Environmental Modelling & Software 25 (2010) 1345–1358

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand

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ARTICLE INFO

Article history:
Received 13 February 2009
Received in revised form
28 November 2009
Accepted 30 January 2010
Available online 19 March 2010

Keywords:
Capacity building
Co-learning
Companion modeling
Rainfed lowland rice

ABSTRACT

Rainfed lowland rice production in lower Northeast Thailand is a complex and adaptive farming activity. Complexity arises from interconnections between multiple and intertwined processes, affected by harsh climatic and soil conditions, cropping practices and labor migrations. Having faced a spatially heterogeneous and dynamic environment for centuries, local rice farmers are very adaptive and are used to adjusting their behavior in unpredictable climatic and economic conditions. Better understanding is needed to manage the key interactions between labor, land and water use for rice production, especially when major investments in new water infrastructure are now being considered.

Based on the principles of the iterative and evolving Companion Modeling (ComMod) approach, indigenous and academic knowledge was integrated in an Agent-Based Model (ABM) co-designed with farmers engaged in different types of farming practices over a period of three years to create a shared representation of the complex and adaptive social–agroecological system in Ban Mak Mai village, in the south of Ubon Ratchathani province.

The ABM consists of three interacting modules: Water (hydro-climatic processes), Rice, and Household. “Household” is a rule-based agent; it makes daily decisions based on its available means of production, taking into account the stage of the rice crop, and water and labor availability. Key decisions made are related to: i) rice nursery establishment, ii) rice transplanting, iii) rice harvesting, and iv) migration of household members. The spatially explicit model interface represents a virtual rainfed lowland rice environment as an archetypical toposequence made of upper to lower paddies in a mini-catchment farmed by 4 different households, and also includes water bodies and human settlements. Thanks to intensive communication, the participating farmers, made sure that the ABM adequately represents their rice farming and labor migration management practices. They found the model useful to deepen their understanding of the interrelations between labor migrations and rice production, which helped to strengthen their adaptive management ability.

1. Introduction

85% of the 5.2 million ha of rice land in Northeast Thailand are under rainfed conditions with a single crop per year and low agricultural productivity (average paddy yield is 1.8 t ha^{-1}). This is mainly the result of the combined effects of low water-holding, infertile coarse-textured soils and erratic rainfall distribution (Jintrawet, 1995; Somrith, 1997). Notwithstanding, 25% of the households living in this most populated region of the kingdom are still engaged in the rainfed lowland rice (RLR) production (OAE, 2005). Cash incomes generated from RLR production are inadequate to meet their basic needs, leading to a relatively high rate of poverty in this region. Therefore, to improve their livelihoods, the resource-poor rice farmers have long been migrating to urban areas, which caused labor scarcity at the household and community levels during the peak labor demand periods of transplantation and harvest.

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doi:10.1016/j.envsoft.2010.01.012

More than a third of all interregional migrations in Thailand – involving more than 2 million rural people – still originates from this region (Santiphop, 2000). Two main types of labor migration can be distinguished: seasonal and 'more-permanent'. Seasonal migrants leave the farm after the completion of the RLR harvest to look for off-farm employment during the long December to May dry season. In general, seasonal migrants come back from urban areas to the village to participate in RLR transplanting (mainly in July–August) and harvest (in November–early December). In contrast, the permanent migrants no longer participate in RLR farming activities but send remittances to the household members in the village to be partly used for hiring farm labor as needed. These migrants are usually young male and female adults. This situation can lead to a relative scarcity of farm labor during the RLR crop cycle and is the source of other social problems.

Several state policies have been implemented to improve farmers' livelihoods by making more water available, but they have had limited success. Presently, ambitious new plans to provide more water for farming in this region are being drawn. In early 2008, the Thai government decided to spend US$ 22 million for the construction of hundreds of new small on-farm reservoirs, and US$ 59 million for other irrigation projects. One very ambitious scheme proposes a US$ 15 billion investment in the construction of a future "hydro-shield tunnel" to divert water from the Mekong River to supply 19 provinces in the Northeastern region (Bangkok Business News, 2008; Matichon, 2008). But, as in the past, the success of water improvement schemes could be limited if they are not based on an in-depth understanding of the interactions between water use, rice production practices, and migration. The co-design with stakeholders of a shared representation of these interactions is a pre-requisite. This was the objective of the collaborative modeling process reported in this article.

RLR farming in lower northeast Thailand is a complex and adaptive system (CAS). Complexity arises from the interconnections between multiple and intertwined processes, modified by unpredictable climatic conditions, rice production practices and labor migration. Having faced a heterogeneous and very variable environment for centuries, local rice farmers have become very adaptive in their farming behavior. Agent-Based Modeling and simulation is becoming more widely used to represent, simulate, and analyze the dynamics of such CASs. Agent-Based Models (ABMs) explicitly represent human decision-making processes by means of agents presented as autonomous computer entities interacting directly among themselves and with their common environment, in order to achieve their goals (Ferber, 1999; Valbuena et al., 2008). An agent has certain knowledge about the system in which it is situated and operates (but it is not omniscient). By nature, an ABM provides a real system representation that is less abstract than a mathematical model. Therefore, it is a tool that can promote discussion and further exploration among researchers and model developers, as well as with subject matter specialists, policy-makers and local stakeholders (O'Sullivan, 2008). The Companion Modeling (ComMod) approach has been designed as an iterative, continuous, evolving method to facilitate dialogue, shared learning and collective decision making through interdisciplinary and action research processes, and to strengthen the adaptive management capacity of stakeholders facing a common resource management problem (Bousquet and Trébuil, 2005).

Local stakeholders are usually involved in ComMod through role-playing games (RPG) that support the whole process. When an ABM is combined with a RPG, most of the time the computer model is simply a computerized version of the RPG, with the same high degree of simplification. The similarity between the two tools enables the local stakeholders to feel comfortable with the computer model and to easily follow the simulations (Barreteau, 2003). In this study, RPG sessions were used to support the co-designing process with local farmers of an elaborated ABM which, by the end of the process, reifies a shared representation of their socio-ecosystem.

Past studies have examined labor migration as a result of economic drivers, often at the macro level, such as push and pull factors in the neoclassical economic theory (Chamratrithirong et al., 1995; Chantavanich and Risser, 2000; Matsumura et al., 2003; Paris, 2003). Some studies (Fuller et al., 1985; De Jong, 1997) have focused on the migration decision-making process as a result of the interaction between individual or micro-factors (often referred to demographic and social characteristics) or macro factors ranging from household to community levels (often referred to economic-related factors). But few studies have examined the relationship between renewable natural resource use and labor migration (Santiphop, 2000; Rattanawarang and Punpuing, 2003). Even fewer have used an ABM to assess changes in technologies and land use in relation to labor migration (Loibl et al., 2002; Laine and Busemeyer, 2004). Recent studies of RLR systems and RLR crop modeling carried out in this region took rainfall variability and the risk of drought into account. But none of them integrated the key interaction between rainfall distribution and farmers' decisions regarding RLR crop management, particularly in cases where the areas under study heavily depend on manpower (Boonjung, 2000; Boling et al., 2008). Furthermore, there has been no effective methodological process to facilitate local RLR farmers in developing a shared representation of their resource management as influenced by interactions between land/water use and migration. Therefore, the purpose of this research is to build a shared representation of the interactions between RLR farming, water availability, and labor migration by integrating indigenous and academic knowledge through a collaborative construction of an ABM with local RLR farmers. In this experiment, such a shared representation is presented by a family of models that was used to facilitate knowledge-exchange and knowledge discovery through the participatory simulation exercises. We also aim to stimulate the participants' thinking and co-learning through the collective exploration of scenarios of varying water and labor availability, with the ultimate goal of further strengthening their adaptive management ability throughout this very interactive participatory modeling and simulation process.

First, the collaborative modeling process of ABM co-construction is presented to illustrate its evolutionary path and degree of stakeholder involvement. The resultant structure and behavior of the ABM is described. The field-based scenarios and their participatory analysis are then introduced, and the salient points of the simulation results, as discussed with the stakeholders, are presented. The analytical elements derived from the laboratory-based simulation and analysis are also presented.

2. A collaborative modeling process

The study area is located in the Lam Dome Yai watershed, south of Ubon Ratchathani province. It covers 1680 km^2 in the district of Det Udom and Na Chaluay's northern region, with 80% of the land used for RLR (Naivinit, 2005). Within that area, the Ban Mak Mai village was selected, as a typical regional RLR-based farming system with a diversity of farming households. Within the village, 11 farming households ranging from small farms (average size of 3.2 ha), to larger holdings (average size of 7.2 ha), were carefully recruited to take into account the diversity of farming conditions among the households, which have different amounts of productive assets, and socio-economic RLR production and labor employment strategies (Naivinit et al., 2008). The husbands and wives from each selected household were invited to participate in modeling field workshops held in the village. Farmers of the same type employ similar strategies, decision-making processes and related practices in managing rice production and labor, including migratory patterns. 8 out of 11 participating households belong to type A small-holding farmers, the dominant farming type in the study area. They play an important role in supplying labor to the community because their farm size per labor ratio is relatively low. Type A farmers often migrate seasonally. Larger farming units belong to type B and C farmers. A key constraint on type B and C farms is labor shortage. A difference between type B farmers, as represented by two participating households and type C farmers, as represented by one participating household is that type C farmers have less labor constraints since they are either mechanized farming households or their family size is large. Nevertheless, these farm types, in particular type B, play a major role in employing hired labor during the periods of peak labor demand, particularly the rice transplanting and harvesting periods. The migration pattern for type B and C farmers is more-permanent.

