**Collaborative Multi-Agent Modelling to improve Farmers' Adaptive Capacity to Manage Water and Migrations Dynamics in Northeast Thailand**[1]

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## Abstract

Northeast Thailand has the largest rainfed lowland rice (RLR) ecosystem in the kingdom and is notoriously known for its high rate of poor smallholders. The low and unstable rice productivity as a consequence of an unfavourable agro-ecological environment drives resource-poor farmers to migrate and look for more profitable employment. Labour migration is an adaptive strategy practiced by local farmers to cope with climatic uncertainty. But the relationship between labour migration and land and water management on the farms is still poorly documented.

Therefore, we used the Companion Modelling (ComMod) approach to improve the understanding of this key interaction and to reinforce stakeholders' adaptive capacity to deal with uncertainty linked to water dynamics and labour management in the Lam Dome Yai watershed of Ubon Ratchathani Province. The cyclic ComMod process is made of iterative loops comprising field investigations, modelling, and participatory simulations relying on combinations of Role-Playing Games (RPG) and Agent-Based Models (ABM) used with stakeholders.

In this case study, five ComMod loops were carried out to better understand the problem being examined, stimulate exchange of points of view among stakeholders and enhance the creativity of the participants while lessening the black box effect of computer models. The RPG mainly helped the stakeholders to understand the features, rules and operation of ABM simulations. The ABM helped the stakeholders to better understand their situations and to examine the causes of other players' actions. After its validation by the users, the ABM will also be used for discovery learning by exploring possible future scenarios selected by the local farmers.

## Introduction

The Northeast or "Isaan", the largest plateau in Southeast Asia, covers one third of Thailand (Fig. 1). The regional topography is undulating with elevation ranging from 140 to 200 meters above mean sea level. This is the most populous region in the kingdom where 21 millions inhabitants belonging to 5.5 millions households reside (NSO, 2005). Around 2.7 millions households are working in the agricultural sector and most of them are resource-poor farmers with a 3.2 ha average size of holding (OAE, 2005).

In Thailand, the total area planted to rice covered almost 20% of the country in 2005. With 42% of the total rice growing area, the Northeast region shared the largest area but harvests only 28% of rice production (Fig. 2). More than 80% of rice areas in the Northeast are in the rainfed lowland rice (RLR) ecosystem. The RLR refers to the level to slightly sloping, bund fields; non-continuous flooding of variable depth and duration; submergence not exceeding 50 centimetres for more than 10 consecutive days; rice transplanted in puddled soil or direct seeded on puddled or plowed dry soil; alternating aerobic to anaerobic soil of variable frequency and duration (Zeigler and Puckridge, 1995).

Key agro-ecological constraints that cause low and unstable rice production are the erratic rainfall distribution and poor soil quality. Though the region has an average annual rainfall comparable to other parts of the country, Northeast farmers still suffer from frequent droughts alternating with floods. Even in the rainy season from June to October, the occurrence of rainfall is

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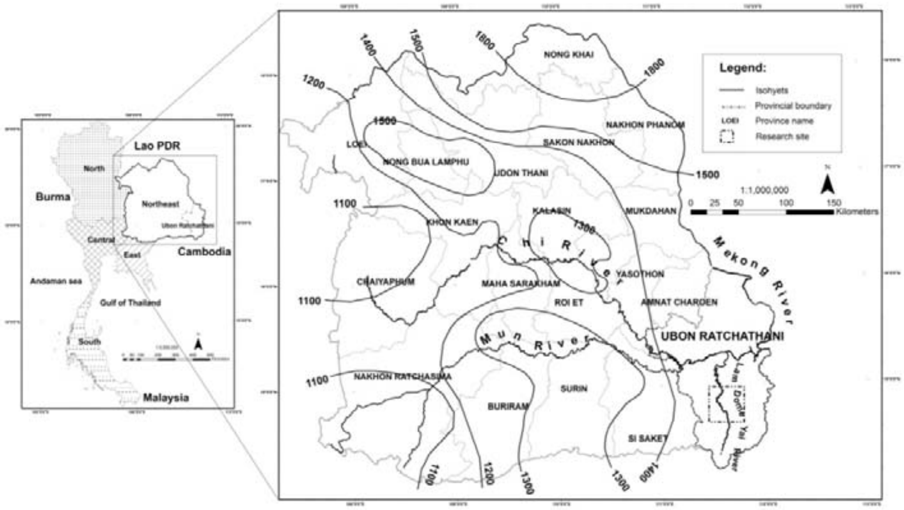
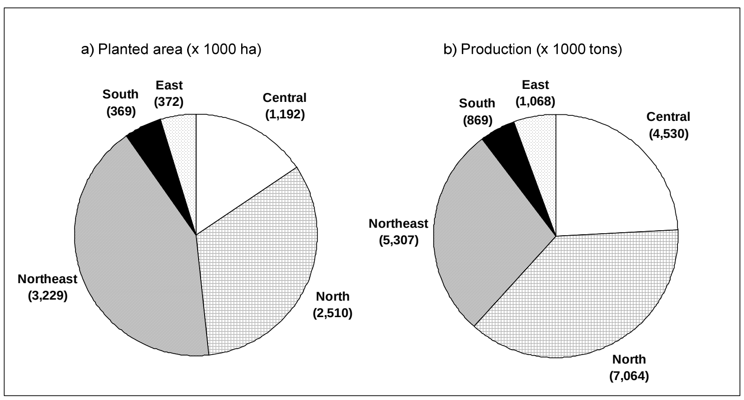



Fig. 1. Annual rainfall distribution in northeast, Thailand and location of the research site in Lam Dome Yai watershed, Ubon Ratchathani Province.




