Multi-agent systems for collective management of a northern Thailand watershed: model abstraction and design

P. Promburom, M. Ekasingh, B. Ekasingh, and C. Saengchyoswat

Scarce farmland and water resources in the highland watersheds of northern Thailand coupled with multiple users and desires have led to conflicts among stakeholders who play important roles in the system dynamics. Integrating the participatory approach and multi-agent systems (MAS) modeling can facilitate adaptive learning processes to result in a collective management strategy that meets the balanced needs of all parties. However, this requires participation and cooperation from all stakeholders involved in the process.

This paper elaborates on the concept and processes of MAS model abstraction and design, which is the first study period of a research project. This project aims at developing an integrated participatory MAS model to support collective resource management in a watershed area of northern Thailand. A prototype MAS model was constructed using unified modeling language (UML) diagrams, and it consists of three major components: a biophysical module, a social module, and a political institution module. UML diagrams are used as an interface for discussing and sharing ideas among an interdisciplinary research team.

This prototype structure will be used as a guideline for further research steps, including stakeholder analysis, eliciting common representations for further model programming, and development. Finally and hopefully, the verified and validated MAS model could be applied in assessing natural resource management strategies agreed upon among all stakeholders and would result in the implementation of a desired intervention scheme for sustainable resource management in this watershed.

The idea of using multi-agent systems (MAS) modeling to understand the complexity of a watershed system with multiple users exploiting fragile natural resources in the northern Thailand highlands stems from the authors' participation in a training course on an introduction to MAS and integrated natural resource management (INRM) in late 1999 and 2000. This training provided knowledge on the concept of agents, software, and tools for developing simple MAS models. This introductory course was followed by a series of MAS for INRM training sessions during 2001-03. Knowledge representation and integration, technologies, and relevant concepts regarding MAS for studying dynamic interactions between societies and the environment were gained gradually and progress was satisfactory throughout recent courses. Meanwhile, the idea of applying MAS for INRM in northern Thailand emerged in early 2001, and system components and possible key interactions and consequences were roughly sketched out. Until late 2002, the initial conception and design of a MAS model was framed and constructed with colleagues from different disciplines.

Existing and recent research dealing with integrated MAS and NRM has been exploring several techniques, tools, and methods to provide a better understanding of complex and dynamic phenomena that may lead to improved collective decision-making. However, the context of human interactions and their effects on agroecosystems, including policy interventions and institutions, are rarely explored and modeled.

Therefore, this study focuses on resource-use planning and potential management intervention at the watershed level that can balance the needs of local people and government efforts to mitigate environmental degradation in the northern Thailand highlands. MAS modeling and a participatory approach are the main tools and concepts to be applied. Key stakeholders, particularly government agencies and local institutions that potentially play important roles in watershed management, will be involved in the study. This study targets the following objectives:

- To develop a MAS model that integrates a spatially explicit model and social systems model, and interconnect dynamics occurring at different scales in space and time.
- To incorporate political and local institutions in the MAS model.
- To apply participatory MAS modeling as a tool to facilitate collective learning and watershed management.

This paper presents results of the first-phase study. It aims at illustrating the concepts and processes used for MAS model design. The design represents our knowledge and understanding of the context of the study area. Thus, this predesign model reflects researchers' perceptions, which are mostly based on a literature review and our experience gained from previous research work in the same area. In further research steps, this will be modified using other stakeholders' perceptions and participation in the model-developing process. In this way, the model will better represent and reflect the real system of the study area.

The first part of this paper discusses the common concerns about natural resources and their management in upper watershed areas of northern Thailand. The paper assesses multiparty causes and consequences resulting in the complexity of the current highland agricultural system, approaches, and efforts that have been applied to tackle this problem. This is followed by the presentation of promising integrated approaches and tools that have been employed to achieve collective common-pool resource management with all stakeholders. Research results and applications of MAS for INRM in other regions and in northern Thailand are reviewed at the end of this section.

The second part of this article states the purpose of the study and hypotheses to be assessed. The following part provides the context of the study area and illustrates preliminary work in progress to analyze and design the prototype of a MAS model using unified modeling language (UML) diagrams. The model simply represents all key stakeholders, their interrelation, and other environmental components in a highland watershed system. This prototype will be further used as a conceptual framework to be developed and implemented into an integrated MAS model. We hope that it will be applied to improve collective natural resource management in the highland watersheds of northern Thailand.

Since these are the preliminary results of the initial period of the study, further research plans and specific objectives, concepts, and methods that can be used are discussed in the last part. In conclusion, the paper states the key concepts and concerns that we have experienced during this first study period, and the challenge in using the participatory modeling process and using the model directly with stakeholders to bring top-down and bottom-up approaches together to achieve desired collective resource management.

Natural resources and their management in the highlands of northern Thailand

The human-/agroecosystem of upper northern Thailand is characterized by its geographical structure, mountainous tropical forest ecosystem, and various ethnic groups scattered over the highland area that practice agriculture for staple food and cash crops. Since the 1950s, drastic changes have occurred in land-use patterns resulting from the adaptation of agricultural systems brought about by the imposition of new cash crop cultivation. This cash crop cultivation was a consequence of opium replacement programs and lowland marketing expansion, coupled with an increase in population density. This resulted in a change from traditional swidden agricultural practices to extensive clearance of forest and shortening of the fallow period, which have had a substantial effect on natural resource viability and the integrity of watershed systems. This led to the Thai government imposing land-use constraint policies to preserve forest area in the highlands, such as the watershed classification system that has produced conflict among land and water users. During the 1990s, public environmental awareness grew rapidly. This brought conflict between lowland and urban communities associated with the situation of natural resources in the highland and watershed areas. Instances of conflict about water use among upland and lowland communities occurred in Chiang Mai in the late '90s. Lowland communities blamed that scarcity and chemical contamination of water downstream on agricultural activities in the upland. They demonstrated and obstructed transportation between the upland and the city.

This rapid change and impacts on social, economic, and natural resources are complex and unpredictable. This has driven development and research efforts from many sectors and several policies and projects with various development strategies have been proposed and implemented to tackle the problem, especially in highland watershed areas (Enters 1995, Rerkasem and Rerkasem 1994). Some of these projects involved local people in the process but still focused on small target areas and rarely incorporated all local government agencies. Eventually, there was not much influence on national policy formulation for natural resource management. The processes of policy-making and implementation continue to rely mostly on a top-down approach.

