomic characteristics (such as the distance to markets, in absolute terms, or in terms of transport possibilities, which determine whether production of a certain commodity is economically attractive). The larger the distance, the higher the transportation costs, and hence the more difficult the marketing of a commodity. For some commodities, however, such as fresh milk or vegetables, distance may be a prohibitive constraint.

First attempts to introduce the spatial dimension in models for land use analysis have been made, but these have been shown to present serious difficulties, so that no established methodology is available. Especially for effective targeting of policy measures, this lack of spatial differentiation is a serious drawback.

Integration of regional analysis and farm household analysis

The ultimate decision makers on land use are farm households, and the possibilities to affect land use therefore depend on the criteria used by the farm households in these decisions and their response to policy measures. The regional land use analysis can illustrate the (bio)physical potentials of the natural resources, but cannot identify the major socioeconomic constraints to modifying land use at the farm household level. For that purpose, the regional analysis has to be integrated with the farm household analysis that incorporates farmers' behaviour. Again, developments in this direction have started, but a much more systematic analysis is necessary, that yields a methodology in which results of regional models can be used to identify boundary conditions and/or objectives for farm household models (FHMs). Results from FHMs, such as production and/or price elasticities, in turn, should provide the revised scenario settings for subsequent regional analysis, and so on.

Such integration is also hampered by the typical methodology applied in socioeconomic analysis, which is based on the identification of so-called farm types, distinguished by economic characteristics. Regional analysis on the basis of upscaling of farm household results typically suffers from aggregation bias, because non-linear relations play a major role in the process. Such biases could be minimized when similar to the biophysical data, which have a long tradition in being geo-referenced, socioeconomic information would also be presented, incorporating its spatial dimension.

Uncertainty analysis

The scope for agricultural development is determined not only by the long-term possibilities and constraints but also by the risks associated with uncertainty. This plays a role in both the biophysical sense (weather cannot be predicted and the more erratic the weather pattern in a region, the larger the uncertainty) and the economic sense (in most situations, producers are price-takers that have no influence on the market price of their commodities). In addition, in subsistence farming systems, which have only weak links with the market economy, food security is a major consideration, and that will lead to risk-aversive behaviour, effectively constraining the possibilities for increased production at higher risks. In explorative land use analysis, the possibility of taking into account this uncertainty should therefore be incorporated.

Interaction with stakeholders

In the development of tools for land use analysis, the biggest challenge is probably their implementation in the ‘practice’ of land use planning and policy analysis. That requires close cooperation with the various stakeholders, in which it is important that the models be designed in such a way that answers are generated to questions relevant to the stakeholders. Moreover, the stakeholders need to develop confidence in the tools being applied. It appears not evident now what the best ‘package’ of procedures is to stimulate, maintain and institutionalize that process.

Annexes

Annex 1: The SysNet Toolkit for land use analysis in Asia

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Introduction

SysNet has developed tools and methodologies for exploring agricultural land use options in four case study regions in Asia. These tools were operationalized into the so-called land use planning and analysis system (LUPAS), which has four components:

- Resource balance and land evaluation
- Yield estimation
- Input-output estimation, and
- Multiple goal linear programming (MGLP)

For each component, various tools and techniques were used. GIS (geographic information systems) and expert systems were used in the resource balance and land evaluation component; crop growth simulation models were applied in yield estimation; technical coefficient generators (TCGs) were used to calculate input-output relationships of production activities; and linear programming models were developed to generate land use options for the case study regions.

The SysNet Toolkit is a CD-ROM that puts together the different tools developed and used by the different SysNet teams. This CD-ROM is menu-driven and contains each tool's installation routine and technical documents describing the tool.

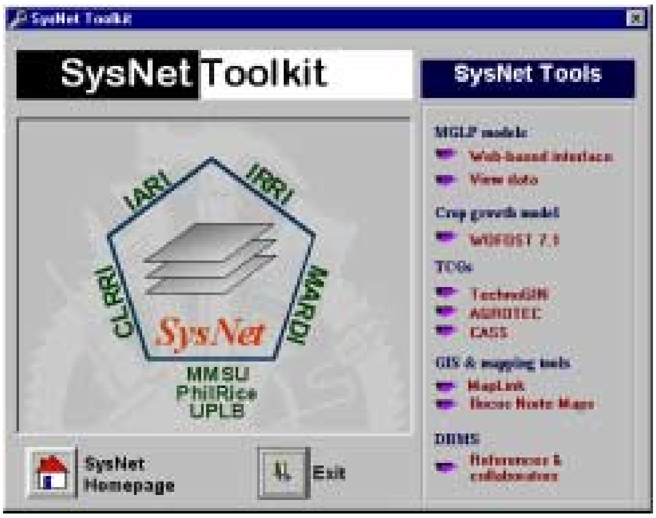

Figure 1. The SysNet Toolkit main menu showing the different tools for land use planning developed by SysNet.

