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Simulation of the Sustainability of Farming Systems in Northern Thailand

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Organisation of Agricultural Production

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Section of Analysis, Planning and Organization of
Agricultural Production

Prof. Dr. Drs. h.c. Jürgen Zeddies

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1. Introduction

1.1 Problem statement

Since sustainable development has been broadly recognized as a normative paradigm of development which has to consider issues of environment and inter-generation equity, it has been widely discussed and considered an issue of research and policy making to reach this common global goal. As it is a catchphrase in international discussion, sustainable development has diverse definitions. However, the definition which is commonly quoted and widely accepted is that in the Brundtland Commission's report, "Our Common Future" which defined sustainable development as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (United Nations, 1987). The implication behind this definition is that development needs to occur sustainably. Development should not only concentrate on economic growth but also should consider degradation of the environment and resources, which could place the future generation in a disadvantageous situation (Bell and Morse, 2003). Therefore, the direction of policy development turns to concern for a broader range of integrated perspectives including economic, social, and environmental dimensions (Rao and Rogers, 2006).

Although this popular concept and definition challenges the world's development path, its definition is so broad that it provides little guidance for implementation. This leads to the following questions: how do we know if progress is being made towards sustainability objectives? and how can we tell, when systems are more (or less) likely to be sustainable? (Müller, 1997). Therefore, observations and measurements of sustainability are required which will provide information to support the development of suitable policy frameworks for sustainable development. This is especially important for marginal areas where the environment and natural resources are sensitive. Regional development and sustainability policies are necessary and thus processes of monitoring and evaluating pathways to reach sustainability goal are needed urgently (TDRI, 1994; Praneetvatakul et al., 2001).

In the Northern part of Thailand which is characterized by relatively large natural forest area with plenty of diverse natural resources and ecological systems, sustainability observation and investigation is also required. Topographically, the area is mountainous, located north of the plain of the central part of Thailand and consists administratively of 17 provinces covering approximately 16,964,428.8 hectares and accounts for 33.01% of Thailand's total area. In 2005, its population was 11,883,517 people which accounts for 11.8% of Thailand's population (Department of Provincial Administration, 2006). The area contributes water resources to Chao Pra Ya River through 4 main tributaries – Ping, Wang, Yom and Nan – to the central plain which is the most important industrial and rice production region of Thailand.

Even though most of this area is designated to various types of protected forest area e.g. national parks, wildlife sanctuary, no-hunting area etc., in fact the area is still occupied by approximately 1,167,055 people of Thai and ethnic minorities which are around 97% of total people living in the mountainous area of Thailand (Puginier, 2002; Hilltribe Research Centre, 2002). The Thai people are lowland-Thai who moved to this area. Ethnic minorities consist of Karen, Hmong, Lahu, Akha, Yao, H'tin, Lisu, Chinese koumin tang, Thai yai, Lua, Khamu, Thai Lur, Palong, Tongsu, Marabi, and others. Some ethnic groups have a long history of migration and settlement dating back to the 17th century while others have just moved there during the last 50 years because of conflicts occurring along the border in neighboring countries (Puginier, 2002). Conventionally, the people living in this area pursued their livelihood by subsistence farming systems in various forms of shifting cultivation which is sometimes based on heavy slash and burn technique (TDRI, 1995; Gypmantasiri and Amaruekachoke, 1995; Puginier, 2002). The diversification to other types of agricultural activities depends on the particular resource availability, culture, and socioeconomic conditions in the respective area.

Because of the continuous growth of population, the demand for food and land tends to increase. Existing agricultural land is intensively used and encroachment to protected forest area is likely to be occurring (TDRI, 1995; Puginier, 2002). Natural resource degradation and depletion are likely, affecting the sustainability of environmental and natural resource use in the area (Walker, 2003). In addition, development projects e.g. improvement of infrastructure and top-down policies implemented to this area e.g. introduction of cash crops as well as market force factors have lead to a change of farming systems into semi-commercial and commercial practices (TDRI, 1994; Santasombat, 1995; Rerkasem, 2003), which increases the pressures and conflicts of competition for the use of resources in the area (Rerkasem, 1995; Wangpakapattanawong, 2002; Walker, 2003).

The study area, Bor Krai village, is one of 3,881 villages (Hilltribe Research Centre, 2002) located in the mountainous area of Northern Thailand facing such a situation concerning natural resource utilization. The villagers pursue their livelihood mainly by subsistence farming systems. However, with the pressure of population growth, and market force factors, their agricultural land and other resources are being more intensively used. Also, farming systems have been changed into more commercial practices (Praneetvatakul and Sirijinda, 2003). Based on this background the sustainability of farming systems in the long run needs to be investigated in detail.

Therefore, this study concentrates on a sustainability assessment to address the question of how target farming system are sustainable in the long term and how farm households cope and recover themselves from stress. Quantification of sustainability assessment through appropriate indicators, covering the economic, social, and environmental dimension representing sustainability aspects of the system are proposed and applied. In addition, in order to capture the complexity of the systems and extrapolate the sustainability path in the long term a Multi-Agent Systems (MAS) simulation model has been chosen as it is a promising tool to tackle behaviour and characteristics of a system which reflect the sustainability situation and its dynamic over time.

1.2 Objectives of the study

1) To investigate the economy and state of farming systems in the study area, Bor Krai village, Pang Ma Pha district, Mae Hong Son province

2) To develop a MAS model in order to evaluate sustainability of farming systems

3) To present the sustainability of farming systems under different scenarios due to a change of significant factors and policy intervention and to investigate the systems' ability to cope with and recover from stress events and change of significant factors

1.3 Methodology

1.3.1 Scope of the Study

The scope of this study covers three dimensions – the scope of farming systems of the study area, the scope of time for monitoring the dynamic of sustainability, and the scope of application of the sustainability assessment method and indicator determination –.

Firstly, farming systems of the study area, Bor Krai village, have been defined as systems centered by farm households who make decision about their resource allocation and interaction with each other and their environment (Norman, 1986; Doppler, 1999; Doppler, 2000). All elements of biophysical and socioeconomic components which are related to and influence their decision processes and behaviour are considered.

The second scope, the time dimension for monitoring and assessing sustainability of farming systems through simulation by a MAS model covers 15 years corresponding to 2003 to 2018.

And the last scope, the application of sustainability assessment method and indicator determination is performed as an application and extension of the studies of Praneetvatakul and Sirijinda (2003 and 2005), as part of collaborative research under the Uplands Program (SFB 564) of the University of Hohenheim. These studies are based on sustainable land use evaluation of the Land Development Department (1998). In addition, indicators are determined as factors representing a system's sustainability relying on the indicator determination framework of this study and an International Framework of the Evaluation of Sustainable Land Management (FESLM) developed by Smyth and Dumanski (1993) of FAO as well as other related literatures.

1.3.2 Conceptual framework

The framework of this study has been developed to address the research objectives. It intends to evaluate the sustainability of farming systems in the study area, Bor Krai village, and examines the ability of such systems to cope and recover themselves after facing stress. To do so, a MAS simulation model is developed (Figure 1) based on the concept and scope of sustainability assessment and farming systems representing the study area's structure.

Initial conditions of the simulation are set according to the current conditions found in the research area. After the conceptual model has been structured, the social validation is executed. Then, the conceptual model is implemented to the CORMAS (Common-Pool Resource and Multi-Agent Systems) platform. After long term simulations, the initial sustainability results obtained are tested for their stability and a validation of the model is performed by statistical data comparison validation. Then, the validated model allows a baseline scenario under current conditions in the study area to be developed, to which prospective scenarios can be compared. Based on the results of the baseline scenario, the prospective scenarios have been identified. They consist of a sustainability improvement policy scenario relying on baseline results and stress and certain event scenarios based on changing economic and biophysical factors. Subsequently, these prospective scenarios are implemented in the model and then simulated. Each scenario simulation provides a new set of sustainability results which are analyzed and compared to the baseline and gives information on the sustainability situation of the study area.