Since development agencies experienced failure in managing natural resources because of their complexity and dynamic context, they turned to emphasis on a participatory development approach that opened the door for local involvement in resource management decisions (Missingham 2001). This approach was officially endorsed in both the Eighth and Ninth National Economic and Social Development Plan (1992-96 and 1997-2001, respectively). In 1997, Thailand adopted a new national constitution, which strengthened the role of local government institutions. Later on, this resulted in a range of new policies aiming at empowering stakeholders and institutions to participate in managing their own local resources in a sustainable way. However, neither suitable practical tools nor a clear mandate to achieve the goal was made available. Thus, roles and actions taking place in watershed areas appear to result in unpredictable changes in the land-use practices, productivity, and food security situation of highland communities.

Integrated participatory NRM in the northern Thailand highlands

From the late 1980s to the mid-1990s, an impressive number of influential highland development projects were implemented in the northern Thailand highlands. These projects aimed to suppress narcotics production and promote sustainable-cropping practices that could also contribute to improving the tribal people's well-being and ameliorating natural resources. In the beginning phases of implementation, most of these projects focused on introducing technological packages. However, they experienced failure with this top-down development approach. The United Nations-Sam Mun Highland Development Project (UN-SMHDP) was one that adopted and integrated a participatory development approach followed by the Thai-Australia Highland Agricultural and Social Development (TA-HASD) project, Thai-German Highland Development Programme (TG-HDP), and many other projects. Various participatory techniques and tools were applied to accompany problem analysis, plan alternative resource management, and finally establish collective rules and actions for watershed management. Examples are group seminars, three-dimensional topographical models (3-D model), the rapid rural appraisal (RRA), the rural system analysis (RSA), and the participatory rural appraisal. All the projects aimed at seeking cooperation and collaboration among key stakeholders through participatory approaches. At the same time, nongovernment organization (NGO) groups implemented development projects to encourage local people to collectively organize, analyze their situation and problems, make plans, and take action. However, they experienced difficulty because of insufficient cooperation from government agencies, and there was no law to support the right of local people to manage their local natural resources (Missingham 2001, Puginier 2002).

Integrated water resource assessment and management (IWRAM) has been conducted in five subcatchments in northern Thailand since late 1997. The project tried to involve all three keys government agencies in a process of adaptive decision-making (ADMP). However, only the Land Development Department (LDD) was incorporated within the project. The project developed an integrated decision-support system (DSS) by linking a biophysical module (hydrology, crop growth, soil losses) with a socioeconomic decision module to allow land managers (for example, LDD and the Royal Forestry Department, RFD) to assess the implications of alternative water resource management scenarios. However, this was not a fully decentralized dynamic model since individual household decisions were aggregated at each subwatershed level. Most of the model conceptualization, design, development, and validation phases were implemented by the researcher (Letcher et al 2002, Lal et al 2002).

Becu et al (2003b) developed CATCHSCAPE, a MAS model using the CORMAS (common-pool resources for multi-agent systems) platform, to simulate scenarios of resource management processes of land-use and hydrological dynamics of a catchment in northern Thailand. They used stakeholder elicitation techniques in digesting key perceptions of farmers toward agricultural practices related to water use to be used in model design and development (Becu, this volume). This model emphasized farmers' individual decision-making based on different viewpoints regarding household resources and land and water management without interventions from local and government institutions.

Trébuil et al (2002) conducted participatory research to test the companion modeling approach (Bousquet et al 1999) by associating MAS, geographic information systems (GIS), and role-playing games to enhance collective learning processes among stakeholders whose activities and interactions affect resource dynamics in a highland and market-integrated watershed of upper northern Thailand. The initial prototype model developed by the research group evolved iteratively between researchers and stakeholders through role-playing game sessions simulating a simplified version of the computer model, followed by individual interviews and group discussions (Trébuil et al, this volume). Thus, the model provides an acceptable common representation of current agricultural dynamics in this watershed system, and it allows stakeholders to experiment and assess land management scenarios. This kind of work is seen as being very useful for facilitating negotiation, mitigating conflicts, and enhancing collective land resource management. This promising approach and tool can be adapted to incorporate other key government agencies and local institutions to participate in desired decentralized natural resource management.

Puginier (2002) illustrated and assessed local land-use planning for natural resource management at the village level in Mae Hong Son Province. GIS and remote-sensing tools combined with participatory tools were used to collectively delineate a mutually agreed-upon land-use boundary and land-use plan among local people, key government agencies, and the Tambon (subdistrict) Administrative Office (TAO). The result of this study revealed that the tambon level is a suitable scale for creating a communication platform for stakeholders to collectively participate in desired land resource planning. However, government agency cooperation and the right of local people to manage their natural resources are needed to carry out these tasks.

Table 1 summarizes the various levels of the key stakeholders involved and tools and methods used in different research and development projects that deal with highland development and natural resource management in northern Thailand.

Most recent research and development projects concerning natural resource management in northern Thailand have been moving toward decentralization and adoption of integrated participatory approaches while government reform efforts have led to a new national constitution and strengthening of local governance institutions. There is now a stimulating challenge to step forward and integrate new tools and approaches to support and encourage participatory and collective management of natural resources at the watershed level in northern Thailand. MAS is one of the promising concepts that has been adopted and applied to deal with natural resource management in many aspects.

Table 1. Projects and research projects with different stakeholders, area scale, and methods and tools.

Project/research[a]	Stakeholder[b]	Implementation level	Methods/tools[c]
UN-SMHDP, TA-HASD, TG-HDP, NGO	Local organization	Watershed	3D model, RRA, RSA, group meeting, networking
IWRAM	LDD, RFD	Watershed	Biophysical and socio-economic model
Becu et al (2003b)	Local people	Watershed	Stakeholder elicitation technique, knowledge engineering, MAS
Trebuil et al (2002)	Local people	Watershed	GIS, MAS, role-playing games
Puginier (2002)	Local people, TAO	Village	GIS

[a]UN-SMHDP = United Nations-Sam Mun Highland Development Project, TA-HASD = Thai-Australia Highland Agricultural and Social Development, TG-HDP = Thai-German Highland Development Programme, NGO = nongovernment organization. [b]LDD = Land Development Department, RFD = Royal Forestry Department, TAO = Tambon Administrative Office. [c]RRA = rapid rural appraisal, RSA = rural system analysis, MAS = multi-agent system, GIS = geographic information systems.