Source: Office of Agricultural Economics, Ministry of Agriculture and Co-operatives, Bangkok.

Fig. 2. Rice-growing area and production by region, Thailand; 2005 crop year.

still unpredictable. There is high possibility that this region would encounter an early-season drought in June and July when rice seedlings are generally transplanted and a late-season drought in October when rice is in its reproductive phase (Fig 3). Furthermore, soils characterized by low fertility with average organic matter content at 0.85%, and coarse-textured with 90% of sand (Harnpichitvitaya *et al.*, 2000) causing low water holding capacity, worsen the biophysical conditions for agricultural production. These soils, particularly the low water holding capacity, magnify the water availability problem.

Although the water table that commonly rises up close to the surface in August mitigates the effects on the rice crop of the dry spells, a severe flood may occur if exceptionally high rainfall takes place. The groundwater level generally fells quickly after flowering making rice susceptible to the late season drought causing significant yield reduction. Supplementing water during the dry spells is an way to alleviate the drought stress. However, these sandy soils limit the development of irrigation infrastructure. Therefore, irrigated areas of the largest rice growing region of the Northeast cover only 6% of the farmland while approximately 50% of agricultural land of the central region is irrigated system (OAE, 2005).

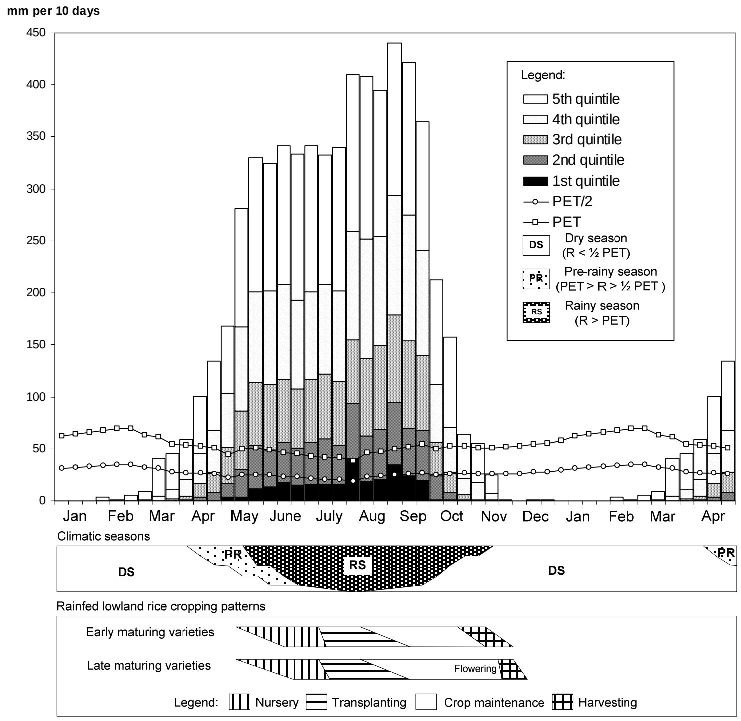


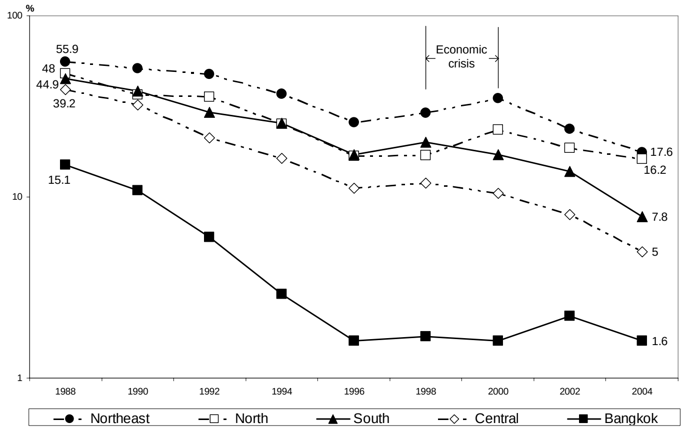

Fig. 3. Frequential analysis of rainfall and rainfed lowland rice cropping patterns in Ubon Ratchathani Province, lower Northeast Thailand; 1954-2003.

Rice being the staple cereal in the local household food systems, its production contributes only 17-20% of the total cash income of farmers but contributes to reduce household's expenses. The poverty rate of the Northeast is all time highest compared to other regions as indicated by poverty incidence (Fig. 4). The 1997 economic crisis resulted in an increase of poverty incidence in this region. The high rate of poverty and underemployment in villages drive many young male and female farmers to cities (Fig. 5) causing labour management problem on local farms.

Under the poverty alleviation national policy, several interventions have been undertaken to strengthen grass root economy and reduce poverty incidence. However the success of the Thai government's attempts to mitigate regional poverty through water resource improvement to increase farm intensification is limited by the undulating topography of the Northeast that are not well suited to large-scale irrigation projects. Very recently, the Thai government planed to take off the shelf a very ambitious and costly project costing up to 10 billion euros to divert water from the Mekong River to supply 19 provinces in the Northeast region through the Chi-Mun system. But the past and recent projects are implemented without prior understanding of relationship between land & water use and labour migration.