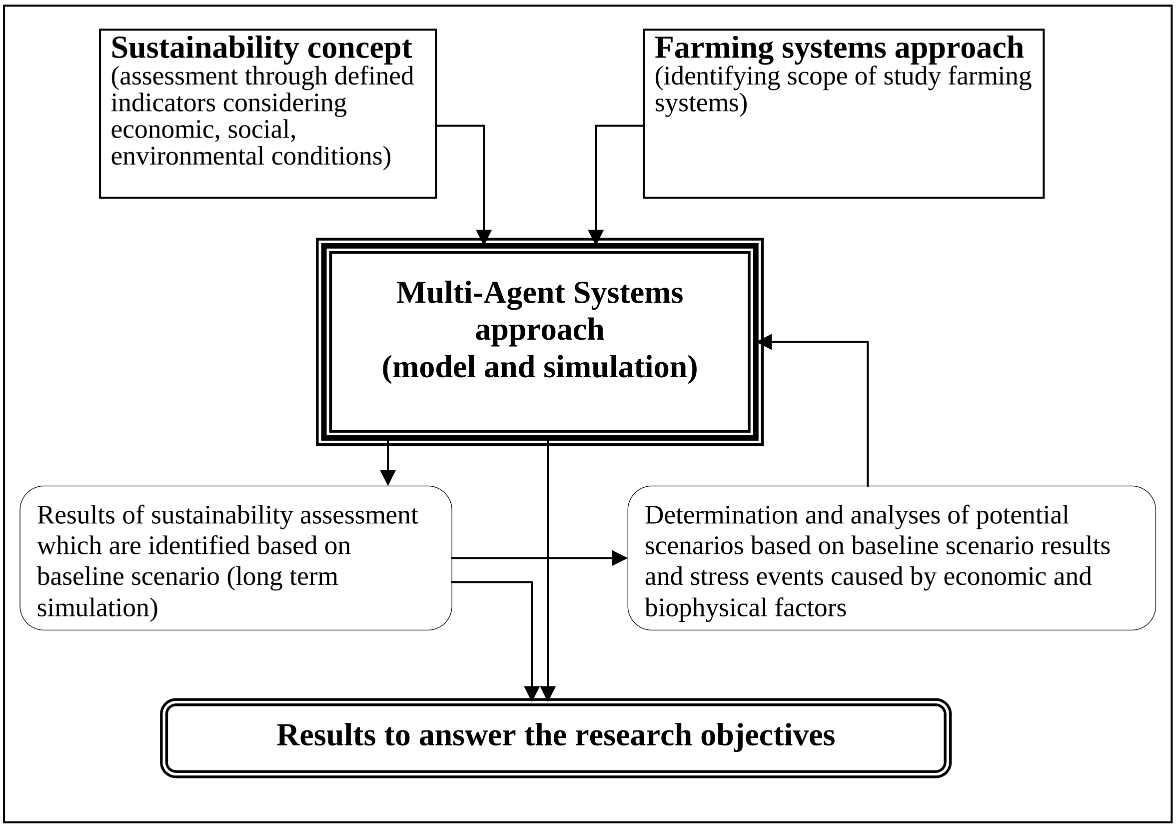


Figure 1: Conceptual framework

1.3.3 Data collection

Data description and sampling

The study area is selected based on a collaborative research project, the Uplands Program of the University of Hohenheim, which is carrying out interdisciplinary research to enhance sustainable development in the mountainous area of Northern Thailand. For this research, data consist of primary and secondary data which are explained as follows.

Primary data

Primary data is composed of two data sets about farm household information. For the first data set, the survey was delivered from Praneetvatakul and Sirijinda (2005), within the collaborative research of Uplands Program and Kasetsart University, which conducted the field survey in 2004. This survey randomly selected 32 out of a total 56 farm households in Bor Krai village. The information of all of these samples was collected by questionnaire interviews. Quantitative information was collected covering farm household aspects, crop and livestock production, on-farm and off-farm incomes and expenditures.

The second data set was obtained from field surveys conducted by the researcher in 2005 and 2006. The data consist of quantitative and qualitative data about behaviour and decision making aspects of farm households. Additional information was collected from other potential stakeholders such as agricultural extension officers, forest officers, traders, local organizations, etc. Moreover, additional data required to fulfill the first data set were collected such as the village's land use, the amount of water resource release from natural springs, and Geographic Information System (GIS) information of the area's important geographic points. In the field survey in 2005, stratified random sampling (Scheaffer et al., 1996) was employed for sampling of the farm households from the list of the first data set. The sample was stratified by total land holding area into three groups – a large (more than 4.8 ha), a medium (2.72 - 4.8 ha), and a small (less than 4.8 ha) land holding group –consisting of 11, 12, and 9 households respectively. Then, the households in each stratum were randomly selected. By this process, 1, 3, and 4 household samples were selected from each stratum respectively. These selected samples were informally interviewed by open-ended questions following the questionnaire while their representation, behaviour, and decision aspects regarding to farm production and other household activities were observed.

The other field survey conducted in 2006 provided information for the model validation and the test of hypothesis on crucial farm households' behaviour and decision making process through farm household group sessions. Diagrams on significant behaviour and decision making processes were presented and used as a tool for information elicitation and confirmation of these diagrams, which were hypothetically pre-determined from all available information and data of the surveys.

Secondary data

The secondary data were collected from many data sources including governmental institutions, local institutions, and universities. The data is complementary data to the primary data and additional data required for the research. The secondary data includes information on socioeconomic and biophysical characteristics such as statistical data on product and input prices, statistical data on climate and precipitation etc. of the region and the research area.

1.3.4 Data analysis

To obtain the results of the first objective of the study a descriptive analysis is employed to explain result and information e.g. general characteristic of the study area and samples. Descriptive statistic data, tables, figures, and graphs are also used with explanation to depict and contribute to the clarification of the area characteristics. In addition, summarized data from literature related to the area e.g. Praneetvatakul and Sirijinda (2005) are applied to fulfill the description.

For the second objective, a MAS model integrating all elements required for simulation and sustainability assessment is developed. A description and details of the MAS model will be presented in Chapter 3. The MAS model is set and simulated under the conditions which were found in the survey. Consequently, simulation results are analyzed and tested for model validation and stability. Then, these results are set as baseline scenario results which are used afterwards to compare to the scenario analysis.

Scenarios for sustainability improvement and possible important events are established and integrated into the model for each scenario simulation to achieve the study's third objective. The scenarios are set based on two themes. The first one is policy invention for sustainability improvement, the second ones are notions separately regarding to stress and important events of the area's farming systems sustainability which are affected by economic and biophysical factor.

Analyses which are carried out can be categorized into two types. Each has particular analysis detail and method applied to suit its particular purpose. The detail of analysis methods are explained as follows.

1) Descriptive Analysis is employed to describe and explain information, results etc. Sometimes, tables, figures, graphs are used with explanation for further clarification.

2) Quantitative and Qualitative Analysis.

Assessment of sustainability through economic, social, and environmental indicators

The approach and method for assessing sustainability is based on Praneetvatakul and Sirijinda (2003 and 2005), a collaborative research under the Uplands Program of the University of Hohenheim, applying the framework of evaluation for sustainable land use management developed by the Land Development Department (1998). In addition, the indicators are defined based on the indicator determination framework of this study.

In the process of simulation, information of farm households corresponding to each indicator is recorded and scored. The Sustainability index (SI) of each indicator is calculated to illustrate the sustainability situation of a particular indicator. Then, the Performance index (PI) is determined to characterize the area's sustainability considering all indicators together and additionally considering groups of indicators which can be divided into economic, social, and environmental indicators. After long run simulations, dynamics of PIs and SIs as well as other significant aspects are used to illustrate the area's sustainability.

The calculation of the PI and SI can be expressed as follows:

$$SI^i = \frac{SSC^i}{MPSC^i} \times 100$$

$$PI^n = \frac{\sum_{i=1}^{n} PFV^i}{MPPV^n} \times 100$$

Where;

SI^i	=	Sustainability index of indicator i
SSC^i	=	$\sum_{j=1}^{m}(SC_j^i \times NH_j^i)$
SSC^i	=	Sustainability score of indicator i; (i = 1, 2, 3,…,n)
SC_j^i	=	Sustainable coefficient of indicator i and Sustainable class j (j = 1, 2, 3,…,m)
NH_j^i	=	No. of households classified in Sustainable class j of indicator i
$MPSC^i$	=	Maximum possible value of SSC^i
PI^n	=	Performance index when considering all indicators (n) and indicators in each condition
PFV^i	=	$MSBS^i \times SSC^i$
PFV^i	=	Performance value of indicator i
$MSBS^i$	=	Maximum sustainable score of indicator i
$MPPV^n$	=	Maximum possible value of sum of Performance value of all indicators ($\sum_{i=1}^{n} PFV^i$)

Farm household classification

A cluster analysis is applied to classify cases or samples of farm households by considering significant characteristics. The analysis is a statistical technique applied for grouping farm households based on similarity of responses to several variables (Field, 2000).