Multi-agent systems and natural resource management

The MAS approach and computational modeling techniques have been progressively developed to explore and understand individual behavior and interaction among agents and the environment that represent the complexity of the whole system (Gilbert and Troitzsch 1999). They have been increasingly used to deal with ecological and socio-economic issues arising from the management of scarce resources by multiple users. Integrating MAS with other biophysical or economic models and spatial database tools can enhance the adaptive learning capability of all stakeholders regarding their role and effects on ecological system dynamics. This has tremendous potential for assisting decision-makers in understanding and managing landscapes (Gimblett 2002, Parker et al 2003, Le Page et al 2001).

In the field of common-pool resource management, many studies have focused on adaptive management to deal with complex situations, with the assumption that better mutual understanding brings about better coordination and greater collective ability, thus strengthening the adaptive capacity of stakeholders who take part in resource management (Lansing and Kremer 1993, Trébuil and Bousquet 2003).

The ideal MAS model that may be applicable to watershed resource management problems should include and dynamically link social and biophysical subsystems at multiple levels, and provide sufficient precise intervention scenarios to support the experimental discovery of possible intervention strategies that appear to be effective to achieve cooperative management by watershed stakeholders (Doran 2001). Several studies provide promising methods to integrate MAS and other tools to enhance decentralized and adaptive resource management. Stakeholders were included and allowed to participate in a research process called "companion modeling" (Bousquet et al 1999). This approach aims at empowering grass-roots stakeholders through the acquisition of a clear understanding and a long-term vision of their system dynamics, allowing them to cooperate and manage their natural resources collectively (Barreteau

2003, D'Aquino et al 2002). This enhances and facilitates research to understand complex phenomena and to develop, modify, and validate models through stakeholder participation. Moreover, this also changes the traditional relationship between the researcher and other stakeholders.

The unified modeling language (UML) is commonly used in conjunction with object-based models because it has mechanisms to communicate the structure, processes, and rules that drive model outcomes. UML has now become the standard for object-oriented modeling and design, as it is in the MAS model (Fowler and Scott 1999). The static class diagram in UML is widely used to enhance the process of identifying agents and their behavioral characteristics, functions, and relations to other agents. UML can be extended to develop events and sequences of models, which thus supports processes of programming, verifying, and redesigning models (Liang 2003).

Recent MAS applications have employed UML as a means of facilitating communication among model designers and programmers. This seamlessly becomes a standard protocol among researchers belonging to different disciplines and having various experience in developing computerized MAS models, and also among the participants in MAS training courses held in Thailand during 2001-03 (Parker et al 2003, Trébuil and Bousquet 2003).

Area under study

The Maehae watershed is situated in two subwatershed areas in northern Thailand. It is located 80 km southwest of Chiang Mai City, in a province that is one of the major forest-covered areas in the upper Chao Phraya River system in Thailand (Fig. 1). It consists of 14 villages, scattered in Mae-Wang, Mae-Chaem, and Sa-Moeng districts. This highland community has 550 households. Two major ethnic groups, the Karen and Hmong, practice agricultural activities in both traditional and new-technology-oriented ways, which have been actively introduced and supported by the Royal Project Foundation (RPF) development center (Ekasingh et al 2001b).

The study area is a slope complex with forest-covered areas of about 70%. The forest cover consists of pine mixed with evergreen and dry-dipterocarp forests. The land-use practice has changed from swidden agriculture to high-value cash crops and fruit orchards introduced by the RPF (Ekasingh et al 2001a). The LDD and RFD are government agencies working in the area. They are responsible for natural resource conservation. The LDD promotes soil conservation practices to reduce soil erosion. The RFD promotes forest resource rehabilitation. The conflict over land and water resource use within the community and also with government agencies in this area was observed during the most recent field visits, when some farmers encroached and cultivated in a restricted forest area.

As in other communities in this region, the heterogeneity of highland people arises from ethnicity, in which social and cultural institutions, goals, attitudes toward doing agriculture, household resource availability, and views of their relationship toward the environment are different (Ganjanapan 1996). In addition, political intervention also significantly influences the diversity of co-dynamic processes between social and environmental systems that make natural resource management situations

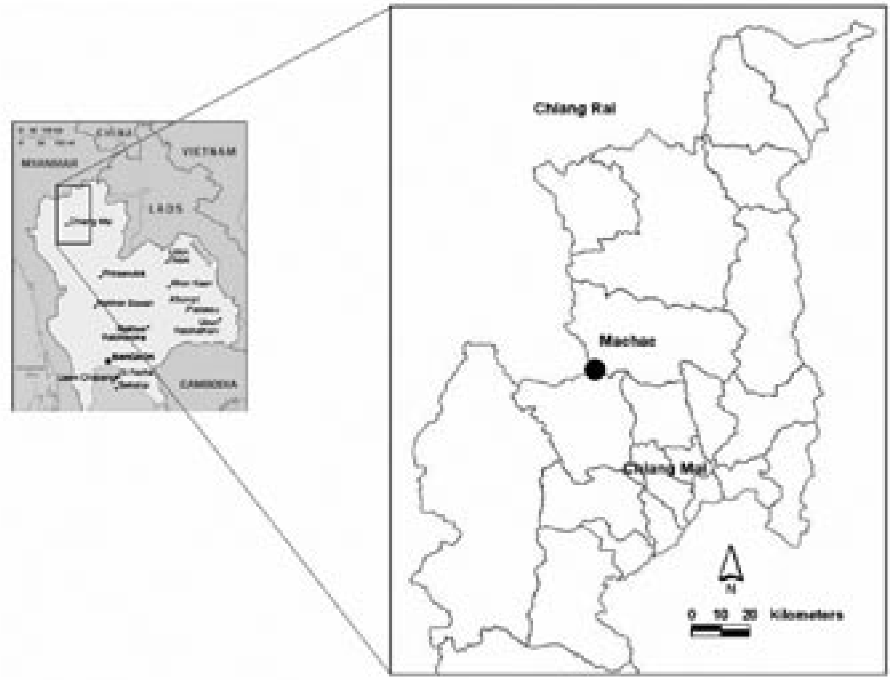

Fig. 1. Maehae watershed area, northern Thailand.

more complex and uncertain. It is not easy to perceive and understand the effect of government agencies' roles and their interactions with social and environmental systems on the overall catchment system.