Since the labor hiring system found in the study area, which affects the household incomes and the migratory pattern selected, depends on the diversity of farming households, we decided to take into account these three main types of farmers to represent heterogeneous characteristics of agents in the model (Valbuena et al., 2008).

Although the research problem, question and hypothesis were initially formulated by the research team mainly driven by academic interests, the subsequent research process became directed by the collective decision making of all stakeholders, including the research team. The participating farmers were not forced into any action, if they did not feel ready and competent enough to face changes either in the tools used or the questions addressed. As a result, a methodology emerged with the conceptual model truly gradually co-designed through a succession of RPG sessions organized to elicit farmers' mental models, in an iterative and adaptive step leading to co-construction of an ABM. In this experiment, six successive participatory workshops were held in the village to co-construct the ABM with different types of rice growers. After each workshop, we organized individual semi-structured interviews followed by a plenary discussion. The objective of individual interviews was to verify our information and clarify the actions that a participant undertook during the gaming session, or the comments that he/she made during the computer simulation session. Another objective was to ask the participants to compare and relate what they experienced in the virtual environment of either games or computer simulations to the reality. After that, we carried out the general discussion about the decisions made by the players during the RPG sessions and how do they relate with their actual decisions in real life. This was a cross-checking to avoid biased answers during the individual interviews and to collectively agree on the actions of each other. In addition to that, we carried out field investigations, including a farm survey to acquire additional information during the exceptionally prolonged drought in 2005. In the early stages of the process, during the role-playing game sessions, participants were requested to make decisions under circumstances very similar to their actual ones (farm size, pond size, location of farm, family labor and members, etc.).

Several modeling tools were used (Fig. 1). The successive versions of RPGs and ABMs used in combination support each other in the system analysis and help to gradually improve the shared representation of the system (d'Aquino et al., 2002). The changes in the model, moving from the more concrete (realistic) features to the more abstract ones reflect the evolution of the conceptual model and its improvement to better facilitate knowledge-exchange. During the first three workshops, this particular type of participatory simulation was used to facilitate interactive

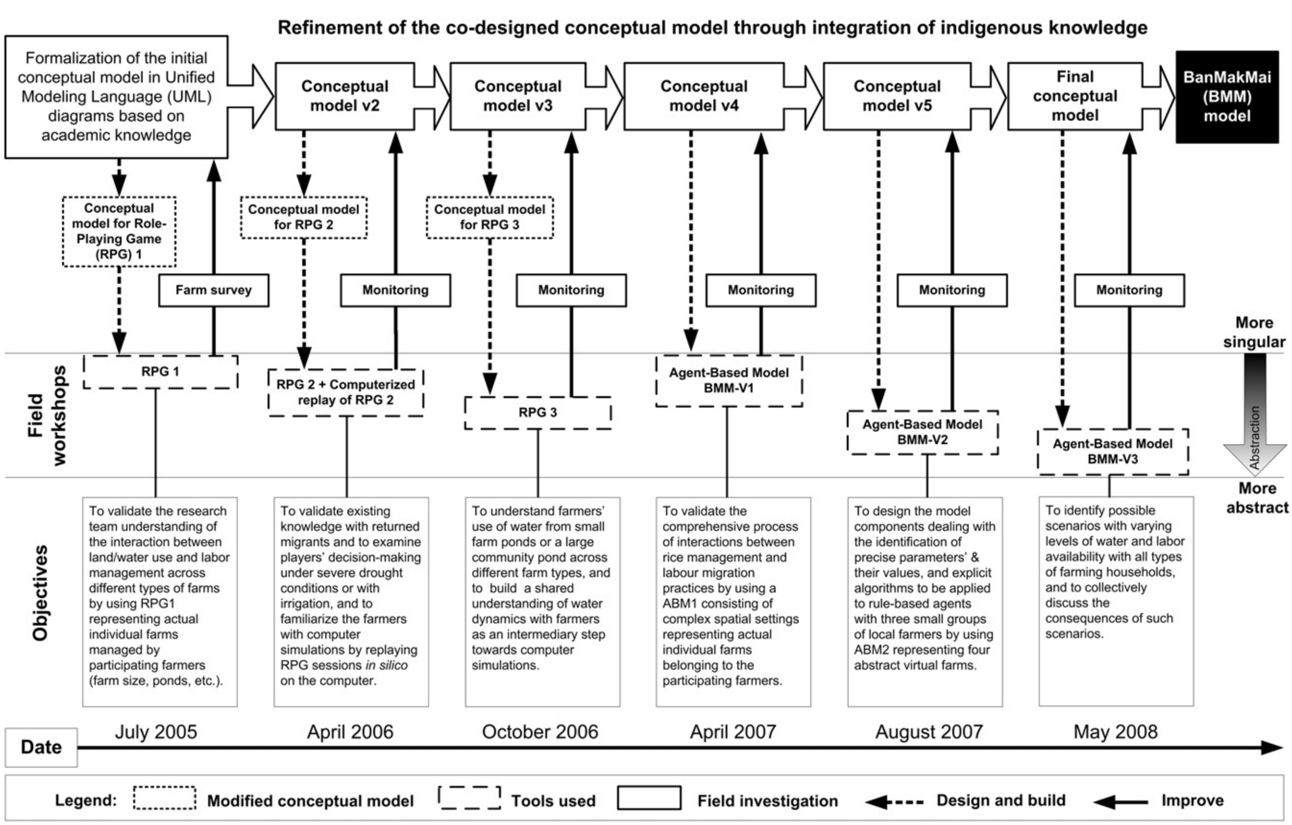

Fig. 1. The ComMod process conducted with 22 rice farmers in Ban Mak Mai village, Det Udom district, Ubon Ratchathani province with objectives and tools used in the six participatory workshops highlighted.

Table 1
Default values, units and sources of key parameters for each module of the BMM model.

Entity	Parameter	Default value	Unit	Source & main tool used
Individual (Member)	Minimum age of farmer villagers	15	years	Field workshop based on BMM model in 2007
	Maximum age of farmer villagers	65	years	
	Minimum age of migrant villagers	17	years	Authors' farm survey in 2004
	Maximum age of migrant villagers	45	years	Field workshop based on BMM model in 2007
	RLR transplanted area	0.16	ha/day	
	RLR harvested area	0.08	ha/day	
	RLR transplanted area by young farmers	0.16	ha/day	
	RLR transplanted area by old farmers	0.08	ha/day	
	Age threshold for RLR transplanting	50	years	
Household	Beginning of RLR nursery establishment	the Royal Ploughing Day	day	Field workshop based on RPG1
	Average annual net income per household	20,000	baht	NSO, 2007
	Average farm input cost excluding labor cost	20,000	baht/ha	OAE, 2007
	Average annual consumption expenditure	9600	baht/per capita	NSO, 2007
	Paddy for self-consumption	350	kg/person/year	Authors' farm survey in 2004
	Daily rainfall threshold to initiate RLR nursery establishment	30	mm	Field workshop based on RPG3
	Daily rainfall threshold to start transplanting	20	mm	
	Daily rainfall threshold to stop harvest for one day	10	mm	
Village	Daily wage at RLR transplanting	120	baht/labor	Field workshop based on BMM model in 2008
	Daily wage at RLR harvest	150	baht/labor	
Rice	Minimum daily rainfall of a wet day at nursery stage	10	mm	Field workshop based on ABM2
	Duration of dry spell for water stress to occur in RLR nurseries	12	day	Field workshop based on ABM1
	Average RLR paddy yield in Ubon Ratchathani province	1970	kg/ha	OAE, 2007
	Age of RLR seedlings ready for transplanting	30	day	Field workshop based on RPG1
	Duration of transplanting after rice seedlings reach 30 days	21	day	Field workshop based on ABM2
	Last week to establish RLR nurseries	3rd week of July	week	Field workshop based on RPG1
	Last week for RLR transplanting	2nd week of September	week	
	Starting date for harvesting of glutinous rice (RD6)	10th November	day	Bureau of Rice Research and Development, 1999
	Starting date for harvesting of non-glutinous rice (KDML105)	21st November	day	
	Maximum harvesting date to get high quality paddy	1st December	day	Field workshop based on BMM model in 2007
	Maximum harvesting date to get fair quality paddy	10th December	day	
	Farmgate price of high quality paddy	18	baht/kg	Thai Rice Mills Association, 2008
	Farmgate price of fair quality paddy	12	baht/kg	
	Farmgate price of low quality paddy	9	baht/kg	
	Water quantity needed to establish a 0.04 ha RLR nursery	80	m^3	Field workshop based on BMM model in 2007
	Water quantity needed to supply a 0.04 ha RLR nursery	40	m^3	
Water tank	Depth of water storage tanks (farm ponds)	3	m	Authors' farm survey in 2004
	Height of ponding tanks (paddy fields)	20	cm	
	Minimum depth of water level needed in water storage tanks as percentage of water storage tank depth	10	%	Field workshop based on RPG1
	Daily volume of water deducted from a ponding tank by the soil–plant system	10	mm	BMM model calibration

NSO: National Statistical Office, Ministry of Information and Communication Technology, Bangkok; OAE: Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Bangkok.

knowledge sharing between participating farmers and researchers, and to acquire new information emerging from the players' interactions under different conditions of water availability.