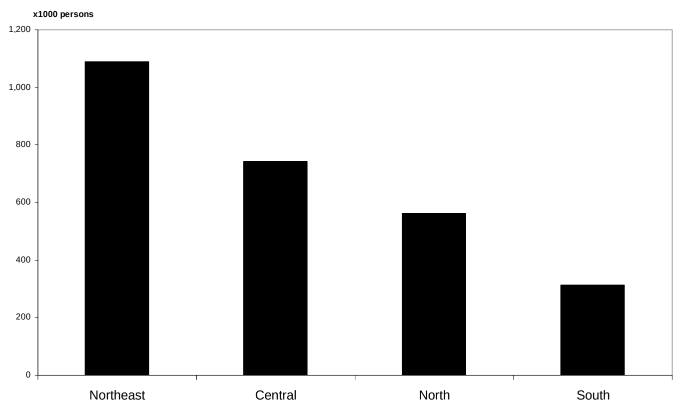
How can we better understand the interaction between land & water use and labour migration to improve farmers' adaptive capacity to manage these agro-ecological and socioeconomic dynamics? Our assumption is that such better understanding could be achieved through co-learning during a process of iterative, collaborative modelling between researchers and RLR growers. Based on a shared understanding of the interaction between land & water use and labour migration, various land & water management scenarios to deal with uncertainty of climatic conditions could be explored with local farmers through series of participatory simulations.

This communication starts with the description of existing knowledge on the problem at the study site. The Companion Modelling (ComMod) and the development of tools used are introduced, and followed by the organization of series of participatory workshops and the selection of participants. Finally, various effects of this participatory modelling and simulation process on farmers' learning and adaptive capacity described and discussed.




Source: Statistical Year Book 2006, National Statistical Office, Ministry of Information and Communication Technology, Bangkok.
Note: Thailand measures poverty incidence at household level by comparing per capita household income against poverty line which is the income level that is sufficient for an individual to enjoy the society's minimum standard of living.

Fig. 4. Evolution of poverty incidence by region of Thailand; 1988 to 2004.




Source: Labour Force Survey Quarter 4/2005, National Statistical Office, Ministry of Information and Communication Technology, Bangkok.

Fig. 5. Number of out-migrants by region of Thailand; 2005.

**Existing knowledge on the problem at the study site**

The RLR ecosystem of Northeast Thailand is made of "mini-watersheds" which are identified based on the landform and consist of uplands and upper, middle and lower paddies. Rice-based cropping systems occupy the middle and lower paddies, and some years in more risky upper paddies. Farmers still rely on human-labour at rice transplanting and harvesting due to their poor economic status and the difficulty of using machinery on undulating land and small paddy fields. But labour availability is often inadequate. Under the same climatic situation, various farm management practices are used by heterogeneous farmers to handle such conditions with different labour limitations.

In 2004, a farm survey was carried out at the study site to identify the different main types of household-based agricultural production systems, and to uncover the differentiated set of management criteria and the determining factors of labour migrations among these different categories of farming households (Naivinit and Trebuil, 2004). The current farm types are categorized into three main groups based on the availability means of production, their socioeconomic objectives, and related farming strategies (Table 1).

Table 1. Characteristics of the main types of farming households in Ban Mak Mai. Det Udom district. Ubon Ratchathani Province.

| Type | A: Very small rice-based, self-subsistence oriented farms | | | B: Small rice-based market-oriented farms with integrated farms for self-consumption | | C: Large market oriented farms with diversification out of rice or high remittance | |
|---|---|---|---|---|---|---|---|
| Farm size | 3.2 ha | | | 7.2 ha | | 8.6 ha | |
| Family size | 4 - 6 members | | | 6 - 8 members | | 6 - 8 members | |
| Farmed area per family labour | 0.64 - 1.6 ha | | | 2.2 - 4 ha | | 1.7 - 2 ha | |
| Objective | Family staple food security and regular income through selling surplus rice and full employment of family labour | | | Produce non-glutinous rice for sale and increase land productivity through integrated farms | | Increase labour productivity through diversification out of rice. | |
| Strategy | Grow one or two varieties of rice, late-maturing (non-glutinous, KDML105) rice for sale, and early-maturing (traditional glutinous) rice for family consumption. Cattle and buffalo are raised and sell them in case of cash-need emergency such as sickness of family members. Fish and poultry is for family consumption and sale. Motorized farm equipment is used for land and water management. Off-farm employment is important source of income to support on-farm activities. | | | Grow two or three varieties of rice, late-maturing (non-glutinous, KDML105 and glutinous, RD6) rice for sale, and early-maturing (traditional glutinous) rice for family consumption. Often hire l labourers to harvest late maturing. Products of integrated farms are used for family consumption and sell surplus. Livestock is raised for saving and sale. Water in ponds is used to establish rice nurseries. | | Grow two or more varieties of rice, late-maturing (non-glutinous, KDML105 and glutinous, RD6) rice for sale, and early-maturing (traditional glutinous) rice for family consumption. Water availability is very good (average 800 sq.m.). Usually use farm machines e.g. small tractors, rice threshers to alleviate labour shortage. Water in ponds is used to establish rice nurseries. | |
| Sub-types | A1: Low water availability. Very poor water accessibility (average 57 sq.m. of pond area) or paddies located in upland areas. Receive low remittance (less than 400 euro per year). Permanent and seasonal off-farm labour. Water is saved for alleviate drought to stabilize rice productivity. | A2: Poor accessibility (average 150 sq.m. of pond area). Raise poultry for sale. Receive medium to high remittance (average 450 euro per year). Permanent off-farm labour. Water is saved for alleviate drought to stabilize rice productivity. | A3: Good water availability because of ponds (average 650 sq.m. of pond area), and paddies located in lower land. Receive low remittance (less than 400 euro per year). Seasonal off-farm labour. Water in ponds is used even in wet year to establish rice nurseries. | B1: Good water availability (average 720 sq.m. of pond area). Relative high remittance (900-1,300 euro per year) used for children education and home improvement. Permanent off-farm labour. | B2: Very good water availability (average 800 sq.m. of pond area). No migrants. Raise livestock for sale. | C1: Upland crops e.g. cassava, mass plantation e.g. cashew nut, para rubber and fish production are used to maximize labour productivity. No migrant. | C2: Large rice-based, market-oriented farms with relative high remittance of permanent off-farm labour (average 1,500 euro per year). Take permanent off-farm employment or be entrepreneurs. |
| Cash flow facilities | Insufficient cash flow for any investment | | | Limited due to the debt | | High | |
| Average annual gross income | 1,150 euro | | | 2,100 euro | | 4,900 euro | |
| Share of off-farm income | 66% | | | 22% | | 6% | |
| Share of Debt | 31% | | | 31% | | 4% | |