Thus, environmental components and key stakeholders with their differing perceptions should be analyzed to bring about a better understanding of how individuals behave and interact with the environment and how this may affect the dynamics of the system.

Model abstraction and design

This study employs the concept of multi-agent systems through agent-based modeling to understand and to simulate the social interactions among stakeholders, decision-making regarding land management, and their effects on human and land-resource dynamics. The research started with a preliminary analysis of the Maehae watershed system to define entities that represent both actors and key environmental elements. The model consists of the following three major components:

1. A biophysical module to account for biophysical processes, particularly erosion. This module integrates the main environmental properties that will affect these natural processes, such as soil conditions, climate, and vegetation types.
2. A social module in which the stakeholders that play important roles in the dynamics of the study area were defined and abstracted using information obtained from field visits and secondary data (Ekasingh et al 2001a,b).

3. A policy and institution module representing the local institutions and government agencies whose interventions affect agents' decision-making regarding land use.

A UML class diagram was used to build and represent the fundamental properties, a set of common foreseen processes, relations, and interactions among entities. This UML static structure is a powerful tool to represent the components, structure, and possible dynamics of the system. It can also be used as a common tool for discussion among researchers with differing disciplinary backgrounds to criticize, modify, improve, and agree upon the structure of the model. Then, the system dynamics were defined and represented using a UML sequence diagram. Later on, an activity diagram will be built to demonstrate rules, function, and flow of particular subprocesses and mechanisms. The next step of this research consists of programming this predesigned model to verify the key functions of the prototype model before focusing in more detail on each component and its function.

From the Maehae watershed to a prototype MAS model

Model conceptualization

To transform the context of the study area into a conceptual model, we conducted a group meeting and discussion to digest and analyze the available literature, secondary data, and information obtained from research conducted in this area during 2001-02. The entities representing key stakeholders, environmental components, and a predefined relationship were identified and designed. Then a prototype MAS model was constructed using a UML static class diagram (Bommel and Le Page, this volume).

The preliminary design of the "world" representing the Maehae watershed system consists of three major components, corresponding to the stakeholders, their ecological environment, and the local institutions. Stakeholders share and intervene in common resources with different objectives and perceptions, whereas local institutions represent formal and informal groups or organizations representing stakeholders who share similar interests.

Model entities and their characteristics

In the first step in the model construction, stakeholders, biophysical components, and institutions were designed as class objects in a UML static class diagram. The stakeholders and environmental components are shown in Table 2.

Figure 2 shows the prototype model structure and illustrates the possible characteristics attributed to each entity and the linkage among these key components in this watershed system. Each agent and component object is represented using a graphical box as class and subclass entities. In each box, the top row gives the agent's name, the second subbox displays the agent's attributes, and the bottom subbox shows the processes of agent evolution or the method names. Lines connecting two objects correspond to either a relationship or an association, which determines possible inheritance, communication, and interactions among agents. The processes and methods are mechanisms that will be activated during the simulation to drive the system dynamics. These mechanisms may result in interaction among stakeholders and biophysical components, or between these two kinds of objects based on the relationship lines.

Table 2. The stakeholders and environmental components in Maehae watershed.

Class name	System component
Stakeholder and institution	
Farmer	The farmer practices agriculture in this highland environment and represents the household unit level.
RPFWorker	The Royal Project Foundation (RPF) worker's task is to promote high-value cash cropping to raise farmers' incomes and promote natural resource conservation.
LandManager	The Land Development Department (LDD) officer is in charge of promoting and facilitating soil conservation practices and other soil erosion controls.
ForestOfficer	The Royal Forestry Department (RFD) officer's duty is to protect the local forest cover, especially in upper watersheds defined by slope characteristics.
Trader	The trader acts as a middleman buying agricultural products from farmers for sale in town.
SocialGroup	Social institutions represent official and potential social organizations such as a village or forest conservation network.
Environmental entities	
LandUnit	This is the smallest land unit with homogeneous environmental characteristics, for example, soil, slope, elevation, climate, and vegetation.
LandusePlot	The aggregation of LandUnit is used for specific purposes or is occupied by a single type of natural vegetation and landscape.
LandFarm	This is a collection of all LandusePlot owned by a Farmer.
SubWatershed	This is a subwatershed within the Maehae watershed area and is delineated according to topographical characteristics.
WatershedClass	This is the official subwatershed classified by the National Environment Board (NEB) in 1983; each class corresponds to a specific permitted use type and management (Tangtham 1992).
Watershed	This is the entire watershed area.
LandCover	This represents different land-use types, including crops, natural vegetation, and physical infrastructure.
Climate	This is climatic variables and factors affecting crop productivity and soil erosion.

To better understand how real-world entities have been represented as entities (namely class) in computer models, the *Farmer* abstraction will be described in detail depicting the UML static diagram in Figure 2 as an example. The *Farmer* class object is associated with *AgentComm* (communicating agents) as a subclass (*Farmer* is a kind of *AgentComm*); thus, it inherits communication capability from *AgentComm*, which means that farmers can communicate with each other in general. Each *Farmer* is characterized by age, ethnicity, goal, and possibly membership in one or more *SocialGroup*. This social dynamics is linked to spatial dynamics through association between a *Farmer* and his or her *LandFarm*. The *Farmer* can perform an action or procedure to manage *LandFarm*, for example, choosing and growing a crop (+manageFarm), selling agricultural products (+saleProduct), and so on.