3. The BanMakMai agent-based model

The BanMakMai (BMM) model was developed with the CORMAS (COmmon-pool Resources Multi-Agent Systems)[1] platform, which is a programming environment dedicated to the creation of Multi-Agent Systems, with a focus on resource management (Bousquet et al., 1998). The model is described according to the "Overview-Design concepts-Details (ODD)" protocol proposed by a group of modelers (Grimm et al., 2006) as a standard format.

3.1. Overview

The BMM model is a spatially explicit agent-based model that was used as a communication tool between scientists and local RLR farmers for knowledge-exchange and knowledge-integration. It is made of five key interacting entities: Individual (Member), Household, Village, Rice, and Water tank. The model parameters, temporal and spatial scales are listed in Table 1. Additionally, a UML class diagram (see Fig. 2) showing the structure of the ABM completes the static representation, whereas a UML sequence diagram (see Fig. 6) is used to elucidate the process overview and scheduling.

The Individual (Member) entity has 4 state variables; age, gender, marital status and migration experience. The age of an individual influences its labor status (dependent, farmer, or migrant) while gender, marital status and migration experience influence the decision to migrate or not. Another key factor affecting the migration decision is the income calculated at household level. The age and migration experience of an individual evolve over time. Fig. 3 shows the evolving labor status (role) of an individual depending on his or her age. The performance (area per day) of an individual when performing the Farmer role depends on age.

The Household entity is a group of individuals, and is a key decision-maker in the BMM model. All main RLR-producing activities are decided at this entity level by considering the physiological state of the rice and the availability of water whenever it is relevant

[1] CORMAS and source code of BMM model are available at http://cormas.cirad.fr.

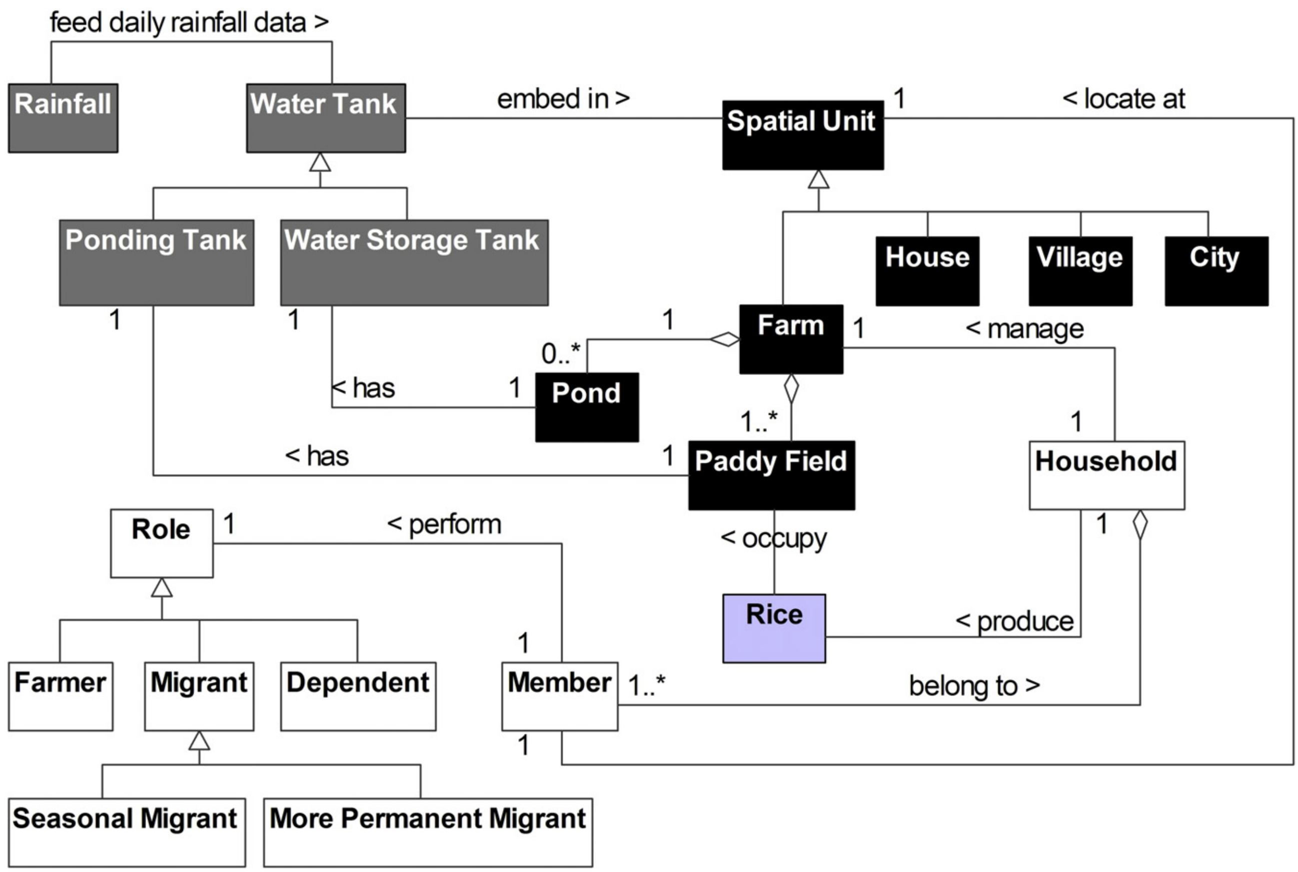

Fig. 2. The BMM conceptual model in a UML class diagram representing key entities and their relationships.

(for instance there are thresholds of daily rainfall to start a nursery bed, to start transplanting and to pause harvesting, see Table 1). State variables embedded in this entity include average farm input cost (used in the income generated from rice sales method), average annual net household income (used in the migration decision algorithm), and annual area of paddy for self-consumption (early-maturing rice variety).

The Village entity is an aggregation of households functioning as a registration desk where all potential farm workers for hire are listed. The daily wages for transplanting and harvesting are defined at this level.

The Rice entity is diversified into two groups of varieties (early and late-maturing). Key dates and durations related to each crop stage (seedling, transplanting, maturing, harvesting and fallowing) are presented in Fig. 4. For instance rice seedlings can be transplanted once they are 30 days old and up to 51 days old. After 51 days, the rice seedlings are too old for transplanting. The lack of water during critical periods of the cropping calendar results in partial (if for maintenance of nursery bed) or complete (if during establishment of nursery bed or at start of transplanting) crop failure. If failures are avoided, to facilitate the comparison of simulation scenarios, the yield is set to a constant value of 1970 kg per ha (OAE, 2007). Three different selling prices of late-maturing rice variety are related to the delay between maturity and harvest (the faster harvesting is completed, the higher the paddy quality, see Table 1).

The Water tank entity is a ponding tank (20 cm high) related to a paddy field or a storage tank (3 m high) related to a pond. The water level in each tank is updated daily by adding the rainfall and

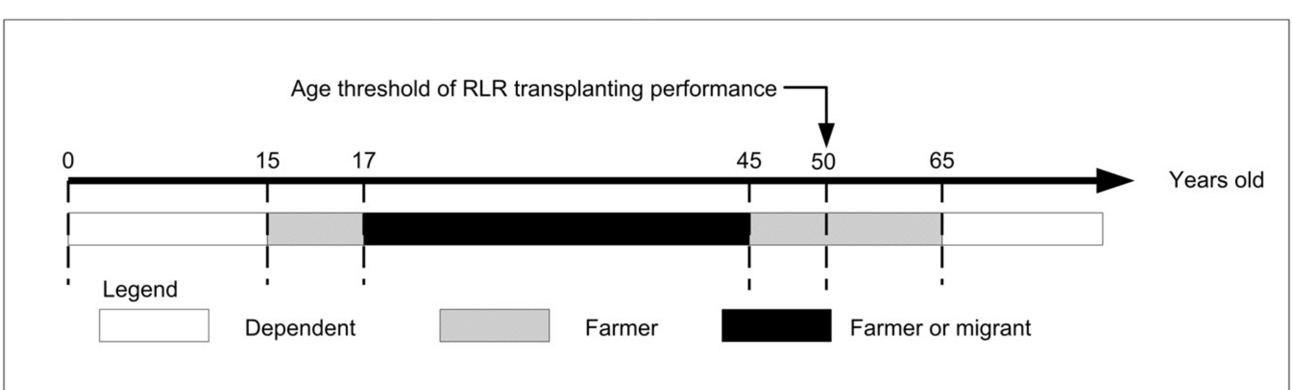

Fig. 3. Labor status evolving according to ‘age’ state variable of individuals.