*Rice production practices and water use strategies*

Because the incidence of drought is more frequent and serious than flooding, drought escape is the most important mechanism to stabilize the rice yield. Escape is achieved by matching variety duration with rainfall distribution so that crop passes critical development stages (Setter *et al.*, 1995). To cope with the climatic variability, photoperiod-sensitive rice varieties are widely grown because regardless of seeding date, they flower at about the same date after the peak rainfall period has passed and climatic conditions are favourable for the harvested grain to ripen and dry (Mackill *et al.*, 1996). The late-maturing variety such as RD6 and KDML105 (aromatic jasmine rice) are grown in the lower and medium paddies to ensure adequate water availability before harvest in late November while the early-maturing varieties are usually planted in the upper paddies and are harvested in late October. Regarding the use of supplementary water from farmponds, type A farmers (very small holders) are not likely to use water in wet years even if its quantity is sufficient. The use of water is carefully planned since the main purpose of having ponds is to store water and use it to alleviate drought effects and to feed fish. Unlike type A farmers, type B and C farmers often use water from ponds to produce their rice seedlings and avoid delayed transplanting.

*Labour management and migration in relation to RLR production and farm types*

Farmers belonging to type A play an important role to supplying labour to the community because their land per labour ratio is relatively low. However, it is risky and unsecured to mainly rely on the off-farm employment. Therefore, seasonal migrants who return to help their family to grow rice are commonly found for this farm type.

A key constraint of type B and C farms is labour shortage. These farm types play a major role in employing hired labour during the periods of peak labour demand in particular rice transplanting and harvesting. Migrants generally do not return home at the beginning of rice season but they remit money back to the village so that their families can use it to hire additional labour. These farm types have relatively high capability to invest in agricultural production through the saving assets (livestock herd) and high remittances.

The diversity of farming systems plays a major role in supporting local labour availability at the community level. During the 6 months of the dry season, most of the young labourers migrate to off-farm jobs to increase household incomes. The labour migration is seen as an adaptive strategy practiced by local farmers to cope with the uncertainty of rainfall and its distribution and the low productivity of their RLR cropping system (2-3 t/ha of paddy and only one crop cycle per year). Therefore, it is important to understand the interaction between this RLR ecosystem and labour management across different farm types prior to initiate any development.

**Companion Modelling (ComMod)**

The ComMod approach stems from adaptive management for collective ecosystem management. The ComMod aims to strengthen local stakeholders by improving their adaptive management capacity with regard to their renewable resources management (Bousquet and Trebuil, 2005). It also aims at the collaborative group model building integrating various stakeholders' perceptions to develop a shared representation of the systems to be managed and of the problem to be examined the platform of collective learning. For this research, the ComMod is used to better understand the interaction between water dynamic and labour management of the RLR ecosystem in Ubon Ratchathani Province, lower Northeast Thailand by facilitating dialogue, shared knowledge, and collective learning with farmers. For the ComMod, the human-environment interaction is investigated through the stakeholders' decision-making process, and assessed through the computer simulation based on the Multi-Agent Systems (MAS).

The MAS emphasizes the investigation of the emergent properties as a consequence of the interactions among agents and between agents and their environment. The MAS is based on the idea that it is possible to represent the behaviours of entities (agents) active in the world in a computerized form, and that it is possible to represent a phenomenon as the outcome of the interactions among an assembly of entities with their own operational autonomy (Ferber, 1999).

The ComMod requires a continuous, evolving and iterative confrontation between theories and field circumstances. Therefore, it is based on repetitive back and forth steps between the model and the field situation to comprehend interactions between ecological and social dynamic in complex systems (Barreteau, 2003). The combination of two complementary tools, Role-Playing Game (RPG) and Agent-Based Model (ABM)—for the creation of the MAS is used to capture such interactions through the co-learning with stakeholders during the cyclic ComMod process.

**Materials and methods**

*Conceptual model formalization*

The preliminary findings of the field survey integrating with interdisciplinary scientists' point of views were used to formalize an initial conceptual model by building a set of Unified Modelling Language (UML) diagrams. Based on these UML diagrams, the RPG were designed and implemented to be used in series of participatory modelling and simulation workshops. Fig. 6 shows conceptual model in an UML Class diagram. The main spatial component is land use types incorporated with vertical arrangement of tanks: ponding tank, root zone tank, subsoil tank, and water storage tank. All tanks have their own hydrological processes such as infiltration, percolation and runoff. Another important component is the "Household" rule-based agents that functions as a decision-maker regarding rice production and labour migration.

*Description of the Role-Playing Games (RPGs)*

The RPGs were designed and constructed based on the initial conceptual model and its gradual modification after each field workshops giving the opportunity to the participants to request changes in the representation of the system. The use of RPGs was also to facilitate mutual recognition and social validation of the representation of rice production and labour migration by different farm types under different climatic situations and water availability conditions. Moreover, the RPGs were used to improve local farmers' understanding of the interaction under study and to acquaint them with the structure and rules of ABM.