The dynamics

Based on a literature review and personal discussions with resource persons in Maehae, the agricultural practices and actions of each stakeholder involved in the system dynamics were transformed into a simple set of successive actions and decisions

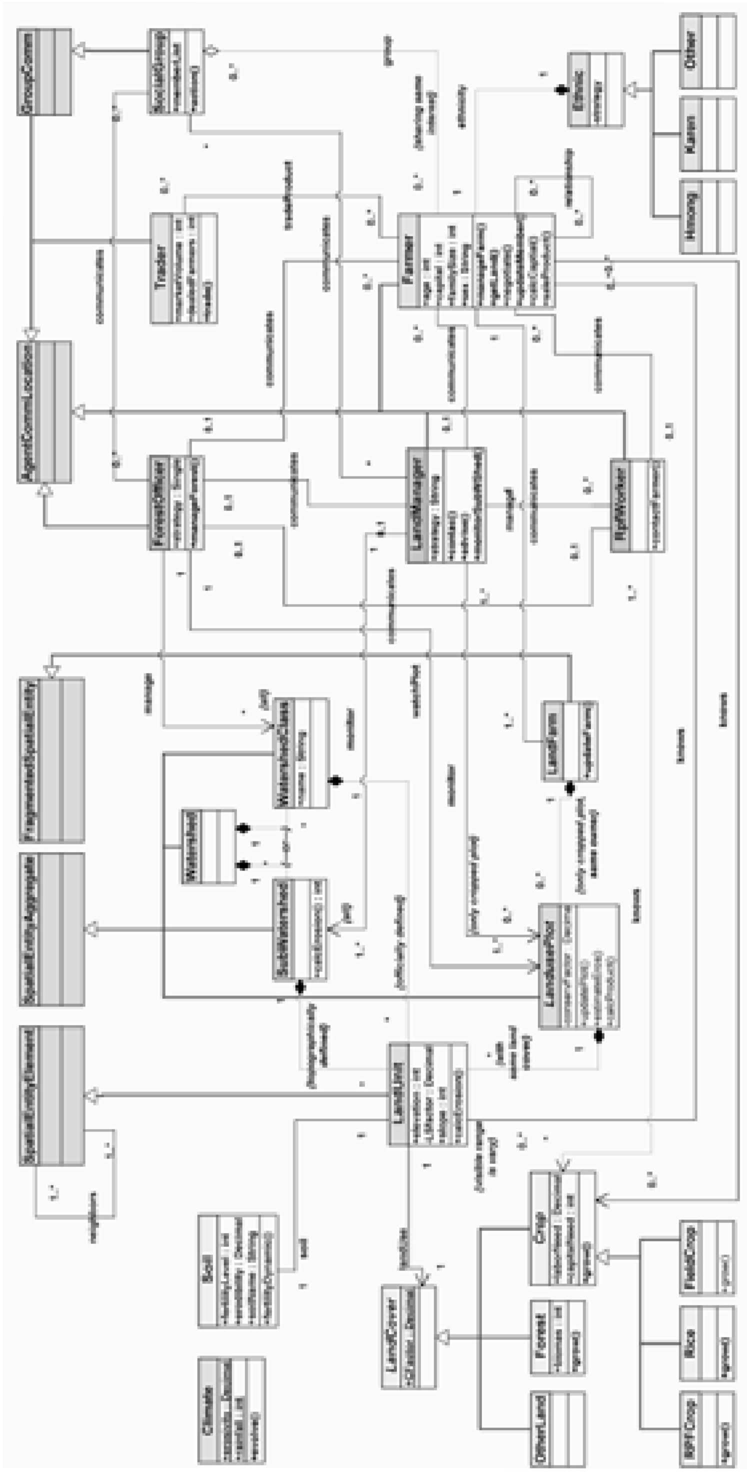

Fig. 2. UML class diagram of Maehae human-/agroecosystem.

illustrated by the UML sequence diagram shown in Figure 3. The time-step of the model operation is one cropping season. Therefore, within one year there will be two successive cropping seasons corresponding to the wet- and dry-season cycles. The main crops in the wet season are paddy rice, upland rice, and other field crops, whereas vegetables and flowers are planted in irrigated areas during the dry season.

At the beginning of this sequence of watershed dynamics, several *Farmers*, his/her household members, and a range of population growth rate are given. The dynamic starts before the beginning of the cropping season. Some *Farmers*' households may have a new member because of the natural growth rate and random occurrence. Some may be contacted by the *LandManager* according to historical records on levels of soil erosion that took place in his/her *LandusePlot* in the previous cropping season to provide advice on soil conservation practices. Thus, the *LandManager* will keep a record of whose *LandusePlot* is prone to soil erosion, and discuss a soil conservation practice that should be applied. The *RPFWorker* will use this information as one criterion in choosing a *Farmer* to become a member of the RPF. In each crop year, the *RPFWorker* will be given the types of crops and quotas to be produced. Then, the *RPFWorker* will look for *Farmers* who are interested and have the potential to produce particular crops. One particular criterion that the *RPFWorker* takes into consideration is to not choose a *Farmer* who cultivated a plot on a steep slope and prone to soil erosion in the previous cropping season unless soil conservation practices were adopted.

Before the cropping season starts, *Farmers* who are members of the RPF will decide what kind of crops they want to grow. The list of crops is not limited only to the types suggested by the *RPFWorker* but also includes other crops according to the *Farmers'* preferences and goals. Criteria and rules involved in how *Farmers* choose their crops have not yet been clearly defined, but will be made precise later. Available land resources and their suitability determined by soil characteristics and location, cost for cultivating a particular crop, and consumption and additional needs will be part of the major factors that determine *Farmers'* decision-making in choosing a crop and looking for new land. Once crops are selected, the *Farmer* will allocate *LandusePlot* for cultivation; this is the start of the interactions with the biophysical dynamics that also involve the *Crop, LandUnit*, *Soil*, and *Climate* entities. Crop yields will vary according to soil properties, climatic conditions, and cultivation practices. *Climate, Soil, Landcover*, and *Farmers*' practices are major factors influencing soil erosion, which is determined by soil physical structure, slope characteristics, crop cover type, and rainfall intensity. For each main crop, the attainable crop yield will be predetermined using empirical data, then a certain amount will be deducted based on soil fertility, rainfall function, and *Farmers*' management level. Thus, at the end of the cropping season, each cultivated plot will yield a certain volume of production.