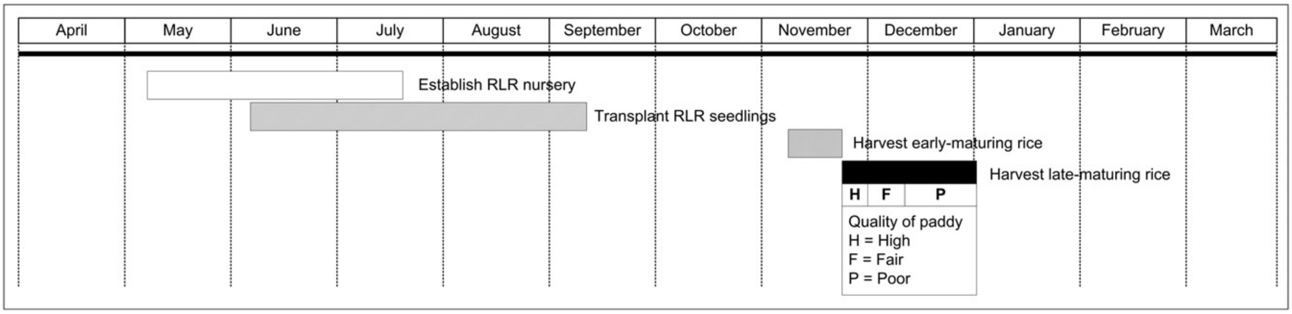

Fig. 4. Specific times/lengths of time embedded in the rice entity determining successful rice production.

subtracting the evaporation (see input section below). Additionally, a constant volume (10 mm per day) used by the soil–plant system is subtracted from the ponding tanks. A minimum water level needed to be kept in ponds (10% of storage tank's height) limits the volume of irrigation water available at the household level.

The spatial resolution was set to 0.04 ha (1 *ngan* in the Thai area measurement system), the area represented by a cell (the smallest homogeneous spatial unit in the model). To represent a typical portion of a RLR system, two small (3.6 ha) and two larger (7 ha) farms were considered (see Fig. 5). Each farm is made of a collection of paddy fields with sizes ranging from 0.28 to 0.96 ha. The human settlements (houses, village and city) are represented in the spatial interface only to allow the visualization of the status of each individual member (dependents in their house, unoccupied farmers in the village, migrants in the city).

The BMM model is a discrete time-step model. A daily time-step was chosen because in reality, participating rice farmers adjust their decisions according to the climatic conditions on a daily basis. However, to some extent this model is also event-driven since occurrences of water stress during the set up of the nursery bed period and in the anticipated durations of the rice stages trigger household agents' reactions. Because unanticipated conditions have a greater chance of occurring over longer periods of time, long-term scenarios have more uncertainty than short-term scenarios. The time horizon was set to ten years to enable an assessment of scenarios simulating diverse climatic situations while limiting the impact of demographic change: within such a relatively short period of time, the reproduction and mortality of individual members, which are not the focus of this model, is not taken into account.

Fig. 6 shows the sequence of farming activities throughout a crop year starting on April 1. The key successive farming activities are as follows: establishment of RLR nurseries and production of seedlings, transplanting, and harvesting. After RLR harvest, each

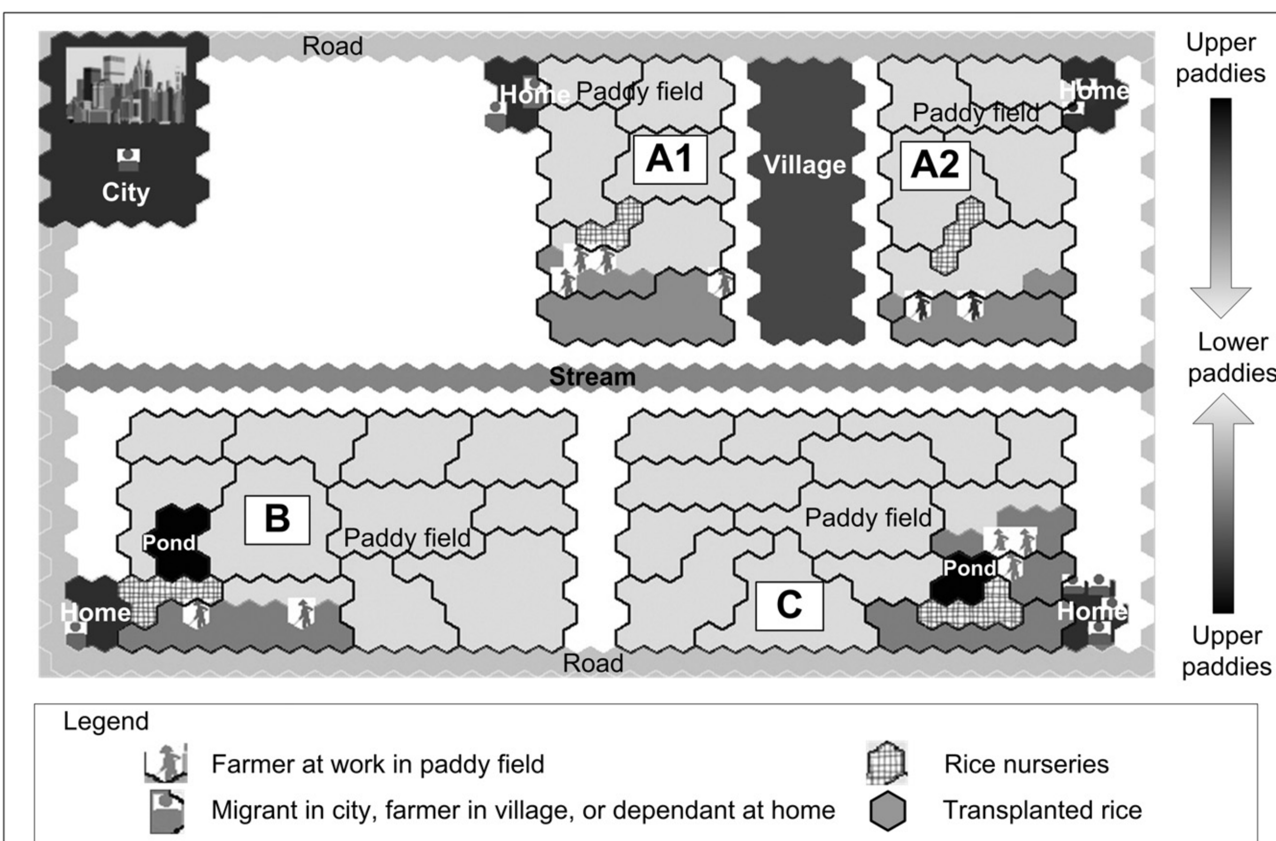

Fig. 5. Spatial configuration of the BMM model representing two small farms (A1 and A2) and two large farms (B and C) during rice transplanting.