The analysis is carried out in order to classify farm households into groups with similarity in significant characteristics. The variables which are significant characteristics of farm households and used for cluster analysis consist of nine variables including age and education of household leader, number of household members, number of household labour, total holding area of household, net household income, net cash farm income, off-farm income, and amount of loan.

For this research, the hierarchical cluster analysis approach, which can be used to classify cases without a pre-defined number of clusters, is chosen. Between all cases, similarity is measured and then the cases are considered and combined in the same cluster by a specific method, the so-called Ward’s test method. Before combining the cases, similarity between cases with possible combinations are measured by Euclidean Distance (Everitt, 1986) which can be expressed as;

$$d_{ij} = \sqrt{\sum_{k=1}^{n} \left(x_{ik} - x_{jk}\right)^2}$$

When;

x_i, x_j = value responses to variable k of case i and j respectively (k = 1, 2, 3, ..., n)

After measuring, the cases are considered to be grouped or clustered together. For the cluster analysis, there are several methods using to combine the cases and clusters together. For this research, the Ward’s test method has been chosen where the cases or clusters will be combined in the same cluster if this combination produces the lowest variance of the cluster. Particularly, at the beginning all cases are considered as their own cluster and then combined if this combination contributes to a minimum increase in the error sum of squares. This means that at each stage in each group or cluster the average of similarity (distance) is measured. Then, the difference between cases and the average similarity within clusters is calculated and squared. The sum of square deviation is considered as a measure for the error of a cluster. The case is considered to enter to cluster if after grouping such case produces the smallest increase of error (Field, 2000). As the considered factors have different units, the Z scores by variable is engaged to standardize data to preserve relative distances (Everitt, 1986; Field, 2000).

1.4 Structure of the thesis

The thesis consists of six chapters. The first chapter is general introduction including problem statement, objectives, and general methodology of this study. Chapter 2 is an explanation of the concept and approaches which are applied to this study. (see also the conceptual framework in section 1.3.2). Here, the farming systems approach, sustainability concept, and agent-based modelling approach are described. The farming systems approach is explained for its contribution to clarify and determine the scope of the study target system and its relationship with other systems. The concept and definition of what we call sustainability and the importance of the evaluation of sustainability are explained. And in the last part of the chapter, the section is dedicated to introduce the Multi-Agent Systems approach (MAS) as a simulation tool of this study. In Chapter 3, details about the study framework application are explained. In this chapter, the study area where the study framework is applied is introduced. Further, details of sustainability assessment through defined indicators are clarified. The MAS model as it is applied to the case study is presented. Details of model description, model farm household agent classification and generation, model implementation, model validation and model stabilization testing are explained. Chapter 4 provides the results of the study analysis. Here, the sustainability situation of the study area farming systems under current conditions is analyzed and explained. The results of this chapter are defined as the baseline scenario which will be compared and further analyzed in scenario analysis. Chapter 5 is dedicated to scenario analysis. The determination of the scenarios is presented in detail, including the potential change of significant factors compared to the baseline situation. Then, the sustainability situation of the defined scenarios is analyzed and explained in detail. In Chapter 6, the conclusions and limitations of this study are discussed. Policy recommendations for future sustainability improvement as well as recommendations for further research and for newcomers who is applying the MAS approach to the research are also presented in this chapter.

2. The concept and approaches of the study

2.1 Introduction

Relying on the study’s conceptual framework, the research is based on principal concept and approaches which are a farming system approach, sustainability concept, and Multi-Agent Systems (MAS) approach. The farming systems approach is applied to determine the study system’s structure and extent. The sustainability concept is applied to define what the research needs to investigate and what factors and evaluation method can be integrated to represent the sustainability situation over time of the study area. The MAS approach provides fundamental of modelling to integrate farming systems and sustainability assessment in the model. In addition, this approach allows capturing interactions and heterogeneous at local level of the system and presenting the consequences as emergence of system at a global level. The details of each of these with the related literatures are described as follows.

2.2 Farming system approach

The farming systems approach is used to understand the characteristics of the study farming systems. The farming systems are similar to the other systems which compose of dependent elements. In addition, farming systems are complex because their internal structures are composed of various processes, interconnections, and interactions between various subsystems (Bossel, 1999). The system organization can be characterized as hierarchy and subsidiarity.

Hierarchical means that a system is composed of subsystems. Each subsystem performs certain tasks contributing to the whole. For example, each crop system contributes to the performance of the farm as a whole. The relation can be seen as hierarchical, with connections and correlations between subsystems directly or indirectly depending on one another (Norman, 1986; Conway, 1987; Bossel, 1999). Interactions can range from simple, for example between two elements, to very complex, for example if each element interacts with many others. Subsidiarity aspect means that the subsystem can be modified and influenced by the suprasystem. For instance, the production system can be adjusted by the farmer according to the needs of the family and the resource availability. Also, the farming systems can be modified and influenced by the institutions at a supralevel e.g. establishment of common resource use regulation, service support extension, etc.

Relationships between components can either be vertical or horizontal. Figure 2 shows that a horizontal relationship can include several elements from different systems. The farm household is a micro decision unit and is located at the same level as the non-farm household in the village livelihood system or rural system. Interrelation between these elements at the same level can occur. For example, the farm household takes the non-farm factors into account when allocating resources. Alternatives for allocating the resources to outside or inside the farming systems are compared. The household can allocate the resources to outside the farm (e.g. to the non-farm family in village livelihood system) or can acquire resources from outside the farm.

In the vertical dimension, Figure 3 shows that the farming system is related to the family, village, watershed, and regional systems, respectively. Meanwhile, the farming systems connect downwards to production systems which are composed of crop and animal agro ecosystems (Hart, 1986; Doppler, 1999; Doppler, 2000).

The farming systems approach deals with holistic and behavioural aspects as it focuses on the objective and decisions of humans in society, from static and dynamic points of view. From the behavioural side, farming systems arise from the decision-making of a farmer with respect to allocating quantities and qualities of resources which will maximize the achievement of the household's goals (Norman, 1986). The farm household as an operator made a decision following its objectives, to allocate the resources that are influenced by and affected to many sectors. At the same time, the household may acquire other resources or products or services from outside the system (Doppler, 2000). Farming systems approach also considers sustainability and dynamics of the system in the long term.

For this study, the principle concepts of the farming systems approach are applied as follows (Praneetvatakul, 1996).

1) The complexity of real world: Since the complexity in farming systems is real, this aspect is thus included in the model for this study. Also, the study model is determined with consideration based on the system theory (Conway, 1987; Becker, 1997). Components in the systems and its hierarchy are considered to identify interactions, trade-offs between

components, and the factors which influence the study system's sustainability. In addition, long term dynamics of the farming systems are considered and applied in the study application to monitor and extrapolate the sustainability situation of the study area.

2) Dynamics and sustainability: In order to extrapolate and evaluate the sustainability situation of farming systems in the study area, the processes and factors influencing the dynamics of the target system are considered and included in the study model.

3) Objectives and decisions of farm household: The behaviour of farm households subject to their objectives is included in the study model as they are central to the farming systems of the study area. Empirical effects experienced by the households in the past are considered and used to verify and validate the study results.

4) Participation of the farm households: The farm households are invited to participate in various stages of this study in order to improve the model results and reduce the gap between researcher and the farm households in the study area.