As soon as a *Farmer* allocates crops to plots and starts cultivating, the *LandManager* will start to monitor the *Farmer's LandusePlot* to assess the severity of soil erosion that may occur along the cropping season, and these records will be used for action in the next time-step. Thus, at the dry-season time-step, the *LandManager* will not be active but will still hold records from the previous step to be applied in the next step. Likewise, the *ForestOfficer* will be monitoring the fragile forest area (determined by slope class and watershed class). At the watershed level, erosion oc-

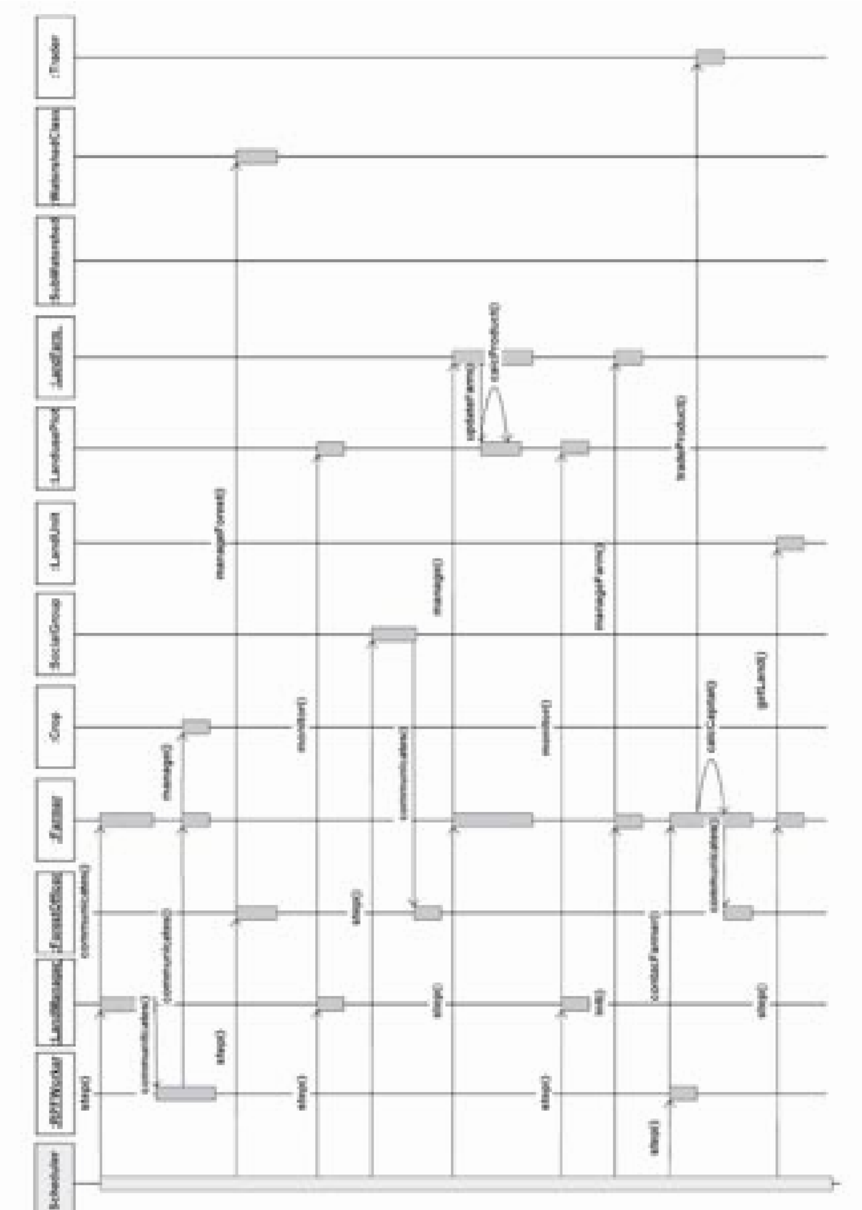

Fig. 3. A UML sequence diagram.

curring in cultivated plots and other erodable area will be aggregated and the result in total runoff and sediments of the whole system estimated at the watershed outlet. If these amounts of runoff and sediments exceed the acceptable level (given by LDD), both the *LandManager* and *ForestOfficer* will need to investigate and look at their monitoring records to find *LandusePlots* and owners (*Farmers*) that contributed to this situation. Then, communication and negotiation among these three agents and the *SocialGroup* will take place in the next step.

After the harvesting period, *Farmers* who are members of the RPF will sell their products as an amount of the given quota. Surplus products and/or non-RPF extension crops will be sold later on to a *Trader*. *Farmers* who are not RPF members will have two options for selling products. More than one *Trader* may come and trade for products and a negotiation mechanism between *Traders* and *Farmers* will be based on offered price, prices of previous cropping seasons, information about current common farm-gate prices, and a chance factor. The process and rules for this interaction and negotiation function will be further explored and analyzed based on *Farmer* and *Trader* perceptions to formulate a simplified decision-making process to be applied in the model. *Farmers* may decide to manage products to be used for household consumption, depending on their objectives and needs.

As soon as a deal can be made, *Farmers* will receive a certain amount of income. Both income and surplus products will be converted and compared to household consumption needs from the present until the next harvesting season. In the case of a consumption deficit, *Farmers* have to seek alternative ways to survive. At this moment, *Farmers* will look for a *LandUnit* to make a new *LandusePlot* to produce more in the next crop season. If a new *LandusePlot* happens to be located within the restricted area (according to the subwatershed classification scheme), which is prone to soil erosion and mostly assigned as a reserved watershed class, the *LandManager* and *ForestOfficer* will take action to either forbid cultivation or allow it under strict soil conservation practices advised by the *LandManager*. This is another communication and negotiation process that may occur. Relevant rules, actions, and mechanisms concerning this process need to be explored in the next research step. Since the government policy on environmental conservation, which is locally enforced by the *LandManager* and *ForestOfficer* to conserve soil and forest resources in upper watershed areas, provides only a broad concept and strategy of what should be done, this can create several implementation methods because of differences in personal attitudes and experiences among these agents. This will result in very diverse and dynamic situations. The UML activity diagram in Figure 4 shows an example of possible rules used in the decision-making process of the *ForestOfficer* in allowing the *Farmer* to open a new plot in a forest area.

In a future revision of the model, the mechanisms of communication and negotiation will not be limited only to individual *Farmers* and these two government agencies but they will try to take into account the local organizations (*SocialGroup*). This requires a participatory approach and companion modeling tools, such as role-playing games, to derive precise information to facilitate further model design and development.