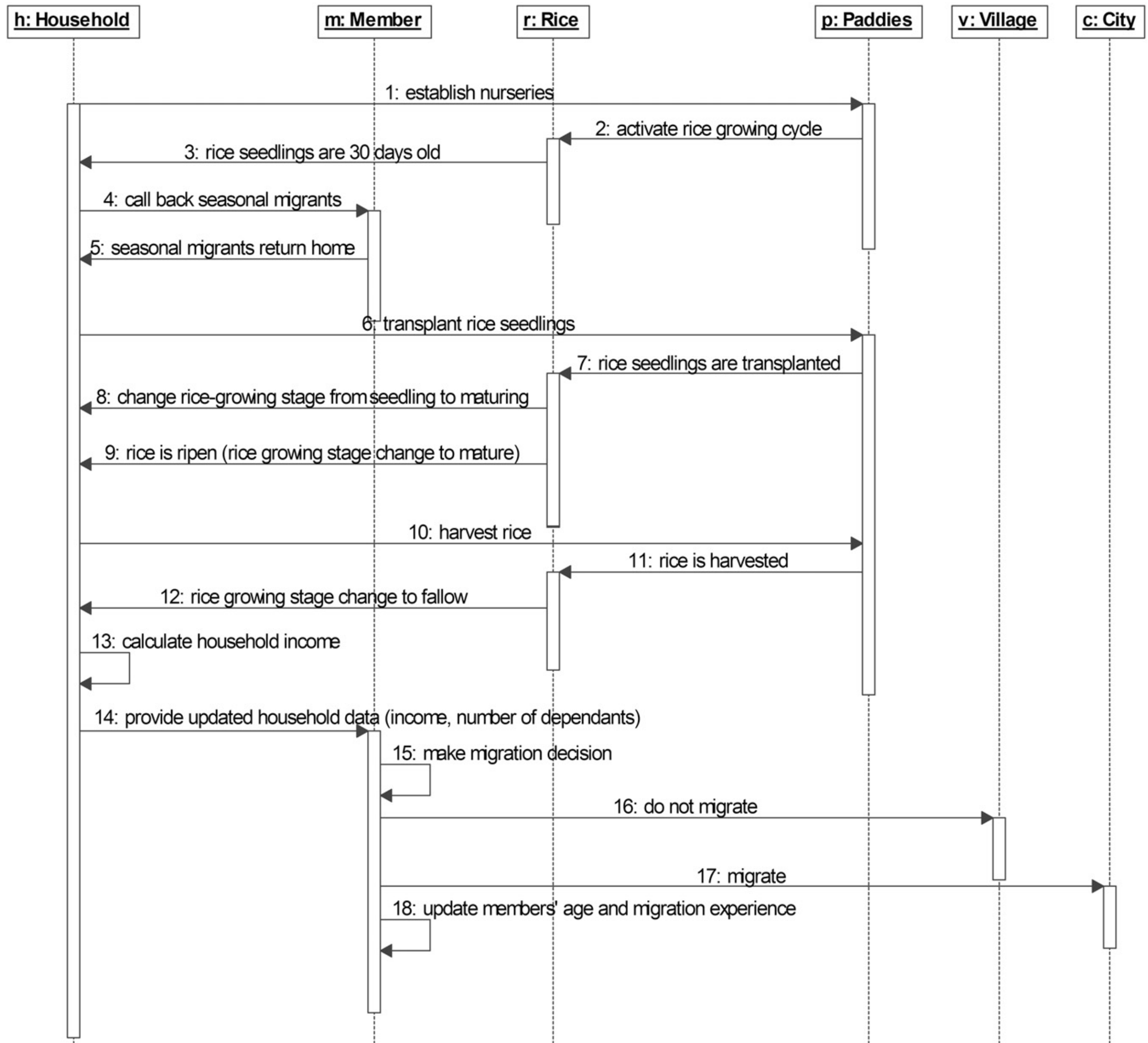

Fig. 6. UML sequence diagram illustrating activities among components in the BMM model throughout a crop year.

household computes the results of the rice season and decisions about labor migration are individually considered by each member.

3.2. Design concepts

The BMM model is purely deterministic. Randomness would be inconveniently confusing when the main objective of the model is to enhance communication among participants. Household agents are able to memorize daily rainfall conditions and therefore to detect the occurrence of water stress in nurseries when the last effective rainfall occurred more than 12 days ago. Additionally, household agents striving to produce rice successfully are able to adapt to time constraints by considering the need to hire extra farm workers during the transplanting and harvesting phases (they are able to anticipate the need). The BMM model integrates three aggregated social levels: individual, household, and village. A list of available farm workers (not busy on their own farms), updated at the village level, is accessible to all household agents. The household agents directly interact when hiring extra farm workers.

3.3. Details

3.3.1. Initialization

Type A farmers, the majority of farming households found in the study area, are represented in the model by two virtual households (A1 and A2), while types B and C are represented by a single virtual household called B and C (see Fig. 5 and Table 2). Moreover, we took into account the farm size in relation to family labor size (farm and labor ratio) to distinguish each farm type based on the results of the on-farm survey and household typology. The characteristics of each individual member have been chosen to represent the heterogeneity of family members at the household level (Table 3). The initial water level in ponds was set to 50 cm.

3.3.2. Input

Daily rainfall and potential evaporation data used in the model were obtained from the regional meteorological center located in Ubon Ratchathani province. The same 10 year chronological series of rainfall data (1986–1995) was used in all simulation

Table 2
Characteristics of households pre-designed for initialization.

Household	Farm size (ha)	Pond volume (m^3)	Family labour			Family dependant
			Farmer	Seasonal migrant	More-permanent migrant	
A1	3.3	no pond	3	1	0	2
A2	3.3	no pond	3	0	1	2
B	6.5	7200	2	0	0	1
C	6.5	4800	2	1	0	4

experiments. The price of rice sales in the market was set based on information obtained from the Thai Rice Mills Association (Table 1).

3.3.3. Sub-models

The sub-models correspond to the key activities implemented by local farmers during rice production. The sequence ends with post-harvest activity corresponding to the updating of Household and Member variables and labor migration.

At the beginning of a simulation run, rice varieties are selected. Depending on the farm land per labor ratio (F–L ratio), either a single variety or two rice varieties are produced. If the F–L ratio is lower than 2 ha/labor, only late-maturing rice is grown. Otherwise, two rice varieties (early and late-maturing) are planted. However, this F–L ratio may change over time as family members update their labor status every year. In this model, early-maturing rice is for family consumption only. The area to be grown is derived from the consumption needs of all household members. If no early-maturing rice is grown, glutinous late-maturing rice (e.g. RD6) is used for family consumption while non-glutinous rice (e.g. KDML105) is kept for sale.

3.3.4. Nursery establishment

According to the farmers, the annual rice production cycle never begins before the Royal ploughing ceremony day in Bangkok. From that date, if the quantity of daily rainfall is higher than 30 mm, the nursery is established (Table 1). If the quantity of daily rainfall is lower than this threshold, water from the pond can be used for nursery establishment (80 m^3/ha), provided the water level is above 10% of the pond depth (see Fig. 7). This activity takes only one day, and must be performed before the third week of July (limit date for nursery bed) to ensure a sufficient duration of the RLR vegetative phase for biomass accumulation and the production of quality paddy.

The irrigation requirements are defined by a combination of two thresholds: a daily rainfall threshold defining what is a dry day, and a continuous succession of 12 dry days to generate water stress in rice seedlings (Table 1). The water stress triggers a household to operate a water pump (40 m^3/ha). The seedlings in the nurseries require 30 days to be ready for transplanting. Seedlings may become too old (over 51 days) when a long dry spell occurs making the household unable to carry out transplanting (farmers consider that ponds can be used only during the nursery phase, and not for transplanting). When the water stress occurs during the nursery bed phase or when farmers have to wait too long for transplanting, the nursery fails and the establishment of a second nursery is needed (Fig. 8). According to the collaborative farmers, when a second nursery is needed, only one third of the whole nursery area needs to be sown.

3.3.5. Transplanting

Once at least 30 days old, rice seedlings are ready for transplanting the household agent decides whether the daily climatic conditions are suitable for transplanting (higher than 20 mm/day) or not. If a household grows both early and late-maturing varieties, early-maturing rice needs to be transplanted before the late-maturing cultivar. Based on their actual practices, participants requested the model to simulate transplanting of the early-maturing variety from upper to lower paddies, and of the late-maturing variety from lower to upper paddies. The duration of transplanting depends on the F–L ratio determining the number of days needed to complete transplanting. Once a household starts transplanting, its seasonal migrant members return home to join in this activity. Seedlings older than 51 days cannot be transplanted, and the deadline for completion of transplanting is set to September 15 (after that date the duration of the RLR vegetative phase would be too short to achieve satisfactory yields and grain quality). Should this happen, some paddies would be fallowed. However, a household can compute data to decide if additional workers need to be hired to avoid such an unwanted result. Once a household has completed transplanting, no more rice-growing activity is conducted until November. Farmers stay in the village and are available for hiring by other households who have not finished transplanting yet.

3.3.6. Harvesting

Farmers return to their paddies at fixed dates for harvesting defined in the "Rice" entity (Table 1). These dates correspond to the agronomic practices for harvesting photo-sensitive rice varieties in this area. Harvest of early-maturing rice starts on November 10 and ten days later in the case of the late-maturing cultivar. To ensure paddy quality, harvesting stops for one day if a wet day occurs. The number of days needed to complete the rice harvest determines paddy quality, resulting in price changes that affect the household income generated from the sales of late-maturing rice, which in

Table 3
Characteristics of individuals (members) of each household pre-designed for initialization.