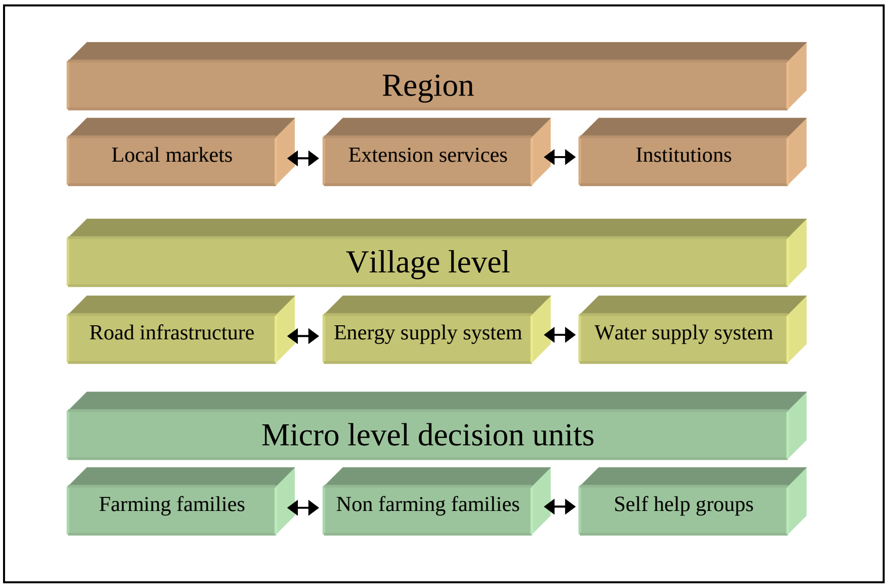


Figure 2: Horizontal linkages and hierarchy in the farming system

Source: modified from Doppler, 1999

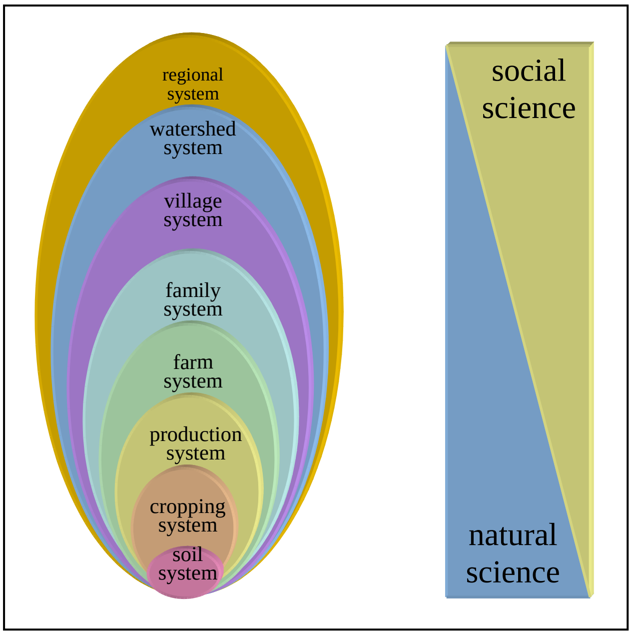


Figure 3: Vertical linkages and hierarchy in the farming system
Source: Doppler, 1999

2.3 Sustainability concept

This section describes the general concept, definition and assessment of sustainability. In addition, empirical studies and how the sustainability concept is applied in this study are presented.

The concept of “sustainability” was first originated in Germany in forestry field during the 1800s by the miner von Carlowitz (Becker, 1997). The term was equivalent and recognized as “Nachhaltigkeit”. This concept was introduced to convey the idea of maintaining the long-term productivity of a timber plantation to supply construction poles for the mining industry. This concept has been extended to areas including soil conservation, poverty, and satisfaction of needs (Müller, 1997).

Before this term existed, the concept of sustainability in agriculture was viewed as a set of farming practices to maintain agricultural productivity. To do this, many technologies were introduced such as rotation, green manure, and mixed cropping. The sustainability concept become latter known as alternative agriculture, appropriate agriculture, and finally sustainable agriculture (Müller, 1997).

Around 200 years later, the sustainability concept has been broadly interested among scientists, politicians, and policy makers after the concept was recognized as the common world objective of development in 1987 (United Nations, 1987). The United Nations general assembly was held in order to express and extend global awareness against the world problems regarding to resource depletion and degradation. Since then, the sustainability concept has been applied to economic development. The efforts were dedicated to find out the sustainable aspects of economic development under the pressures of environment and global population (Becker, 1997). This new development paradigm has highlighted that the development should not only be concerned with economic growth but also the environment and inter-generation equity should be taken into account. Accordingly, the terms – sustainability and economic development– are linked and known as "sustainable development".

The term sustainable development has various definitions depending on objectives and application domains. For example, a popular definition by the Brundtland Commission's report defined it as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (United Nations, 1987). The CGIAR's mission statement in 1989 defined the term as the "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (Becker, 1997). In ecology and agriculture, the term is defined in the sense of productivity: "sustainability is the ability of a system to maintain productivity when subject to a major disturbing force" (Conway, 1987).

The definitions above show that sustainable development is a multi-faceted concept. Therefore, quantifying sustainability is difficult. Economic development is required but not sufficient for overall of society development under limitation of natural resources. The issue of distribution of development benefits and environmental effects should be considered. Müller (1997) argued that none of the definitions are operational in the sense of allowing the determination of a given sustainability situation. In practice, policy intervention initially requires understanding of the current situation toward the conceptual sustainability condition. Furthermore, monitoring policies towards a sustainability pathway is necessary. Therefore, investigation and evaluation of sustainability of underlying systems in particular in spatial and temporal dimensions is required.

To assess sustainability, ex-post and ex-ante analyses can be applied under limitations and given assumptions. The ex-post sustainability analysis can be performed by investigation the past experience. Although some of the discussions about long term predictability are rather limited, this approach can be used as the basis for the ex-ante approach. For the ex-ante analysis, there are several challenges related to system properties such as complexity, interrelatedness, non-transparency, and dynamics due to feedback mechanisms, cumulative effects, time lags, or evolution (Becker, 1997). However, the ex-ante analysis is possible to a limited extent. This requires an appropriate time frame and spatial scale as well as knowledge of the system components with their dynamics throughout the considered time span. Accordingly, sustainability assessment by ex-ante analysis challenges the researcher to understand the current situation of the system and its dynamic behaviour towards sustainability.

2.3.1 Sustainability assessment approach

The assessment approaches are based on three aspects: intragenerational equity, the value of nature of the environment, and intergenerational equity (Becker, 1997). The aspect of intragenerational and intergenerational equity considers the issue of distribution and elimination of poverty as well as the rights of future generation to maintain the options of consumption (Müller, 1997). For the aspect of the value of nature, the environment has importance in two components. First, the environment is considered as a pool of resources that can be exploited by humans to maximize their economic prosperity. Second, the environment is considered a value of nature in its own advantages which is threatened by human destruction and consumption. Accordingly, sustainability assessment is needed to determine the impacts due to a change of environmental conditions.

The sustainability assessment based on scientific operationalization allows us to quantify sustainability and provide a guide for the policy intervention. Evaluation of the development project can proceed based on the sustainability concept which takes economic, social, and environmental conditions into account. According to this, the sustainability evaluation can be categorized into three approaches which are the Extended Cost-Benefit Analysis (ECBA), the Multi-Criteria Decision Mechanisms (MCDM), and the sustainability indicators (Müller, 1997). These are explained as follows.

1) The Extended Cost-Benefit Analysis (ECBA)

This approach is based on the concept of project investment evaluation. The project or policy intervention will be evaluated with regards to its performance. Useful information for investment decision in the project is derived by comparing the performance with and without the project or policy. The evaluation criteria are the Net Present Value (NPV), the Benefit Cost Ratio (B/C), and the Internal Rate of Return (IRR).

The NPV is the difference between the present value of the social benefits (PVB) and the social cost (PVC) of the project. The B/C is calculated by comparing the social benefits with social costs. The IRR value is obtained by solving to determine the discount rate which makes NPV equal to zero. Among alternative projects, the project with the highest positive NPV, the highest B/C ratio, and a IRR above the selected discount rate is the most desirable and most efficient project.

The CBA approach is extended to sustainability issue as the Extended Cost-Benefit Analysis approach (ECBA) by considering the environmental impacts of the project. The environmental impacts are evaluated in economic terms based on the economic value of environment assets. The total economic value of resources composes of the use value and non-use value. The use value consists of the direct use value, indirect use value, and the option value. The direct use value is the benefit of the resources that contribute to production and consumption. Indirect use value is the benefits of functional services of the environment to support production and consumption. Option value is determined by willingness to pay (WTP) for an unused resource for the potential use in the future.

The non use value composes of existence value and bequest value. The existence value is determined from the satisfaction of recognizing existence of the resource even if the valuer has no intention to use it. The bequest value is derived from the satisfaction of the valuer to keep the environmental resource for the next generation.

2) The Multi-Criteria Decision Mechanisms (MCDM)

This approach is based on applying Multi Criteria Decision Making techniques (MCDM) to environmental management problems (Müller, 1997). Decision making is pursued to obtain efficiency following Pareto optimality with respect to several different objectives (Romero and Rehman, 1989). This approach allows the inclusion of social and environment criteria to analyze the sustainability. In addition, some of the MCDM techniques can be applied with either quantitative data or qualitative data or a combination of both. Examples of these techniques include goal programming (GP), multi-objective programming (MOP), multi-attribute utility function approach (MUF), compromise programming (CP), and the analytical hierarchy technique (AHT). Each technique is briefly described as follows.

Goal programming (GP) is applied to handle decision problems that aim to optimize among various simultaneous goals (Romero and Rehman, 1989). The optimal goals can be obtained by minimizing the deviations of the actual equality from the target desired levels. The minimization process can be accomplished either by using preemptive weights as in lexicographic goal programming (LPG) or by introducing non-preemptive or relative weights to goals as in weighted goal programming (WPG).