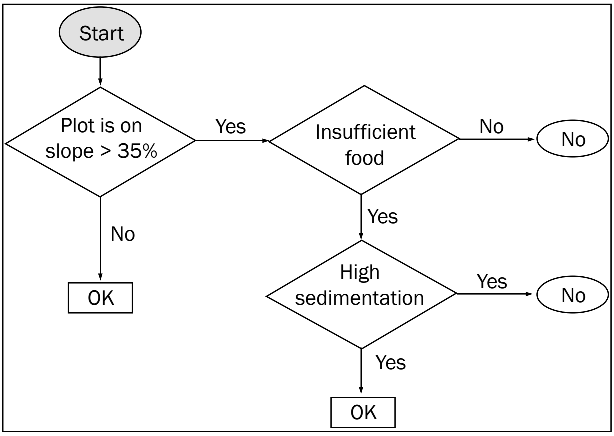

Fig. 4. Activity diagram showing the decision-making of a *ForestOfficer* in allowing a *Farmer* to cultivate a new plot in a forest area.

Future plans and perspectives

A prototype model of the Maehae watershed system composed of major stakeholders and a set of basic behavior and rules has been built. This model will be developed using the CORMAS platform (Bousquet et al 1998) because of its capabilities in modeling and simulating agent behaviors at both the individual and aggregate levels. Furthermore, it has ability to link MAS with a GIS database and software used to enhance spatial data import and export, spatial analysis, and visualization of simulation results. Then, simple scenarios will be simulated to verify the proper functioning of their various key components. Later, this prototype model will be used as a conceptual framework for further development.

For the model development, three major tasks will need to be accomplished: (1) evaluate and analyze stakeholders and their representations, (2) formulate rules and functions of the individual decision-making process, and (3) assess existing ecological dynamics models to be used in the model. Each task requires specific processes, steps, and tools for investigation and data inquiry.

The social dynamic is one factor that creates complexity, particularly because of the heterogeneity among the various agents involved in managing this system and the variability of their respective behavior and decision-making processes. As mentioned above, in the present model, agents, attributes, and processes were designed based on our past field experience and available data. This process did not take into account stakeholders' points of view. This may not be enough to represent correctly the stakeholders' behavior and actions during simulations. Thus, further participatory field surveys with stakeholders need to be carried out, coupled with stakeholder analysis and elicitation techniques as used in the field of collective INRM (Allen 2001, Becu et al 2003a, Becu et al, this volume). Apart from this, the model also provides insights into the decision mechanisms of such processes. This allows us to formulate a rule-based decision function to be applied in the model, for example, how *Farmers* choose a *LandUnit* to create a *LandusePlot* and allocate a *Crop* and what are alternative off-farm activities *Farmers* could choose to cope with insufficient goods for household use. However, defining agents and elicitating their representations is an iterative process, and, since it has been predefined and structured, it can be evaluated to modify the attributes and verify the functioning of the model through participatory approaches and tools (Bousquet et al 2002, Trébuil et al 2002).

The elements involved in the representation of the watershed biophysical subsystem are soils, climate, crops, and forest cover. Before building a spatially explicit model, data requirements and availability and scaling and integration of spatial heterogeneity are key aspects to be examined. The different perceptions of stakeholders toward their environment and its dynamics will determine the type of ecological dynamics model and data needed. The *LandManager* and *ForestOfficer*, whose perceptions may focus on soil, water, and plant dynamic processes, may request that the model represent their perceptions, whereas *Farmers*' perceptions formulated from empirical monitoring and observations accumulated over many years may be represented using simple cause-and-effect rules.

Several research teams have already attempted to develop spatially explicit biophysical models to represent and simulate human-environment dynamics employing various approaches and tools. These applications cover diverse kinds of environments and scales (Parker et al 2003, Le Page et al 2001). In the next step, some of these methods, including recent GIS technology, will be employed to develop an integrated and spatially explicit module appropriate for representing the biophysical subsystem of the Maehae watershed and which will be well adapted to match common stakeholders' representations.

Along with the research process, we try to involve stakeholders in the model development, validation, and simulation. With these participatory processes, stakeholders can help shape their representations and decision-making rules and processes. These iterative procedures between field work and modeling activities will result in an increase in stakeholders' cognitive ability and a better understanding of phenomena and consequences that may occur following actors' decisions, actions, and interactions.

Now, we are designing a role-playing game to be played by stakeholders in the Maehae watershed. This is a method used to clarify our point of view toward the context and dynamic of this area. It can also enhance the collective learning processes of stakeholders (Trébuil et al 2002). Furthermore, criteria and rules the players used in the game will be applied in the MAS model-developing process.

The challenge of this study is how to integrate the different perceptions of various stakeholders toward the environment and its dynamics to result in a common agreed-upon MAS model for all. Once the model structure and function are completed and accepted by stakeholders, this should allow us to simulate scenarios under alternative sets of indicators and rules proposed by stakeholders. This will lead to the suggestion of diverse discussion topics regarding each individual perception, decision-making process, and negotiation on rules and regulations for resource management. Therefore, this participatory and collective learning process should result in the identification of alternative watershed management schemes that are jointly acceptable to all key stakeholders.

Conclusions

We found that abstracting and designing real-world phenomena represent a crucial initial step for developing a MAS model for NRM. UML is a useful tool to bring together differing viewpoints regarding the area under study to transform the Maehae human-/agroecosystem into a conceptual framework representing a holistic view of the system. We can use this common framework to guide further research activities. This kind of research and action-oriented work needs to employ a participatory approach since stakeholders, their behavior, and the consequences resulting from their decision-making and interactions are key driving factors for system dynamics.

In the field of NRM, MAS and companion modeling tools, such as the role-playing game, the CORMAS platform, and GIS software, can be integrated to construct MAS models incorporating key components, functions, and mechanisms to represent dynamic phenomena occurring in complex agricultural systems such as a watershed. This innovative integrated participatory approach also provides an interdisciplinary environment and involves stakeholders in the research process itself.

This work tries to extend previous and current research efforts to bring together actors in different hierarchies who are involved in watershed resource intervention, accompanied by the MAS model as an interface and negotiation tool for the stakeholders. This is one of the recent applications using participatory MAS modeling for NRM in Southeast Asia that tries to fill the gap for stakeholders and move closer to a real collective effort to manage natural resources in the highland watershed system.

References

Allen W. 2001. Monitoring and adaptive management: resolving social and organisational issues to improve information sharing in natural resource management. Nat. Res. Forum 25(3):225-233.

Barreteau O. 2003. The joint use of role-playing games and models regarding negotiation processes: characterization of associations. J. Artif. Societ. Soc. Simul. 6(2).