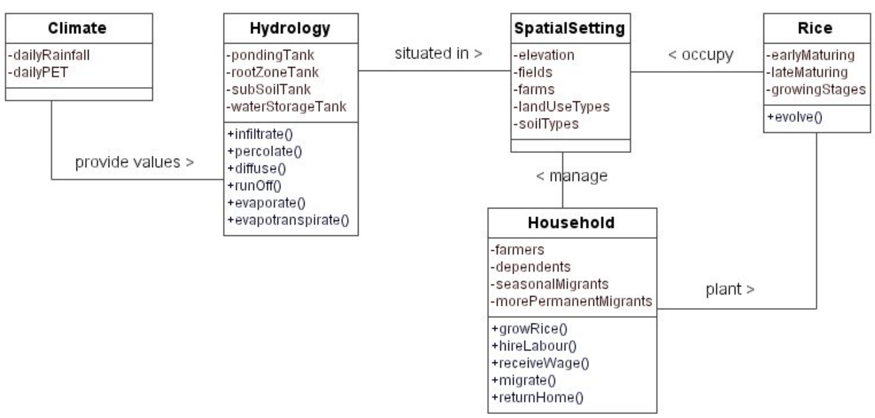



Fig. 6. UML Class diagram showing the structure and the key components of RLR production system in Det Udom District of Ubon Ratchathani Province, Northeast Thailand.

RPG sessions were based on simplified sequences of actions by the participants playing their own role (farmers). The scheduling of actions and some external information like rainfall conditions were provided by the facilitator during the RPG sessions. One round of the game represented one crop year and included three steps; i) RLR crop establishment, ii) Rice harvest, and iii) activities during the dry season including migration.

The RPG session in July 2004 started with the allocation of rice-growing areas for two varieties, KDML 105 (for sale) and RD6 (for self-consumption) on the 2D game board representing individual farms (Fig. 7a). In the 2nd step, the players were allowed to find labourers to transplant rice from a job broker played by a research assistant. Then the players had to identify where to allocate their family labour on the map of Thailand when they moved into the 3rd step. The 4th step was purposely set to let players migrate as they wished. In the final step of a gaming round, they received fake money on the computation (in an Excel spreadsheet) of their annual rice production and sales. 4 rounds of play with different rainfall conditions were completed.  The second RPG session in April 2005 was similar to the first one but new migrant players who just returned home could participate. Furthermore, this time, we introduced to the participants a computer simulation "playing the game" as a replay version of the RPG session during the plenary discussion.

The last RPG session in October 2005 was organized to specifically address the issue of farmers' perceptions of water availability. First, the players were requested to delimit rice growing area for KDML105 and/or RD6 on a "grid" where 1 square was equal to 0.16 ha (or one "rai" the Thai land unit). To simulate rainfall for each successive week starting in April, a drawing card was revealed by the facilitator. Each player had then to decide whether or not they started to work in their paddy fields. If so, he/she had to draw a cross on the corresponding week on his/her form recording his/her decisions (Fig. 7b). Every time a player decided to use water from his/her pond, he/she had to draw water levels in both pond and paddy fields, before and after using water. Finally when all players had announced the end of the crop establishment phase, each of them had to allocate family members in one of the 4 following categories: farm labour; returned migrants; dependent; migrants in cities. Once it was time to harvest, the players had to allocate family labour and decided to hire labour by negotiating with other players and/or asked the facilitator to hire labour from other villages. For the dry season activities, the players decided to allocate family members as they did in the crop establishment phase. Two scenarios were set according to their actual situations:  availability of individual ponds or a community pond. 6 rounds of game were played.

The decisions made by the players were recorded and analyzed during individual interviews and plenary discussions after the gaming sessions to clarify the players' decision-making processes and actions. The results were used to enrich and modify the initial conceptual model and then to construct the ABM.

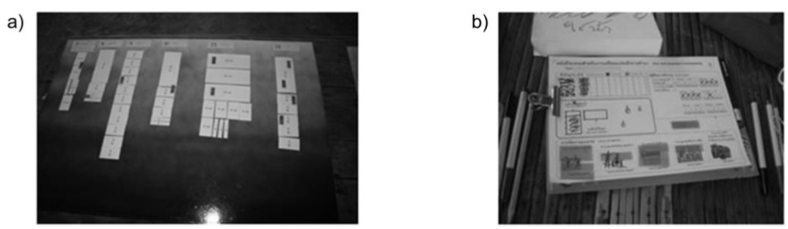



Fig. 7. 2D game board used for the 1st and 2nd RPG (a), and an abacus to record players' decisions used in the 3rd gaming session (b).

*Co-construction of the Agent-Based Model (ABM)*

The ABM called "BanMakMai" was co-designed and built with local farmers to represent the human-environment interactions regarding water dynamic and labour management of farmers working in Ban Mak Mai Village, a typical RLR production area of lower Northeast Thailand. The model is built under the CORMAS (COmmon-Pool Resources Multi-Agent System) platform, which is a programming environment dedicated to the creation of Multi-Agent systems, with a focus on resource management and is using the Smalltalk object-oriented language (Bousquet *et al.*, 1998).

The BanMakMai model integrates knowledge obtained from the farm survey and previous participatory workshops. The model consists of five main interacting components; Climate, Hydrology, Spatial setting, Household and Rice (Fig. 6). The spatial settings represent land uses; paddies, pond, and human settlement (house, village, city). A pixel (smallest unit) is equal to 0.16 ha. Each pixel has its elevation and soil type as attributes. Pixels are aggregated into a rice field. Fields are aggregated into farms with houses. Two small farms (3.3 ha), and two large farms (6.5 ha) with different size of farmpond are displayed (Fig.8). The spatial entity integrates a hydro-dynamic module that was developed to simulate the availability of water in paddy fields and ponds depending on daily rainfall patterns (Lacombe and Naivinit, 2005). The actual daily rainfall and potential evapotranspiration (PET) recorded by the meteorological centre in Ubon Ratchathani are used to provide climatic values to the BanMakMai model to feed the hydrological processes.