Multi-objective programming (MOP) is used for decision making with multiple objectives (Romero and Rehman, 1989). The technique includes two principle stages. The first stage is the determination of the efficient set which consists of the Pareto optimal feasible solutions. And, the second stage searches for an optimum between those efficient solutions with incorporation of the decision maker preferences.

Multi-attribute Utility Function approach (MUF) is useful when the problem is characterized by several attributes (Romero and Rehman, 1989). The purpose is to generate a utility function with a number of arguments that are equivalent to the number of considered attributes. However, the techniques have some restrictions when applied to agriculture. First, agricultural problems are limited by the specific features with a discrete number of feasible solutions (Romero and Rehman, 1989). Second, the technique has a strong assumption about the preference of decision maker to implement this technique to the problems.

Compromise programming (CP) aims to identify an ideal solution which is the reference point of the decision maker (Romero and Rehman, 1989). This technique assumes that the decision maker tries to find a solution as close as possible to the ideal solution. The ideal solution coordinates the optimum value of various objectives. To achieve this, the distance function as a proxy measure for human preference is applied to the analysis. The optimum is carried out as the efficient solution that is closest to the ideal solution (Müller, 1997).

Analytical hierarchy technique (AHT) formulates the decision problem as a hierarchy. The techniques applies a specific measurement scale to obtain vectors of normalized weights or priorities by using a pairwise comparison (Müller, 1997).

3) Sustainability indicators

The sustainability indicator approach has gained acceptance as an approach internationally. The indicators are considered as a tool which is used for aggregating or simplifying the diverse information into a meaningful and more advantageous form. Indicators are seen as an analytical tool for sustainability assessment for many reasons (Segnestam, 2002). First, the indicators provide information on its situation and the change towards sustainability condition. Second, they contribute information to the policy making. Third, for an interpretation, one indicator is simpler than complex statistics. And the last reason, indicators facilitate communication among experts or non-experts.

Additionally, the indicators are flexible instruments as they can be defined in different degrees of precision and aggregated according to the objectives of the analysis and the available data (Müller, 1997). Regarding system theory, the indicators can be defined at different hierarchical levels and at the specific condition of the system (Bossel, 1999).

However, using the indicators as evaluation instruments is difficult since there is no existing universal indicator and justifications for the choice of indicators are not provided. Therefore, a methodological framework for indicator determination is needed to avoid arbitrary or subjective indicators. The criteria for the indicator selection and the respective assumptions should be transparent and all the aspects regarding the system's sustainability should be included (Müller, 1997).

The application of the indicators to sustainability assessment can be classified into two approaches (Becker, 1997). The first approach is to measure the individual factors and to aggregate them into the form of meaningful parameters. The second approach is to use many indicators to express a system's situation. Without combining them, the indicators provide information of complex processes, trends, or states in a meaningful form. Development of indicators is consistent with sustainability definitions representing the economic, social, and environmental condition. The details are described as follows.

Economic indicators

The economic indicators are based on two basic approaches which are the valuation of discount rates of resource depletion and the Total Factor Productivity (TFP) (Becker, 1997). The first approach is based on neoclassical economics where discount rates are derived from the concept of intergenerational equity or from its predecessor concept of limited unrenewable resources. The concept is applied as a rate of potential use to maintain the natural capital stock of resources within a certain period before its depletion. Another possibility is to apply this as a pollution rate of the environment under a given absorption capacity of environment. During the last few decades, the issue of determination of discount rate has been debated among economists. Arguments are focused on the notion of substitution between manmade and natural capital in which the discount rate is identified. These different concepts are known as strong and weak sustainability (Neumayer, 2003). This reflects the difference about the value of nature, with the weight differently assigned to the future demands and to the intergenerational transfer of wealth (Becker, 1997).

The second approach is focused more at a farm level and is called the Total Factor Productivity approach (TFP). Sustainability is represented by the ratio of total value of all outputs to the total value of all inputs under a given production system. An extension of this approach is known as the Total Social Factor Productivity (TSFP) which includes external costs of the production activity. The TFP and TSFP approach views sustainability as the capacity of a system to maintain output at a level equal to or greater than the historical average. Also, technology induces sustainability if it increases the slope of the trend line.

Under the TFP approach, the economic indicators are also developed in which the natural resources are considered as material assets or inputs of the global ecosystem. To identify economic sustainability, it was debated how to value these inputs or natural resources. Accordingly, different approaches are proposed which are modified Gross National Product (MGNP), cost estimates for conservation and rehabilitation measures, and contingent valuation methods. The MGNP is adjusted from the conventional Gross National Product (GNP) to represent the overall net income of national economy when environmental damages or social rehabilitation are taken into account. For the cost for conservation and rehabilitation, valuation of non-monetarized resources is performed by calculating real or fictitious costs of production, conservation, and rehabilitation. For contingent valuation method approach, valuation by assessing the subject value of resources to the population is applied by surveys of Willingness-to-Pay. Also, indirect evaluation of resources can be assessed using the Hedonic Price Method or Travel Cost Approach (Becker, 1997).

Environment indicators

The indicators representing environment sustainability condition can be developed by several approaches. These consist of using either yield trend, coefficients for limited resources, bio-indicator, target-oriented approach, or material and energy flows and balances.

The yield trend is the most explicit indicator for assessing sustainability of agro-ecosystems. However, using this indicator is questioned because it is unclear whether yield reflects any environmental stress. The sudden collapse of an agricultural system can occur without any signal from crop yields. In addition, the yield trend is highly specific to the site and crop variety. Therefore, quantification of this requires a huge amount of data to apply to a particular system.

The coefficients for limited resources approach implements discount rates of resource depletion and pollution similar to the economic indicator development. However, for this case the indications are expressed in the physical units e.g. tons/ha/year instead of using monetary values in economic dimension.

The bio-indicators are based on the ecological domain and development of these can be seen in three generations. For the first generation, the indicators consist of many types of species that react sensitively to changes of in their environment. The two examples are canaries used in mines to detect increasing of carbon monoxide in the pre-industrial era and lichens were used to indicate increased levels of SO_2 or heavy metals. For the second generation, the indicators were more focused on system dynamics by considering structure and function of entire ecosystems. The parameters for stress/response assessment were developed and chemical compounds and metabolic products were measured and quantified. Additionally, the approach included assessment of values such as purity of nature, amenities, or ecosystem integrity. For the third generation, the ecological indicators are developed by including socioeconomic and cultural condition relying on the concept of sustainable development. Therefore, the environment indicators can be seen as ecological indicators of pollution (first generation), of ecological structure and function (second generation), and of socioeconomic aspects (third generation).

The target-oriented approaches were developed for national policy makers aiming to assess environmental sustainability. However, these approaches are rather static and do not reflect the dynamics of the underlying systems.

Material and energy flows were applied by considering ecosystem properties. These are likely pragmatic approaches related to industrial production and trade similar to Production Chain Analysis using as monitoring instrument for material flows.

Social indicators

Social indicators are developed based on the approaches which intend to quantify and operationalize the intragenerational equity aspects (Becker, 1997). Measurement of equity can be represented by the degree of wealth distribution within a society. Quantification of this aspect can be performed through parameters which are the Herfindahl Measure for absolute equity dimension and the Gini coefficient for relative equity dimension.

In addition, the social indicators can be developed regarding social acceptability which influences to system sustainability (Smyth and Dumanski, 1993; Maglinao, 2000). For this, stakeholders and their interest should be identified. Social acceptability can be seen as aggregated views that reflect the attitudes, knowledge, beliefs, and norms of various individuals and groups. The indicators can be developed from social condition issues, for example, meeting physical and strategic needs, ratio of resource availability to population overall needs, conflicts over resource use, access to resource and to outputs, and etc.

Combination of indicators

In order to evaluate sustainability of particular system, using a single indicator to represent sustainability situation is not adequate. Therefore, the application of using combined or integrated indicators are considered. There are three basic approaches which are the lists of heterogeneous indicators, the scoring systems, and the system-based approaches.

The lists of heterogeneous indicators approach is the simplest approach. The approach is performed by applying scientific information to policy development. This provides sustainability information through respective indicators with the same weights for all issues. Also, this is performed without aggregating those indicators to represent sustainability situation in a single dimension. The advantage of this approach is the transparency because the list is based on available data and normative principles (Becker, 1997).