Becu N, Bousquet F, Barreteau O, Perez P, Walker B. 2003a. A method for eliciting and modeling stakeholders' representations with agent-based modeling. Paper presented at the 4th Workshop on Multi-Agent Based Simulation 2003, Melbourne, Australia, 14 July 2003.

Becu N, Perez P, Walker B, Barreteau O, Le Page C. 2003b. Agent-based simulation of a small catchment water management in northern Thailand: description of the CatchScape model. Ecol. Modelling 15(2-3):319-331.

Bousquet F, Bakam I, Proton H, Le Page C. 1998. CORMAS: common-pool resources and multi-agent systems. Lecture Notes in Artificial Intelligence 1416. Berlin (Germany): Springer. p 826-837.

Bousquet F, Barreteau O, d'Aquino P, Etienne M, Boissau S, Aubert S, Le Page C, Babin D, Castella JC. 2002. Multi-agent systems and role games: collective learning processes for ecosystem management. In: Janssen MA, editor. Complexity and ecosystem management: the theory and practice of multi-agent approaches. Cheltenham (UK): Elgar Publishers. p 248-285.

Bousquet F, Barreteau O, Le Page C, Mullon C, Weber J. 1999. An environmental modeling approach: the use of multi-agent simulations. In: Blasco F, Weill A, editors. Advances in environmental and ecological modeling. Paris: Elsevier.

D'Aquino P, Le Page C, Bousquet F. 2002. The SelfCormas experiment: aiding policy and land-use management by linking role-playing games, GIS, and ABM in the Senegal River Valley. In: Parker DC, Berger T, Manson SM, editors. Agent-based models of land-use and land-cover change: report and review of an international workshop. Irvine, California, USA, 4-7 October 2001. p 70-72.

Doran J. 2001. Intervening to achieve co-operative ecosystem management: towards an agent-based model. J. Artif. Societ. Soc. Simul. 4(2):1-20.

Ekasingh B, Ekasingh M, Promburom T. 2001a. Sustainability indices of highland agriculture and natural resources: socio-economic point of view. Multiple Cropping Center, Chiang Mai University, Chiang Mai, Thailand. 164 p.

Ekasingh M, Samranpong C, Weerajit W. 2001b. Land use and cover changes detection in Mae Hae and Nong Hoi. Annual Academic Conference 2001, Chiang Mai, Thailand, Royal Project Foundation. p 286-307.

Enters T. 1995. The economics of land degradation and resource conservation in northern Thailand: challenging the assumptions. In: Rigg J, editor. Counting the costs: economic growth and environmental change in Thailand. Institute of South East Asian Studies. p 90-110.

Fowler M, Scott K. 1999. UML distilled: applying the standard object modeling language. New York City (USA): Columbia University Press. 163 p.

Ganjanapan S. 1996. Indigenous and scientific concepts of forest and land classification in northern Thailand. In: Hinsch P, editor. Seeing forests for trees: environment and environmentalism in Thailand. Chiang Mai (Thailand): Silkworm Books. p 247-267.

Gilbert N, Troitzsch KG. 1999. Simulation for the social scientist. Open University Press, Buckingham, Philadelphia. 288 p.

Gimblett HR. 2002. Integrating geographic information systems and agent-based modeling techniques for simulating social and ecological processes. Cambridge (UK): Oxford University Press. 344 p.

Lal P, Lim-Applegate H, Scoccimarro M. 2002. The adaptive decision-making process as a tool for integrated natural resource management: focus, attitudes, and approach. Conserv. Ecol. 5(2):1-11.

Lansing JS, Kremer JN. 1993. Emergence properties of Balinese water temple networks: co-adaptation on a rugged fitness landscape. Am. Anthropol. 95(1):97-114.

Le Page C, Etienne M, Bousquet F. 2001. Using geographic information systems in agent-based simulations to model natural and social dynamics at multiple scales. In: Ghassemi F, McAleer M, Oxley L, Scoccimaro M, editors. Modsim 2001, The Modeling and Simulation Society of Australia and New Zealand (MSSANZ).

Letcher RA, Merritt WS, Croke BFW, Jakeman AJ, Buller C. 2002. Integrated Water Resources Assessment and Management (IWRAM) Project: integrated toolbox. iCAM Working Paper, 2002/2. 28 p.

Liang Y. 2003. From use cases to classes: a way of building object model with UML. Inform. Softw. Technol. 45:83-93.

Missingham B. 2001. Participatory development in Thailand: a review of some relevant literature: Integrated Water Resources Assessment and Management (IWRAM) Framework Project, 2000/01. 45 p.

Parker DC, Berger T, Manson SM. 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Ann. Assoc. Am. Geog 93(2):314-337.

Puginier O. 2002. Hill tribes struggling for a land deal: participatory land use planning in northern Thailand amid controversial policies. Universitat zu Berlin. 151 p.

Rerkasem K, Rerkasem B. 1994. Shifting cultivation in Thailand: its current situation and dynamics in the context of highland development. IIED Forestry and Land Use Series 4. London (England): International Environment and Development. 31 p.

Tangtham N. 1992. Principles and application of watershed classification in Thailand. Paper presented at the Training Course on Natural Resource Management and Conservation in Watershed Area, 7-11 December 1991, Asian Institute of Technology, Bangkok.

Trébuil G, Bousquet F. 2003. Interdisciplinary Training Course on Multi-Agent Systems, Social Sciences and Integrated Natural Resource Management in Thailand: lessons from an inter-university project. Paper presented at the international conference "Grand Blueprint 2003: Multidisciplinary Programs: Management for Future Graduate Studies," Deans of the Graduate Schools of Public Universities of Thailand and The Graduate School, Chulalongkorn University, 7-9 May 2003, Bangkok, Thailand.

Trébuil G, Ekasingh B, Bousquet F, Thong-Ngam C. 2002. Multi-agent systems companion modeling for integrated watershed management: a northern Thailand experience. Communication presented at the 3rd International Conference on Montane Mainland Southeast Asia (MMSEA 3), Lijiang, Yunnan, China, 25-28 August 2002. 14 p. Conference proceedings and electronic document at www.cbik.ac.cn/cbik/resource/MMSEA_INdex.asp, accessed 8 September 2003.

Notes

Authors' address: Multiple Cropping Center, Faculty of Agriculture, Chiang Mai University, 50200 Chiang Mai, Thailand, e-mail: panomsak@chiangmai.ac.th.