A "Household" is made of heterogeneous "Member" agents having different demographic characteristics (age, gender, and marital status). The "Household" is a central decision-maker responsible for assigning specific roles (farmer, seasonal migrant, more permanent migrant or dependent) to its "Member". Once rice is planted, it will grow from seedling stage to maturity. Three main decision-making processes are i) decisions during nursery establishment and transplanting, ii) decisions at harvest, and iii) decisions after rice harvesting, including migration.

*Organization of series of participatory workshop and selection of participants*

Five loops of the cyclic ComMod process were implemented for this research since 2004. The successive sequences of key activities are shown in figure 9. Each loop addresses specific objectives to serve the model's co-design purpose. To achieve this purpose, the joint use of RPG and ABM tool was adopted to work with local farmers (Table 2).

The players were carefully selected to cover all farm types based on the typology of farming systems in this agrarian system built in the initial farm survey. 11 farming households were invited to participate, including three large farming households belonging to type C (1), and type B (2) plus eight households belonging to type A took part as they are the most frequent type in this area. These same households participated through the five loops of the ComMod process. But some members from the same family were reshuffled when the former participants could not join again.

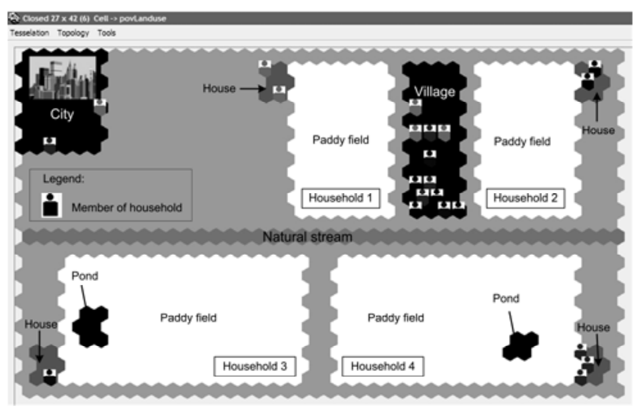



Fig. 8. Spatial interface of the BanMakMai model displaying land use for each of the four farms, the village and city.

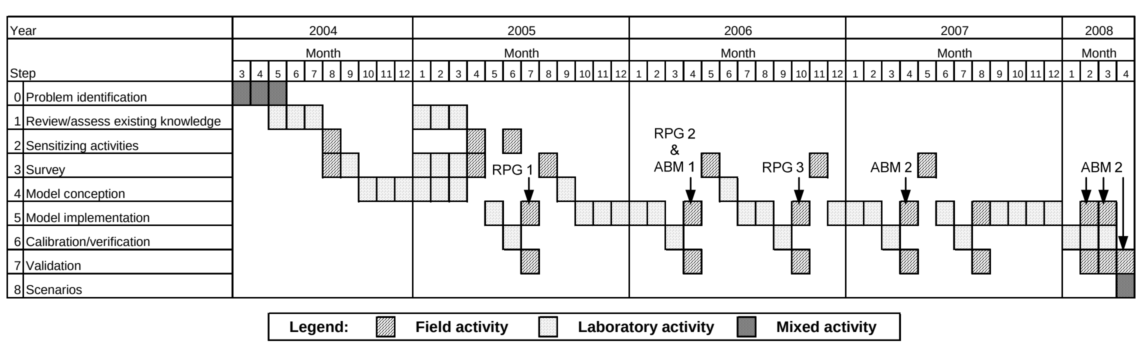



Fig. 9. Successive sequences of main activities in the Companion Modelling process implemented in the Lam Dome Yai watershed of Ubon Ratchathani Province; 2004-2008.

An activity to evaluate the learning effects of farmers participating in the ComMod process in the Lam Dome Yai was carried out after three successive participatory workshops held in Ban Mak Mai village (2006-2007). The evaluation consists of producing transcripts based on individual interviews with participants, and analysis of the contents of the interviews. The analysis was based on the coding of the transcripts.

**Results**

Table 3 and 4 display the different kinds of effects generated by the ComMod activities on the different types of participating farmers. We show only the results obtained from the sub-group of 7 out of 11 farmers who were the most at ease during the gaming and computer simulation activities: 4, 2 and 1 for type A, B, and C respectively.

Table 3 shows that in the case of type A resource-poor farmers, the kind of new agro-ecological knowledge gained from the collaborative modelling process deals with the effects of rainfall and water availability on the pattern of rice production. Even if technical topics are not explicitly examined in this process, the exchanges taking place among the participants seems to lead to the acquisition of new knowledge in this field as well, for example on direct seeding of rice and vegetable production after rice. We know that these are the small farms providing under-employed workforce to other larger holdings or migrants looking for wage-earning jobs, therefore it is not surprising to see that they found interest in getting a better understanding of the pattern of labour migration in the village during the ComMod process.