The scoring systems approach presents sustainability through a single measure. The different sustainability characteristic components are combined and probably weighted depending on objectives or preferences of the researchers to figure out sustainability situation. Examples of this approach are Sustainable Livelihood Security Index (SLSI) and the Agro-ecosystems Analysis Framework. These measurements were achieved by integrating and weighting selected components together. However, disadvantages of this approach are assuming objectivity and uniformity while determination of sustainability components and their weights is actually highly subjective (Becker, 1997). In some cases, aggregation of different spatial, temporal, and sectoral dimensions is probably not meaningful.

The system-based approach applies systems theory to select a number of system properties as sustainability indicators. Also, the approach determines the rules to integrate the indicators into the meaningful form of system sustainability.

Selection of indicators

Selection of indicators depends on the system that is being monitored. For example, in subsistence farming system the food security indicator would be important. Also, sustainability investigation of slope land agriculture, the indicators regarding erosion, runoff, and land management would be interesting indicators. Among several sustainability indicators, the criteria used to select indicator are summarized and discussed in Becker (1997). The researchers can use these criteria to guide selection of indicators which these are presented in Table 1. Using the entire range of them is preferable but with limitations and objectives of application it is not necessary that all criteria are met (Becker, 1997). Selection must be closely linked to research objectives and the research questions being addressed.

Table 1: Criteria for the selection of sustainability indicators

Scientific quality	Ecosystem relevance	Data management	Sustainability paradigm
▪ Indicator really measures what it is supposed to detect ▪ Indicator measures significant aspects ▪ Problem specific ▪ Distinguishes between causes and effects ▪ Can be reproduced and repeated over time ▪ Uncorrelated, independent ▪ Unambiguous	▪ Changes as the system moves away from equilibrium ▪ Distinguishes agroecosystems moving toward sustainability ▪ Identifies key factors leading to unsustainability ▪ Warning of irreversible degradation processes ▪ Proactive forecasting future trends ▪ Covers full cycle of the system through time ▪ Corresponds to aggregation level ▪ Highlights links to other system levels ▪ Permits tradeoff detection and assessment between system components and levels ▪ Can be related to other indicators	▪ Easy to measure ▪ Easy to document ▪ Easy to interpret ▪ Cost effective ▪ Data available ▪ Comparable across borders and over time ▪ Quantifiable ▪ Representative ▪ Transparent ▪ Geographically relevant ▪ Relevant to users ▪ User friendly ▪ Widely accepted	▪ What is to be sustained? ▪ Resource efficiency ▪ Carrying capacity ▪ Health protection ▪ Target values ▪ Time horizon ▪ Social welfare ▪ Equity ▪ Participatory definition ▪ Adequate rating of single aspects

Source: Becker, 1997

2.3.2 Selected empirical studies of sustainability assessment

Since the 1987 announcement of the United Nations assembly report, World Commission on Environment and Development, the sustainability concept are been widely applied in development research. The concept has been incorporated in various disciplines such as agriculture, economics, ecological, environment, and etc.

In agriculture, sustainability has been the ultimate aim for research, improving technology, and development. Sustainability is also evaluated to provide a path way for agricultural development in the future. Based on systems theory, the sustainability concept can be applied at several levels of agricultural system hierarchy. Accordingly, the evaluation of sustainability in an agricultural system can be investigated at any level of the entire system.

At the land subsystem level, as land is the most important resource for agriculture, using the land to meet the higher consumption demand should be made sustainable. Attention to using land resources in a sustainable way leads to development of land sustainability assessment known as an International Framework for the Evaluating of Sustainable Land Management (FESLM) which was proposed by Smyth and Dumanski (1993). The framework is based on the concept of sustainability concerning the limits of resource availability, environmental impact, economic viability, biodiversity, and social justice. With this, the sustainable land management issue is raised because of three important factors. The first factor is the fixed supply of land suitable for agriculture and food production. The second factor is the impact of competitive use on the fixed supply land by the growth of population. The last factor is depletion of biological production accelerated by human activities which lead to global soil and land degradation.

The framework is concerned in evaluating whether the form of land management is sustainable or will lead to sustainability. The framework path way seeks to connect all aspects of the land use with the multitude of interacting conditions –environment, economic, and social. Assessment is based on five pillars –Productivity, Security, Protection, Viability, and Acceptability– under the scope of sustainable land management definition. The definition is defined as "Sustainable land management combines technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns so as to simultaneously: maintain or enhance production/services (Productivity), reduce the level of production risk (Security), protect the potential of natural resources and prevent degradation of soil and water quality (Protection), be economically viable (Viability), and socially acceptable (Acceptability)".

Example studies that applied this framework are Pushparajah (1995), Land Development Department (1998), Maglinao (2000), and Praneetvatakul and Sirijinda (2003). These applications investigated the sustainability situation and developed a set of indicators concerning economic, social, and environmental conditions.

Pushparajah (1995) suggested the use of FESLM to assess sustainability especially in the issue of soil conservation. The suggestion was based on the importance of soil which relates to other resources and influences productivity as well as sustainability. Evaluation of a change in soil productivity should consider the physical, chemical, biological, and pedotransfer functions of the soil attributes. In addition, based on the five pillars of FESLM framework, Pushparajah (1995) proposed the additional indicators especially the indicators regarding soil to represent sustainability. Also, other indicators concerning economic and social perspectives to evaluate the efficiency of soil conservation practices in agricultural systems were suggested. The author also suggested that selection of indicators would depend on the particular research objectives. Also, the critical indicators and the threshold values of the selected indicators should be identified. Furthermore, the conclusion was made that using this framework to assess sustainability coupled with using models to project the important phenomena may form a beneficial approach to assess sustainability.

Based on the FESLM framework, Maglinao (2000) proposed the indicators of sustainable land management for slope land farms in Philippines. The study was performed with awareness of the danger of land degradation from agriculture activities on slope lands. In the study, soil erosion is the most important issue caused by cultivation on slope lands. This application used the indicator approach to monitor and evaluate the sustainability which contributes to decision making. Development of the indicators was under the pressure-state-response framework used to identify the key set of indicators representing farmers' land management and the consequent impacts. The sustainability indicators were defined in two groups. The first group was concerned with resource conservation corresponding to the protection pillar of the FESLM framework. The second group deals with the farmers' satisfaction and corresponds to the productivity, stability, viability, and acceptability pillars of the framework. Beyond using these indicators to evaluate sustainability, they will also be used in an expert system-based decision support system (DSS).

In application to the case study in Thailand, Land Development Department (1998) applied the FESLM framework to assess land management in Pha Duea village, Mae Fha Luang district, Chiang Rai province and Bua Ngam village, Detch U-Dom district, Ubonrachathani province. Evaluation was performed through defined economic, social, and environment indicators in two levels, household and regional level. At the household level, performance of the households in corresponding indicators was scored and classed into sustainable classes as Sustained, Conditional sustained, and Non-sustained class. After that, the Sustainability index, Performance value, and Area performance percentage were analyzed to indicate a village's sustainability situation. The study suggests that application of sustainability assessment under FESLM can be applied to other areas of Thailand. In addition, the critical issue regarding to sustainability can be ranked to support policy decision making.

The work of Land Development Department (1998) was adopted and applied to the research of Praneetvatakul and Sirijinda (2003) for sustainable agricultural planning in the highland area of Thailand. The case study of Mae Sa Mai village, Mae Rim district, Chiang Mai province was applied. Assessment of sustainability was performed through defined economic, social, and environment indicators. The Sustainability and Performance index were used to represent the sustainability situation at village level. In addition, Sustainability index of all indicators were ranked to present the priority of critical sustainability issues. The result of this study showed the issue of chemical pesticide usage as the most critical issue harming the area's sustainability followed by biodiversity and agricultural land type issue respectively. In addition, the study expressed that among the defined indicators the environment indicator was the most non-sustained issue for this village.

Investigations of sustainability above were done to evaluate sustainability through defined indicators within the extent of research objectives. Predictions of unforeseen change were analyzed within the scope of the investigated period. With this, there is still the challenge of sustainability evaluation at a generalized or regional level. Using the simple aggregation of the results from a lower level to evaluate the sustainability situation of a higher level is not adequate (Smyth and Dumanski, 1993). This is because interaction between the elements at a low level produces complexity and influences behaviour of the system at a higher level. At the same time, conditions at a higher level determine the elements' characteristics and behaviour at a lower level. In addition, the dynamics of these elements determine the system situation at higher level. Therefore, some techniques such as Hierarchy theory, metamodelling, or others are required to complete the evaluation (Smyth and Dumanski, 1993). This also needs integration of the processes and phenomena produced by the interrelated elements at the fine level to present the regional sustainability.