Household	Name	Gender	Age	Marital status	Migration experience
A1	M1-1	Male	55	Married	Yes
	M2-1	Female	55	Married	No
	M3-1	Female	30	Married	Yes
	M4-1	Male	25	Single	Yes
	M5-1	Female	10	Single	No
	M6-1	Male	8	Single	No
A2	M1-2	Male	55	Married	Yes
	M2-2	Female	52	Married	Yes
	M3-2	Female	32	Married	Yes
	M4-2	Male	29	Married	Yes
	M5-2	Female	10	Single	No
	M6-2	Female	6	Single	No
B	M1-3	Male	50	Married	Yes
	M2-3	Female	45	Married	No
	M3-3	Male	5	Single	No
C	M1-4	Male	50	Married	No
	M2-4	Female	45	Married	No
	M3-4	Male	30	Married	Yes
	M4-4	Female	14	Single	No
	M5-4	Male	12	Single	No
	M6-4	Male	5	Single	No
	M7-4	Female	2	Single	No

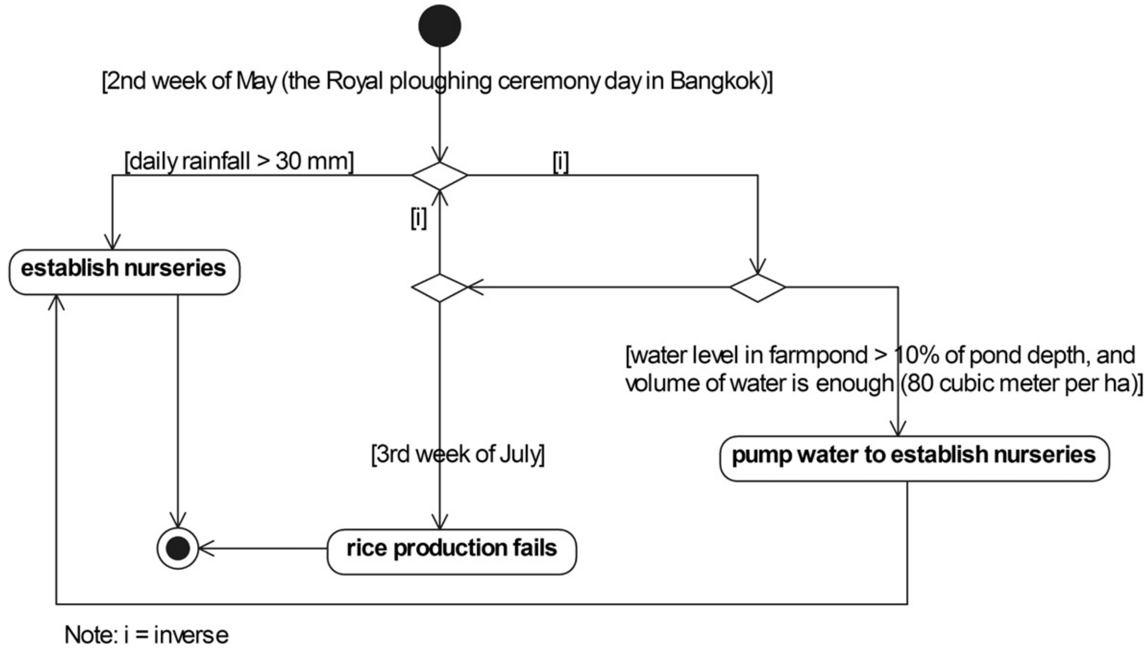

Fig. 7. Activity diagram representing thresholds and methods to establish nurseries operated by the household agent.

turn influences migration decisions. Therefore, hiring off-farm labor is a common practice to accelerate harvesting and have it completed before December 1 to sell paddy of the highest quality. The recruitment of hired laborers is often competitive during this period, resulting in higher wages than during transplanting (see Table 1). Participants requested that the rice harvest in the model starts from upper paddies and proceeds to lower areas. This is the actual practice used to avoid the harvest of poor paddy quality because of high moisture in lower areas.

3.3.7. Labor migration

Once rice harvest is completed, two key operations are made in sequence. First, households update their net incomes and their members update their age and migration experiences. Then migrants make their move. The household income is generated from rice sales and wages earned during rice production. Household expenses are calculated from farm inputs depending on the farm size and labor costs. This new net income is added to the previous household income. The level of the updated household

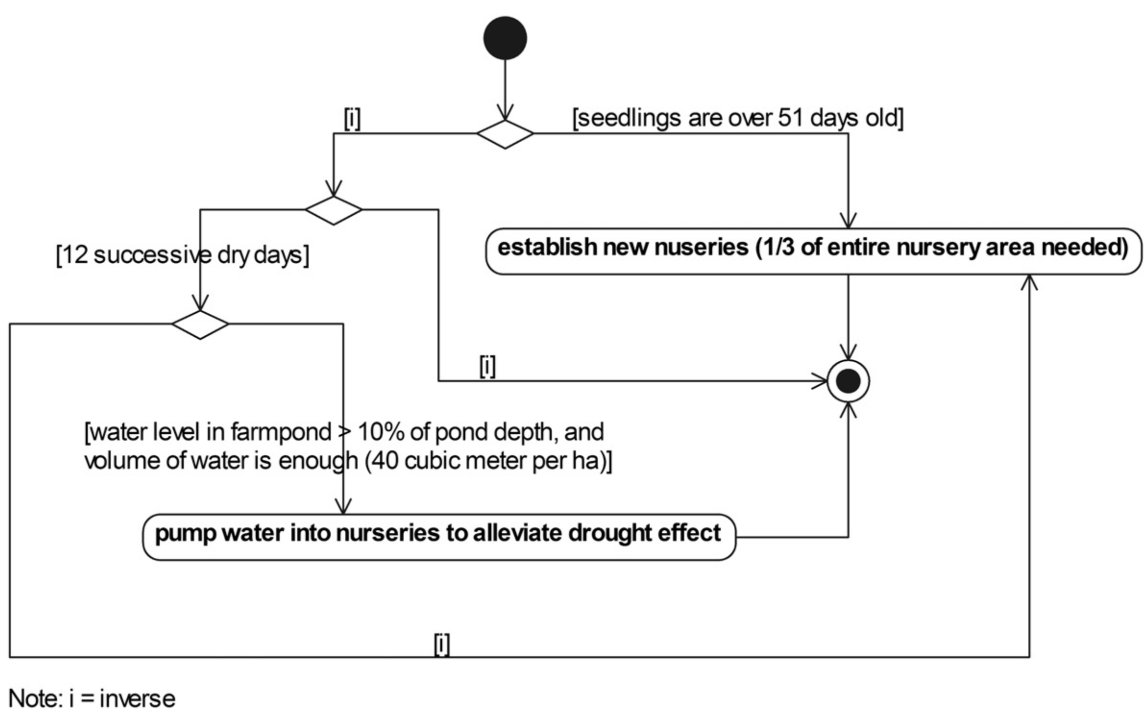

Fig. 8. Activity diagram representing “maintenance of nursery” as a result of the first nursery establishment failure.

net income affects the selection of migratory patterns individually decided by the concerned household members.

In reality, the migration decision involves multi-level factors from the individual to village levels. Due to the lack of reliable data, we decided to avoid the representation of the complex evolution of demographic characteristics related to reproduction and changes in marital status, and did not account for the income from migrants' employment outside of the village during the dry season. Only the age of the member changes every year. The individual characteristics of members, as well as their household's social and economic status, determine whether a member migrates during the dry season (seasonal migrant) or migrate without returning home to join in rice production (more-permanent migrant), or does not migrate at all (Fig. 9). An important social tie is the presence of elderly and/or children (dependents) who need to be looked after by working household members. Another key determinant in the decision not to migrate is the household economic status. We could not precisely identify the level of annual net income that satisfies farmers and stops migration; the data were fuzzy yet clear differences emerged among participating farmers. As a result, we decided to use the average annual net income for Northeast Thailand (20,000 baht per household, National Statistical Office – NSO, 2007).

4. Field-based simulations and participatory analysis

The spatial settings and characteristics of the four virtual households and their members presented in the previous section were used to define a baseline scenario. We used it as a reference for comparisons with other subsequent ones. We decided to present this baseline scenario to the farmers who participated in the design process, prior to performing an in-depth sensitivity analysis. We wanted to check whether the participating farmers would react to potentially inconsistent or hard-to-explain results, but also to see whether this "business as usual" scenario would stimulate their imagination to propose unusual situations to be investigated through computer simulations. Two scenarios emerged from the discussions held in May 2008 with the collaborating farmers. The first one includes the availability of cheap foreign laborers from neighboring Lao PDR and Cambodia during the RLR transplanting and harvesting phases. The second proposed scenario assumes that all farms have access to enough water to satisfy their irrigation needs.

4.1. Cheap foreign labor scenario

In this scenario, 30 hired laborers from neighboring countries are available at low wages. The simulation results display important differences in incomes across the farm types compared to the baseline scenario. Incomes from rice sales of small virtual farms A1 and A2 were not significantly different, but they lost off-farm income usually received from virtual households B and C to foreign workers. In contrast, in the absence of any labor constraint, the large virtual households B and C earned higher incomes from selling high quality paddy thanks to faster harvests despite higher labor costs. However, the participating farmers argued that, in actual circumstances, small farms may not lose as much of their off-farm income as indicated by the simulated results because such immigrant workers are not considered to be skilled rice farmers and thus are less likely to be hired.