In term of changes in personal perceptions of the system represented in the models, most of the type A farmers would like now to get a better understanding between the various commodities they can grow, especially if more water is available (such as vegetable production after rice, or mixed farming systems around farm ponds), and the relevant markets. They also think that they are now better prepared to face drought events and have learned how to plan rice establishment and the use of agricultural water from their small ponds. They mention three interesting opportunities that emerged from this learning process. The first one is the possibility to diversify their agricultural production out of RLR into vegetable cash cropping after rice and mixed farming. Another one deals with the possibility to exploit underground water to increase the volume of the resource available for farming activities; again, this was not explicitly discussed with the research team during the field workshops but from more informal exchanges among the participants during and after these short events. This is because they also recognize here the usefulness of sharing ideas and knowledge among farmers to generate such opportunities. It seems from these results that this has already an effect on the way some of them interact with others. While others claim that the learning cum modelling process has already led to some changes in their farm practices (go back to RLR production, adoption of direct seeding and vegetable production).

Table 4 show the same kind of results but this time for the larger type B and C holdings which are the most affected by the lack of labour during the peak demand periods of RLR transplanting and harvest. The topics they cite regarding the new agro-ecological and technical knowledge gained from the collaborative modelling process are similar to the ones already mentioned by type A farmers. But due to their labour constraints, it is not surprising to see them mentioning the effects of a shortage of labourers on the economic results of RLR production. Regarding changes in personal perceptions of the system, like the type A farmers, they emphasize their wish to better understand the market opportunities for their farm products. The type B farmers also mention their better ability to plan their farm operations, and one of them appreciated the opportunity to merge their farmer empirical knowledge with the more academic agricultural one from the research team. Like for type A farmers, these three larger favourable farms seem to be ready to increase and diversify their agricultural production if water is made available. But for the time being, no effects related to change of behaviour or farm practices could be noticed in their case.

## Discussion

The various types of effects generated by the ComMod activities on this sample of participating farmers confirm the hypothesis that such an interactive collaborative modelling process can trigger both individual and collective learning through the intensive exchanges facilitated and stimulated by the evolutionary gaming and simulation models used along the process. Even at this stage, some farmers mention limited change in their decision-making, behaviour and farming practices that they relate to their participation in the ComMod activities. We must also say that this is valid for the research team too because its members learned a lot from these exchanges, especially on farmer decision-making processes related to the adaptation of RLR production practices to rainfall distribution, and the management of the labour force on the different types of farming households.

But it was observed that not all the representatives from the eleven farming households could be active participants feeling comfortable in the simulation workshops. While the gaming sessions where more inclusive, the participatory simulation ones were obviously more difficult to follow for some of the older, male or female, farmers. More attention should be given to this aspect when selecting the participants in this type of community.

This relatively long process could seem costly, both in term of time and funding, but it is because the team leaders in the field are Ph.D. and M.Sc. students who are still on the learning curve about how to design, implement, monitor and evaluate a ComMod process, and how to conceive and implement ABM models. For example, the long periods of time separating each of the successive field workshops were due to the unavailability of the team leader while he was tight by academic duties, or was spending time to master the modelling and simulation platform.

## Conclusion

The ComMod process enhances our understanding regarding the interaction between land & water use and labour migration at the study site through its evolving iterative, collaborative modelling. The farm diversity plays an important role in labour availability at village level. The interaction across farm types is clearly seen during wage negotiation. Type A farmers who mainly grow small-scale rice production areas with less farm diversification take part in the local labour system as hired labour, and they seasonally migrate for off-farm jobs. In contrast, the larger farms belonging to type B and C play a key role in employing hired labour due to their high land and labour ratio. Moreover, through the co-learning and knowledge sharing during series of participatory workshops, participants' adaptive management capacity was generated. Better understanding the relationship between water availability and rice production was gained leading to be better prepared to face droughts with the use of ponds. New ideas, for instance mixed farming and the use of underground water, were emerged. Some participants even changed their farming practices as a result of learning process through collaborative modelling.

## Further steps

The following steps will be made of a series of participatory simulation sessions to (i) validate the most recent version of the ABM models, (ii) identify scenarios dealing with water and labour use that the farmers are interested to explore together with the research team, and (iii) simulate these scenarios and assess their results with the different types of farmers.

Table 2. Successive tools used in Companion Modelling process implemented in Lam Dome Yai watershed, Ubon Ratchathani Province.

| Tool | RPG 1 | RPG 2 and ABM 1 | RPG 3 | ABM 2 | Collective illustrating algorithms of rule-based agent | ABM 2 | ABM 2 |
|---|---|---|---|---|---|---|---|
| Date | 9-10 July 2005 | 20-21 April 2006 | 10-11 October 2006 | 24 April 2006 | 5-6 August 2007 | 5-6 February and 19-20 March 2008 | 8-9 April 2008 |
| Objectives | To validate the research team understanding of the interaction between land/water use and labour management on the different types of farms. | To investigate the impact of exceptional prolonged drought and access to an irrigation canal on players' farm management and to present the playing game computer simulation for collective learning. | To acquire the knowledge of players' water perception across farm types and to provide the players an intermediate stage of learning simulated conditions and scenarios through RPG. | To validate the comprehensive process of interaction between water dynamics and labour migration by using the ABM simulation. | To design the model with farmers by using the drawings translated from decision-making algorithms of rule-based agents as a tool for collective validation. | To validate the Lam Dome Yai Agent-Based Model (LDY model) regarding rice-growing practices and labour management including migration with farmers. | To use the final Lam Dome Yai Agent-Based Model (LDY model) to explore desirable scenarios with farmers. |
| Knowledge production | • Enrichment of the initial conceptual model regarding farmer's decisions about farm management when different climatic conditions.<br>• The diversity of farming system plays a major role in supporting local labour market since different farm types have different cropping calendar and farm size. | • Small holders were more adaptive to take advantage of better access to water while this had little impact on medium and large farm holdings.<br>• The RPG helps the farmers to understand the rules and sequence of ABM simulation while the ABM helps to better understand self-situation and examined causes of actions of other players. | • For very small holders, water in individual farmponds was mainly conserved to be used only in case of a very dry year to reduce rice-yield loss caused by drought.<br>• A community pond scenario effectively provoked the increase of farm intensification of very small-farming households. | • The hydrological processes implemented in the model seem to be sufficiently validated to represent water level of paddies composed with sandy soil.<br>• Rice-nursery establishment is based on the relationship between toposequence and availability of water. Other rice-growing activities (transplanting, harvesting etc.) depend on the relationship between water and labour availability. | • Algorithms of agent's decision-making rules are similar to the actual farmers' practices.<br>• The algorithms of decisions to hire labour and migration is still not transparency to the farmers. | The LDY model was calibrated to match the actual rice-growing practices purposed by farmers during the workshop. But there was no major difference between decisions made by rule-based computer agent and farmers. | |
| Participants | Research team, 11 farming households, an agricultural extension officer, a NGO personnel, and local administrative officers. | Same as the RPG 1 excluding a NGO personnel. | Same as the RPG 1 excluding NGO personnel and an agricultural extension officer. | Same as the RPG 3. | Research team. Farmers were divided into 3 small groups based on farm types and they were invited to participate separately. | Same as the collective illustrating algorithms of rule-based agent. | Same as the RPG 1. |