Simulation model is one of techniques that can be applied to deal with these circumstances. Simulation application can deal with complexity of the system. This is done by capturing interaction processes at the low level and presenting them as phenomena or emergence of the system at the higher level. In addition, the technique can be used to extrapolate the trend of the effects under the present situation (Daniell et al., 2006). This can enhances the precision of farming systems sustainability assessment by including the dynamics of systems due to long-term impacts of natural resource use, living standards, social development as well as innovations and regulation.

2.3.3 Application of the sustainability concept to the current study

Application of sustainability definition for this study

Based on definitions and concepts of sustainability mentioned previously, the definition of sustainability of farming systems for this study is defined as "the capacity of farming systems to maintain or enhance their performance or output over time in order to satisfy the need of stakeholders while the quality or supply of resources and environment is maintained or improved". This definition covers three implications which are;

1) maintaining or enhancing capacity of farming systems at a certain level within particular time period; this refers to the farming systems practices that can provide or maintain outputs and natural capital or man-made capital which leads to maintaining or improving the income of the farm households during a certain time period

2) satisfy the need of relevant stakeholders; this implies that to achieve the goal of maintaining or enhancing capacity of farming systems, the acceptability of relevant stakeholders should also be obtained

3) maintaining or improving quality or supply of resources and environment; this indicates that to reach the goal of maintaining or enhancing the capacity of farming systems, the quality or supply of resources which are considered as a part of the system's capital should be considered in their quality and supply sufficiency.

Application of sustainability assessment through indicator

This study is performed under the collaborative research project, the Uplands Program (SFB 564), of the University of Hohenheim (Germany) and Kasetsart University (Thailand). Methodology of sustainability assessment proposed by Praneetvatakul and Sirijinda (2003 and 2005), the researches under the project, is applied and extended. The assessment details are described in section 3.2.1. In addition, sustainability assessment of this study is also based on the FESLM framework (Smyth and Dumanski, 1993). All indicators from selected literatures are considered and selected within the framework of indicator determination of this study as presented in the section 3.2.2.

Application of system identification

To represent sustainability of the study area, the concept of system and hierarchy theory is applied. These theories contribute to the understanding of the study system structure and define the key aspects of system sustainability. Following these theories, the farming systems of the study area are considered as a system consisting of several dependent elements interacting with each other. In addition, the farming systems inherit hierarchical aspects which are located in the upper and lower systems. The upper system can be seen as an agricultural system or rural system while the lower system can be seen as crop system, livestock system, soil system, or land system. The relationship between hierarchical levels is taken into account. The significant aspects contributing to the sustainability of the study area can be captured through *pressure aspects* affecting the farming system from outside, *state aspects* as situation of elements composed in the farming system, and *effect aspects* as the consequences produced from the farming system. Furthermore, the theories support modelling which is the tool for sustainability investigation of this study.

Application of sustainability to modelling

With the challenge of sustainability evaluation to deal with future projection, application of modelling is performed in this study as the promising technique for this purpose. In addition, the technique of modelling is chosen as the tool which is compatible to address research questions for the following reasons. First, modelling can be applied with the concept and issue of sustainability of this study and can be used to extrapolate the sustainability situation of the study area. Second, the model can capture complexity of the study area's farming systems which emerge as complexity evolution from interactions of various elements and components. Therefore, sustainability complexity aspects can be captured and be able to deliver the complicated aggregation results produced from system behaviour. Third, the defined model can be used to present the study area farming system under the significant events and also can be used to monitor the policy intervention scheme towards sustainability situation in the study area. This is an advantage to support decision making for policy development in the study area.

2.4 Multi-Agent Systems approach

This section describes of the modelling tool as it is applied to this study. First, the simulation technique parties explained. After that, Multi-Agent Systems (MAS) approach as a simulation technique is introduced in section 2.4.3. In section 2.4.4, application under MAS approach to agricultural economics is explained. In section 2.4.5, the selected empirical applications under MAS approach are presented. Here, the exemplary applications of MAS in the field of economics, agricultural economics, ecological and resource management are explained. In section 2.4.6, how the MAS is applied in this study is described.

2.4.1 Simulation approach

Simulation is considered as a particular type of modelling that is used to get a better understanding of the world (Gilbert and Troitzsch, 1999). Simulation means driving a model of a system with suitable inputs and observing the corresponding outputs (Axelrod, 1997). With particular simulation technique, the model outputs can be considered as the emergence of complex behaviour which are produced from relatively simple behaviour and activities.

Simulation is performed using a model of the system processes. A model that is developed for simulation is therefore a simplification of some structures in the smaller form, with less detail, and lower level of complexity. The development of simulations can serve many purposes. The first is to obtain a better understanding of some features of the social world (Gilbert and Troitzsch, 1999). The second is to predict the trends and changes of some variables or system phenomena, though it should be a faithful reproduction of the real system.

The third is using simulation as a tool to substitute for human capabilities, for example, expert systems. The forth is using simulation for training, for example, a flight simulator to train pilots. The last is using simulation for entertainment, for example, the flight simulator can be also used as an entertainment game.

In general, the researcher enters the inputs while the outcomes can be observed through a model run. A computer simulation has the potential in social science to assist in formalizing and discovering (Gilbert and Troitzsch, 1999). For contribution to formalization, to create models the theories in the text form are precisely considered in relation to what the theory means. Later, they are formalized into a specification which can be programmed into a computer. Discovering the consequences of the theories in the artificial society can be done in this way. To get into the profound implications, the spatial location and rationality are included in the simulation as these aspects are often neglected in social science (Gilbert and Troitzsch, 1999).

In principle, the simulation is somewhat similar to an experiment in the field of natural science. The researchers can set up a simulation model, then execute, and observe the results for desirable time repeats. Some significant variables can be controlled and designed. By varying conditions through different parameters, the consequences of altered conditions can be explored. In some cases, simulations make clarification of the causal relationships and interdependencies of unexpected events which never occur in reality. However, the obvious difference between experiment and simulation is that experiment is controlling the actual objects whereas simulation is not (Gilbert and Troitzsch, 1999).

2.4.2 Multi-Agent Systems approach

Multi-Agent Systems (MAS), also called Agent-Based Systems or Agent-Based modelling, have recently been applied in a wide range of social sciences. MAS are a promising way to simulate social phenomena. The application is known as Multi-Agent simulations or Agent-Based simulations, and is as a key concept of this study.

MAS originated from the field of artificial intelligence (AI), an area of computer science, to develop human intelligent simulations and the tools to illustrate intelligent behaviour characteristics (Gilbert and Troitzsch, 1999). This had increasingly gained interests in investigation the interaction of the artificial intelligent agents, and leads to another subfield known as distributed artificial intelligence (DAI). Whereas the interest in the DAI field is to reproduce knowledge and reasoning of several heterogeneous intelligent agents to jointly solve problems, the AI interest is to reproduce one intelligent agent (Bousquet and Le Page, 2004). By this concept, the MAS approach arose with an interests in individual agent behaviours and their consequences at the global scale (Ferber, 1999). The approach had increasingly gained interest and has been applied a wide range of research field.

Bousquet and Le Page (2004) divided MAS applications into three categories; (i) the application for interacting hardware agents (collective robotics); (ii) the application for systems of interactive software agents (softbots) e.g. Telecom scheduling applications (program design), and (iii) the application for simulations, also known as multi-agent simulations. In the last category, scientists from different fields used the MAS simulation as their research methodology, for example, Janssen et al. (2006), Balmann (1997), Berger (2001), Happe (2004), Tesfatsion and Judd (2006), and Epstein (1998), Antona et al. (1998), Bousquet et al. (2002), Becu et al. (2003), and Castella et al. (2005).

In social science, the MAS approach is used to better understand social phenomena. The application of the concept is individual-based and bottom-up approach whereby an individual is considered as the elementary unit or the atom of society (Bousquet and Le Page, 2004). Social phenomena are observed as they are produced through interactions among heterogeneous social elements.

Definition and the key features of Multi-Agent Systems

Although there are several definitions of agent and multi-agent systems, there is no general standard definition (Bousquet and Le Page, 2004; Happe, 2004). This study follows the definitions given by Ferber (1999). First, an agent is defined as a physical or virtual entity. The physical entity refers to something which acts in the real world, for example, a tree, a man, or a table. The virtual entity refers to the virtual things that have no physical existence such as software, computer modules, or procedures. An agent is autonomous, and is driven by a set of tendencies which can be based on individual objectives or a satisfaction or survival function form which an agent will try to optimize based on its abilities and resource condition (Ferber, 1999). In addition, an agent has capabilities in its environment, communicating with other agents, possessing resources, perceiving and having representation of its environment to some extent, having skills, offering services.