4.2. No water constraint scenario

In this scenario, all virtual farms are able to start producing rice at the same time. The simulated results show that this synchronization of rice farming activities is unlikely to change the situations of larger virtual farms B and C compared to the baseline scenario. The virtual farms B and C could not hire extra workers at the beginning of transplanting like they did in the baseline scenario. However, the transplanting period can be extended without critical damage to rice yields. Therefore, virtual farmers B and C could

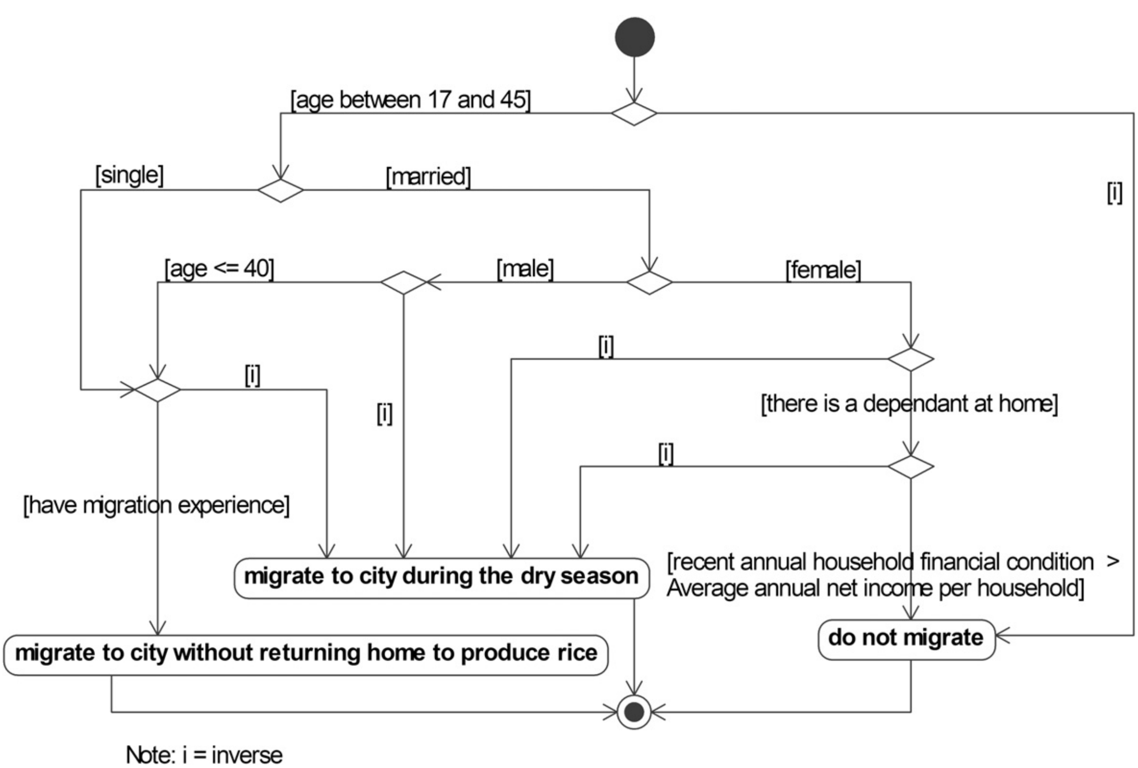

Fig. 9. UML activity diagram depicting the individual migration decision process.

complete transplanting by hiring extra workers from virtual households A1 and A2. Compared to the baseline scenario, there is little difference in terms of local off-farm income gained by small farms and labor costs incurred by large farms. In this scenario, a small virtual farm A2 could not complete transplanting of its entire farm when the onset of the wet monsoon was delayed as by that time part of its rice seedlings were too old and he had not enough labor force. However all the participants said that such situation was unlikely to happen in reality because rice farmers take adaptive precautions like establishing more nurseries or buying rice seedlings from neighbors. Nevertheless, this simulated outcome helped the collaborating farmers to reflect on such risk-taking decisions in relation to water dynamics that may lead to increased expenses to acquire additional rice seedlings.

5. Laboratory-based simulation and analysis

Additional exploration of scenarios based on labor and water availability was carried out. Nine scenarios were selected to examine interactions between water and labor availability, as shown in Table 4.

The results show that, in all three sets – *Ln*, *Li* and *La* scenarios – labor availability positively and significantly influences the household income generated from rice sales. This is because more farm workers can accelerate the rice harvest leading to higher paddy quality sold at higher market price. The most significant income differentiation is found between the “no additional laborers from outside the village (*Ln*)” and the “10 hired workers from outside (*Li*)” scenarios. But no difference is observed between the *Li* and “20 hired workers from outside (*La*)” scenarios. This indicates that more workers may not provide different outcomes once the entire paddy area has been completely harvested before December 1. Even if the harvest is completed long before this threshold date, the income generated from rice does not increase but more cash needs to be spent for hiring extra workers.

In contrast to the household income, the most significant differentiation in wages received by virtual smallholders A1 and A2 is between the *Li* and *La* scenarios while the difference between *Ln* and *Li* scenarios is not significant. This is suggesting that abundant labor has a negative impact on the poorest farmers (type A) while it does not impact the other ones.

The number of seasonal migrants is clearly influenced by the availability of hired farm workers from outside the virtual village. When these farm workers are unavailable (scenarios with *Ln*), the number of seasonal migrants is significantly lower. This could be linked to the negative effect of higher household income thanks to local wage employment on labor migration.

However, the effect of water availability during the rice-growing season on labor migration is not clear. It is only in the case of the *Ln* set of 3 scenarios that smallholders have more seasonal migrants when they manage ponds with plenty of water (*WaLn*). Further investigation is needed to better understand the interaction between water availability and labor migration.

6. Discussion

6.1. Validation: a shared representation of the interactions between land & water use for rice production and labor migration

Validation relates to the extent to which the model adequately represents the system being modeled (Casti, 1997). The canonic view of validation mainly considers the difference between simulated and observed data. However, the correlation between observed and simulated data might be induced by irrelevant mechanisms introduced in the model (Amblard et al., 2007). In any case, the validity of a model should not be thought of as binary event (i.e. a model cannot simply be classified as valid or invalid). The adequacy of the representation provided by the BMM model refers to its acceptance by the local farmers who participated in its collaborative design as a fair and useful representation of the interactions between labor migration and land and water use for rice production in their village. The purpose of this model is not to precisely estimate the effect of water availability on labor migration, but to investigate how they are interrelated during the rice-growing season. Our simulation results suggest that water availability for rice production is not sufficient to explain labor migration patterns, as farmers developed many adaptive ways unrelated to labor to avoid the complete failure of their paddy crops even when water is lacking at crucial time of the cropping calendar. From this better understanding of what is happening during the rice-growing season, the next investigative stage would be to consider the possibility to use the water stored in the ponds during the dry season to grow short duration crops such as vegetables. Would local farmers exhibit diversification strategies as a direct effect of a more secured availability of water during the dry season? Would this additional activity generate enough income to convince former migrants to stay in the village during this period of the year? This is another research question related to the diversification of the local agricultural production. We believe that our study, while focusing on rice production, provides useful insights to frame a more integrated study of the overall effects of water availability on labor migration.

The BMM model has been recognized by the participating farmers as a sufficiently accurate representation of their current situation. As a result, they eventually proved to be comfortable and confident enough with it to present and comment the BMM model in front of master students, lecturers, and researchers – who did not participate in the modeling process – at the Faculty of Agriculture, Ubon Rajathanee University, on October 18, 2008. The students who have learnt about the farming practices mainly through lectures have a scholastic perception of the RLR ecosystem. Most of the time, the empirical knowledge is gathered by scientists in the field and then re-interpreted before to be delivered to students. This special seminar was a direct confrontation between empirical and academic knowledge. The discussion that followed the model presentation showed that farmers and students have clearly different views and understandings and even use different concepts about RLR farming in Northeast Thailand. This confirmed

Table 4
Coding of the nine scenarios defined to explore the interactions between water availability and labour availability.

		Water availability (W)		
		No farm has farm pond (n)	Two large farms (B and C) have farm ponds with water level 200 cm (i)	All farms have farm ponds with water level 200 cm (a)
Labor availability (L)	No hired farm workers from outside the village (n)	WnLn	WiLn	WaLn
	10 hired farm workers from outside the village (i)	WnLi	WiLi	WaLi
	20 hired farm workers from outside the village (a)	WnLa	WiLa	WaLa

the fact that any model might be an accurate representation of some stakeholders' views, but, at the same time, be an inaccurate (though precise) one for a different stakeholder having another point of view (Moss, 2008). Such collaborative modeling practice is valuable because of its efficiency in communicating and therefore sharing such diversity of viewpoints.