Table 3. Learning effects of small and resource-poor farmers (type A) participating in the ComMod collaborative modelling process in the Lam Dome Yai watershed, Ubon Ratchathani Province in 2006-2007.

| *Farm type* | *A1* | *A2* | *A3* | *A4* |
|---|---|---|---|---|
| **1. Knowledge acquisition** | | | | |
| Agro-ecological | • Water availability in relation to location of paddy fields<br>• Change of water level in field/pond depending on rainfall | • Water availability in relation to location of paddy fields | • Impact of rainfall distribution on rice production | • Impact of drought on rice production |
| Technical | • Use of direct seeding in very dry year | • Different rice-growing practices between upper and lower paddies<br>• Use of pond to grow rice | • Vegetable production for sale in dry season | • Drought mitigation by having more ponds to store water<br>• Integrated farming practice |
| Economic | • Benefits of better access to water | • How to share land between RD6 (for family consumption) and KDML105 (for sale) rice varieties | | |
| Social | | • Labour migration situation in the village | • Togetherness among participants as a result of collective discussions | • Labour migration patterns in the village |
| **2. Change in perception/Own** | | | | |
| Want to improve | • Better estimate of farm income<br>• Understanding the relationship between farm products and markets | • Understanding the relationship between farm products and markets | • Understanding the relationship between farm products and markets | • Want to build a pond |
| Capacities | • Better prepared to face drought<br>• Timing of water pumping from ponds for higher benefit | • Plan for rice transplanting<br>• Better prepared to face drought | | • Negotiation is needed to avoid water sharing conflict |
| Opportunities | • Possibility to grow vegetables after rice<br>• Underground water more suitable than irrigation canal<br>• Sharing my ideas with other farmers | • More income could be made during the dry season<br>• Sharing knowledge is better than using only own one | • Underground water is suitable for my farm | • Integrated farming practice<br>• Pond and underground water is suitable for my farm |
| **3. Change in perception/Others** | • Better social networking in the village | | • Sharing knowledge and ideas helps to understand other participants' farm management skills | |
| **4. Change in decision-making** | • More family labour to work on-farm if more water is available | • Will produce more farm commodities if more water is available | • More family labour to work on-farm if more water available | • Build a new pond or improve the existing one to store more water<br>• More family labour to work on-farm if more water is available |
| **5. Change in behaviour** | • More sharing of farming ideas with other farmers | • Spend more time to work in paddies | | |
| **6. Change in action (s)** | | | • Returned to rice production instead of leasing the land to neighbours<br>• Started to grow vegetables in dry season | • Use direct seeding technique for rice production |

Table 4. Learning effects of medium sized (type B) and large (type C) farmers participating in the ComMod collaborative modelling process in the Lam Dome Yai watershed, Ubon Ratchathani Province in 2006-2007.

| *Farm types* | *B1* | *B2* | *C* |
|---|---|---|---|
| **1. Knowledge acquisition** | | | |
| Agro-ecological | • Relationship between rainfall and water level in field/pond<br>• Duration of rice growing cycle in relation to water availability | • The difference between sandy and clayey soils in relation to water availability in paddy fields | • Relationship between rainfall distribution and rice production |
| Technical | | • Rice transplanting practice in relation to field location<br>• Usefulness of having ponds and time to use water from them | • Rice production in relation to water dynamics in paddy field/pond depending on rainfall |
| Economic | • Low rice production because of lack of labour to look after rice | • Impact of labour shortage on farm production | • Less income from rice is expected if drought occurs |
| Social | • Labour migration patterns in the village | | |
| **2. Change in perception/Own** | | | |
| Want to improve | • Better estimate of farm income and investment<br>• Understanding the relationship between farm products and markets | • Want to understand rice trading system | • Understanding the relationship between farm products and markets |
| Capacities | • Timing of water pumping from ponds for higher benefit | • Make annual farm operation plan | |
| Opportunities | • Learn to merge academic agricultural knowledge with own experience | | |
| **3. Change in perception/Others** | | | |
| Capacities | | • Negotiation process regarding water sharing | |
| Opportunities | | | • Observe and analyze the actions of other farmers whose means of production are similar |
| **4. Change in decision-making** | • Will produce more farm commodities if more water is available | • More family labour to work on-farm if more water is available | • Will produce more farm commodities if more water is available |

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