The tools

MGLP models

At the core of LUPAS is the MGLP model, which is the integrating tool that is used to generate land use options by optimizing an objective (e.g., maximize income) subject to certain constraints (e.g., available resources, production targets).

The models programmed in XPRESS-MP (Dash Associates, 1999) along with the data used in the optimization (in Excel format) can be viewed in this section (e.g., available resources and input-output data) for each case study.

For two case study regions, Ilocos Norte Province in the Philippines and the Kedah-Perlis Region in Malaysia, a Web-based user interface was developed. This interface allows the user to make an optimization run by selecting an objective and the constraints to impose. The model will optimize, based on the selections, and give output results in tabular, map, and graphical format (Laborte *et al*., this volume).

Crop growth simulation model

WOFOST is a computer model that simulates the growth and production of annual field crops. A graphical user interface facilitates the selection of production level, input parameters (e.g., crop, soil, weather data) and output options (Boogaard *et al*., 1998).

Technical coefficient generators (TCGs)

Three different TCGs were developed:

- TechnoGIN, developed for Ilocos Norte Province (Philippines), optimizes fertilizer use and uses of cost models to calculate fertilizer requirements (Ponsioen, 2000);
- AGROTEC was developed for Can Tho Province (Vietnam) to describe land use systems, considering crop rotations, and flooding as a specific factor that hampers crop production (Jansen, 2000); and
- CASS calculates the resource requirement, environmental impact assessment and cost-benefit analysis of agricultural production systems in Haryana State, India (not documented).

GIS and mapping tools

In SysNet, GIS is used as a supporting tool for resource assessment, delineation of land units and mapping of land use options and goal achievements. MapLink is a tool that facilitates linking of data in Excel files to a GIS (Laborte *et al*., 1999).

DBMS (data base management system)

The SysNet DBMS has two sections, the references and collaborators databases, containing, respectively, literature relating to agricultural land use and contact addresses of SysNet team members and collaborators (Lopez & Laborte, 2000).

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Project Reports

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- Consultancy Reports by Don Jansen (3)
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    Cuu Long Rice Research Institute (CLRRI), Can Tho Province, Vietnam
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    Cuu Long Rice Research Institute (CLRRI), Can Tho Province, Vietnam
  - 12 - 22 April 1999
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- Consultancy Report by Kees Van Diepen
  12-21 March 2000
  Malaysian Agricultural Research and Development Institute (MARDI), Malaysia
  Summary of findings: Land evaluation for Kedah Perlis
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- Consultancy Reports by Gon Van Laar (4)
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    International Rice Research Institute (IRRI)
    Model Evaluation, WOFOST and ORYZA1
  - 1 October - 25 December 1998
    International Rice Research Institute (IRRI)
    SysNet Int. Workshop Proceedings; Model Evaluation (RL1, CE6 Project)
  - 25 September - 6 November 1999
    International Rice Research Institute (IRRI)
    Editing of the SysNet '99 International Symposium Proceedings and assist in the documentation of crop parameters used for yield estimation in SysNet case studies (models WOFOST and new ORYZA)
  - 10 February - 3 March 2000
    International Rice Research Institute (IRRI)
    Final editing and coordinate the publishing of the SysNet '99 International Workshop Proceedings

Training Manuals

- March 10-17, 1997, IARI, New Delhi
  Training Course on Land-Use Systems Analysis Methodology for SysNet Team, India
- April 28 - May 1, 1997, PhilRice, Muñoz, Nueva Ecija
  Training Course on Land-Use Systems Analysis Methodology for SysNet Team, Philippines
- June 9-14, 1997, CLRR, Can Tho
  Training Course on Land-Use Systems Analysis Methodology for SysNet Team, Vietnam
- August 25-29, 1997, MARDI, Kuala Lumpur
  Training Course on Land-Use Systems Analysis Methodology for SysNet Team, Malaysia

Internet Web-sites

- SysNet Project Homepage: http://www.cgiar.org/irri/sysnet
- SysNet '99 Conference Homepage: http://www.cgiar.org/irri/sysnet/sysnet99
  (disabled after the conference)
- SysNet user interface on IRRI intranet:
  http://irriwww.irri.cgiar.org/IRRIIntra/sysnet/mglp/SysnetMGLP.htm

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