6.2. From singular representations of actual households to the abstract concept of a BMM household

In a preliminary stage, we have attempted to integrate a map of the actual study site into the spatial interface of the model. This was supposed to represent the realistic spatial entity of the study site and to help explain it to local farmers. However, the map scale was too small to be able to observe land and water use changes at the micro level, which was the research focus. The spatial representation of the first version of the BMM model used in the participatory simulation workshop organized in April 2007 (see Fig. 1) was much simpler. Eleven farms corresponding to the actual farm sizes, main components and location of the paddy fields (upper, middle and lower paddies) of the as many collaborating households involved in the workshop were represented. Unfortunately, while this version of the model simulated eleven realistic farms, it did not stimulate a collective discussion about the interactions between water dynamics and labor migrations at a higher level. Instead, the participants focused on correcting what they perceived to be 'mistakes' made by the simulation displayed on the screen, rather than sharing opinions on the proposed representation of the interactions between water dynamics and migratory behaviors, or discussing scenarios of interest to be examined later. As a result, the representations of these interactions were not sufficiently validated and no further scenarios were identified at this stage.

As the overly realistic spatial configuration used in this version of the model did not provide good results, we decided to simplify it and to make it more abstract by representing only four virtual farms related to existing farm types with characteristics based on the results from a preliminary farm survey and the construction of a farmer typology (Naivinit et al., 2008). These abstract landscape settings were a key spatial configuration of the second version of the model. They were designed to stimulate discussion by shifting the participants' focus from their own actual situations to being 'experts' on the management of virtual RLR farms and providing comments on the actions of agents observed during simulations. However, the main features of the landscape configuration – e.g. toposequence and land use types – remained unchanged. Although this final version of the BMM model interface is more abstract than the first one, it was accepted by all the participating farmers to sufficiently represent their system in the last workshop held in May 2008.

6.3. Effects of ComMod activities on participating farmers

According to the ComMod principles, the BMM model was built through the confrontation of the views of different types of stakeholders and the views of the researchers in order to clearly express scenarios built to explore the opportunities and risks of an uncertain future (Moss, 2008). Different kinds of effects of the ComMod activities were observed during this collaborative modeling process thanks to a series of individual interviews with players just after each main field workshop. The participating smallholders, especially resource-poor farmers declared that they had gained new agro-ecological knowledge about the effects of rainfall and water availability on rice production patterns. They think that they are now better prepared to face droughts and have learned how to plan for crop establishment and use of agricultural water from their small on-farm ponds. Even if technical topics were not explicitly examined in the collaborative modeling process, the exchanges among the participants seemed to have led to the acquisition of new technical knowledge as well. For example, several farmers declared that they are now considering experimenting with direct seeding of RLR and vegetable cultivation after rice harvest. As these small farm holdings hire out part of their under-employed workforce to larger holdings or as migrants looking for wage-earning jobs, it is not surprising to observe that they have also become interested in gaining a better understanding of the pattern of labor migration in the village, especially through the behavior and actions of other players during the gaming sessions.

In terms of changes in personal perceptions, most of the small farmers adopted a wider perspective. They are now interested in acquiring a better understanding of various other agricultural activities that they can undertake, especially if more water becomes available, such as vegetable production after rice, or mixed farming systems around farm ponds, and related market-based activities. Smallholders mentioned two interesting and related opportunities that emerged from this learning process. The first one is the possibility of diversifying their agricultural production out of RLR into vegetable cash cropping after rice and mixed farming. Another one deals with the possibility of exploiting underground water to increase the volume available for more diverse farming activities; again, this topic was not explicitly discussed with the research team during the field workshops held in the village but emerged from more informal exchanges among the participants during and after these short events. This indicated that the ComMod activities had an effect on the way some of the participants interact with others.

The other group of participating farmers represented the larger holdings which are most affected by labor shortages during the peak labor demand periods of RLR transplanting and the main harvest of late-maturing varieties. They also declared that they gained the same kind of new agro-ecological and technical knowledge as the smallholders. But due to their labor constraints, it is not surprising that these more well-off RLR growers focused on the effects of labor shortage on the economic results of RLR production in the participatory simulations. Regarding changes in personal perceptions of the system, like smallholders, they emphasize their wish to better understand the market opportunities for their farm products; these larger farm holdings also seem ready to increase and diversify their agricultural production if more water is available. But for the time being, distinct changes in their behavior or farming practices could not be observed.

These findings suggest that a more comprehensive representation of the interactions between land and water use and labor should also consider the commercial diversification of farm production in relation to water availability. In this study, having first focused on rice production allowed us to launch a participatory process with farmers being invited to elucidate the decision-making processes they were most familiar with. Along the succession of workshops, self confidence and trust were improved. Participating farmers are now used to the kind of intellectual activities involved in designing and using an agent-based model. Referring to the iterative and evolving dimensions of the companion modeling approach, they would engage more comfortably in a new, more speculative, phase of the collaborative modeling process to explore and discuss farm management options they have not experienced yet.

6.4. Cost and benefit

The modeling process was long and costly, with only a very local impact so far. This inescapably raises the question of the cost–benefit of the whole approach. Many factors dealing with the academic work of a Ph.D. candidate including mastering in coding computer program and the limited time available for collaborative gaming and simulation activities of the participating farmers impeded a faster implementation. As a result, we could not organize the workshops in the periods of peak labor demand in RLR production. The field workshops, especially for RPG sessions, were held mainly in April –May, just before RLR crop establishment, and again after transplanting and before harvesting in August or early October.

The RPGs sessions were definitely needed in this case study because it proved that they could offer lively discussion, inclusive outputs and prepare the participants to be ready to use the more challenging ABM tool. But, the preparation and organization of RPG sessions were costly. Once the BMM model was used as a knowledge-sharing platform instead of RPGs, we could organize more interactions with farmers (4 times within 6 months) with less time needed to prepare them and to spend with participating farmers (usually half a day per workshop).

Future ComMod sequence on this topic could be faster if the main tool used with the recent participating farmers is still the BMM model. Based on the ex-post evaluation, the participants said that they needed to learn the structure and operations of ABM through, at least two RPG sessions. Therefore, the RPG session may need to be organized if there is involvement of new participants. Although, this long-term investment in training a new ComMod modeler who will teach this approach and its tools to generations of students in the coming years may seem high, the returns will be obtained during many years. Also, if the entire process needs to be repeated for other sites, the experienced ComMod modeler will be able to work more efficiently, in a less time and cash costly way (Etienne, 2010).

7. Conclusion

The final version of the BanMakMai model integrates scientific and empirical knowledge, each part equally understood and accepted by the researchers and the farmers who participated in its design. Through co-learning and knowledge-sharing activities, farmers accepted that they better understood their RLR system, particularly the interaction between rainfall and water availability on rice production. Farmers became familiar in using RPGs and ABMs. They praised the usefulness of these tools to express their representations, to facilitate their collective assessment of the problem at stake, and to improve their coordination through the collective identification, simulation and assessment of scenarios of change.

The BMM model is undoubtedly a site-specific model, far from a generic tool. In terms of out-scaling, the current model can be considered as a communication tool to be reused in villages similar to BMM to stimulate knowledge sharing, leading to the enrichment of the underlying conceptual model. We believe that the computer model could be introduced straightforwardly to other farmers without being perceived as a “black box” if the presentation is made by the BMM farmers themselves: there is no reason why the communication of the model among farmers would be more problematic than the communication of the model from farmers to scientists.

Finally, from this experiment, we found that it is possible to collaboratively co-design a conceptual model and co-construct a computer model with marginal rice farmers. Through this innovative model co-construction methodology, participating farmers had a high sense of co-ownership of the computer model and gained confidence in communicating across broader social networks to share their perceptions regarding their RLR and labor management.

Moreover, both the researchers and participating farmers benefited from knowledge shared during the co-construction of this simulation tool. However, it was observed that not all of the representatives from the different types of farming households felt comfortable and actively participated in the simulation workshops. While the gaming sessions were more inclusive, the computer simulations were obviously more difficult to follow for the older farmers. More attention should be given to this aspect when selecting participants in such a context. Nevertheless, the series of participatory village workshops stimulated co-learning and knowledge sharing while improving the participants' adaptive management capacities. They adopted a more reflective, pro-active style of farming and gained greater confidence in managing change in their farming environment. A better understanding of the relationship between water availability and rice production was gained leading to a better preparation of the participants to face early droughts through the use of farm ponds. New ideas on how to improve the local agro-ecosystem also emerged, such as the adoption of mixed farming and the complementary use of underground water. Some participants even declared that their farming practices had already changed as a result of the learning and exchange in the collaborative modeling process.

Acknowledgements

The research presented here is part of the “PN 25: Companion modeling for resilient water management”, a project funded by the CGIAR Challenge Program on Water and Food, and the Echel-Eau Project, MAE, France. The authors also thank the bilateral Franco-Thai cooperation program in higher education and research for its support.

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