According to this definition, the multi-agent system can be defined as a system that is composed of various kinds of elements including (Ferber, 1999);

1) An environment (E) that is a space.

2) A set of objects (O) which these are situated in E and also these are passive which can be perceived, created, destroyed, and modified by agents.

3) An assembly of agents (A) which are specific objects and a subset of O representing the active entities of the systems.

4) An assembly of relations (R) linking objects (and thus agents) to each other.

5) An assembly of operations (Op) which this makes possibility of the agents of A to perceive, produce, consume, transform, and manipulate objects from O.

6) Operators with the task of representing the application of these operations and the reaction of the world to this attempt at modification which we should call the laws of the universe.

General features of MAS

The key features of MAS models that distinguish them from conventional approaches of modelling are: heterogeneity, autonomy, explicit space, local interactions, bounded rationality, and non-equilibrium dynamics (Epstein and Judd, 2006).

Heterogeneity: The MAS models are composed of various individual agents. Each agent differs from one another, for example, resource properties, preferences, memories, decision rules, social network, and location. The state of the differences can be endogenously adjusted or changed over the timeframe considered.

Autonomy: The MAS models are based on autonomy of agents, that there is no central or top-down control over individual agents. The agents have control over their own actions and internal state. In addition, the agents are not directly commanded by the modeler from outside but they act based on a set of tendencies in the form of individual goals or satisfaction (Ferber, 1999). To some extent, an agent's autonomy depends on their capacities and resource endowment.

Explicit space: The events typically transpire on an explicit space. This can be a landscape of renewable resources, an n-dimensional lattice, a dynamic social network, or any other structures.

Local interaction: The agents interact with other agents in their environment.

Bounded rationality: The agents have neither global information nor an infinite computational capacity. Therefore, actions of the agents are in some extent under limitation of information and computing power. According to this, the agents have only a partial representation of their environment and react by following simple rules based on local information.

Non-equilibrium dynamics: This is of central concern to agent modelers. These are large-scale transitions and emergence of macroscopic regularity from decentralized local interactions. These are different from equilibrium existence theorems and comparative static approach.

2.4.3 Application of Multi-Agent Systems approach in agricultural economics

In agricultural economics, MAS has gained interest because of the need for quantitative models to handle complex phenomena. MAS is considered as a way of modelling complex economic systems composed of various individual actors with their interdependencies. The technique contributes different modelling perspective from top-down approach which is limited in consideration to behaviour and interactions of the system's actors. The MAS approach relies on a bottom-up approach and can be flexible with some assumptions, for example, fixed decision rules, representative actors, market equilibrium constraints, common knowledge, and perfect foresight. In addition, the MAS approach is able to represent the feedback mechanism between micro and macro level which at micro level the system is characterized by various different actors.

Applications of MAS in agricultural economics are sometimes developed to support policy decision making. To improve agricultural sustainability, policy makers requires better understanding of the complex dynamics of agricultural systems at the farm level and other relevant levels (Dent et al., 1995; Bontkes and Keulen, 2003). These have to concern with decision making processes of the farms with the consequences to their environment. These can be seen in crop and livestock production systems which are affected by, for example, the farm economic situation, land and other resource allocation, soil property dynamic, erosion occurrences. Also, the price and production supply at higher levels affect farm level decisions. In addition, individual farm behaviour and interactions among farms which influence decision making of farms should be also taken into consideration.

Using MAS to analyze a dynamic path of the underlying system can potentially give more significant information for the policy makers (Parker et al., 2003). This information can be used to support analysis regarding the differential impacts on local stakeholders. The study can be applied to investigate short-run impacts and how the path of the system changes. With this, the model parameters can be perturbed and the changes can be observed in response to exogenous shocks.

MAS models are also useful for an active or interactive policy testing (Parker et al., 2003). The models support learning in resource management because the MAS approaches can model both decision making and social, physical and biological processes. The models provided by spatially explicit cellular model especially those coupled with GIS contributes a wide range of result communication to policy makers and relevant stakeholders. In addition, by flexibility of representation and implementation, the models can fit well with interactive scenario analysis and participatory of stakeholders at many levels.

The models developed under MAS approach have some advantages to the study of agricultural economics. In particular, the selected features which the MAS contributes to agricultural economic applications are flexibility with regard to assumptions, the potential to represent complex emerging structures with heterogeneous and individual behaviour, and the integration of spatial aspects (Happe, 2004).

Relying on bottom-up modelling approach of MAS, the theoretical assumptions required in top-down approach to ensure consistency between micro and macro level such as fixed decision rules, perfect rationality, perfect information, representative agents, and market equilibrium constraints can be adjusted or exempted (Happe, 2004). The approach allows implementation of axiomatic assumptions based on theory or specific assumption for a particular interest. However, with this flexibility, the researchers or modelers are required to identify and formulate model assumptions carefully. The assumptions should be based on criteria that are acceptable, justifiable, reasonable, and documented.

To deal with complexity and emergence of interested systems, the MAS has potential to generate complex structures produced by endogenous change without external influences (Happe, 2004). Emergence of interested systems can be produced through its complexity at macro level by a large number of interactions and individual actions of the system's parts. Emergence can also occur when interactions among objects at one level give rise to different types of objects at another level. For example, temperature is an emergent property of the motion of atoms but each atom has no temperature. The temperature is made by their collections. Therefore, the MAS is appropriate when complex phenomena have an important influence on the study results.

For the last specific feature, MAS has the ability to integrate spatial models with agricultural economic models. This linkage provides a better understanding of interrelationships among system elements, and between biophysical and socioeconomic components.

In sum, these aspects explained above mean that the research questions in the field of agricultural economics can be extended by the use of MAS. Challenges still remain for further applications relying on this approach.

2.4.4 Selected empirical applications of Multi-Agent Systems approach

Applications in economics

In the field of economics, applications of MAS have been raised as concerning to the way of study economies which are complicated systems composed of micro behaviours, interaction patterns, and global regularities (Tesfatsion and Judd, 2006). The application approach in this field is known as Agent-based Computational Economics (ACE). This is the computational study of economic processes represented by the model of dynamic systems of interacting agents. The studies are performed with the intension of taking real world aspects into consideration. Those include asymmetric information, imperfect competition, strategic interaction, collective learning, and the possibility of multiple equilibria.

The ACE model can be normatively used as computational laboratories (Tesfatsion, 2001). This approach involves applying alternative socioeconomic structures to investigate and test the effects on individual and social welfare. This helps to explain the evolution of global regularities which have been observed in reality. Furthermore, the ACE models contribute possibility to research work on economic self-organization and evolution in five ways (Tesfatsion, 2001; Happe, 2004).

1) Artificial economies can be computationally modeled on the computer with the models composed of heterogeneous agents whose interactions to each other and the environment are determined. These interrelation rules are potentially defined based on internalized social norms, internal behavioural rules, and data acquired on the basis of experience. The agents constructed under this approach have more cognitive structure and more autonomy than the agents defined in conventional economic models.

2) A broad range of agent behaviours (e.g. profit maximization or satisfaction) and interactions among agents can be determined in these models which are considered as economic artificial world. The models can illustrate self-organization which is produced from behaviour adaptation of agents. This is the possibility that agents adapt their behaviour in response to interactions among agents and their environment to reach their satisfaction. For example, self-organizing structures can evolve because behavioural rules defined at the outset of a simulation can change during the simulation.

3) Agents in these artificial worlds can co-evolve that is the individual performance of an agent depends on the evolving behaviour of other agents.

4) Artificial economic worlds can grow along a real time-line. This means that the initial conditions are set by the modeler. All subsequent events can be initiated and driven without further outside intervention. The consequences under defined conditions can be observed. This is similar to growing bacteria cultures in a petri dish.

5) The artificial economies or agricultural structures can explicitly be connected to a space in order to analyze land use change caused by economic activities.

There are a large number of studies of ACE models in the economics field. The selected literature presented here is a study of Tesfatsion (2001). The study applied an ACE model under labour market framework to examine the relationship between job capacity, job concentration, and market power. Under a labour market framework, investigation focused on evolution of market power produced from interactions between work suppliers and employers under their strategies. The labour market framework comprises several suppliers and employers. They repeatedly engage in repeatedly searching for worksite partners based on continually updated expected utility. They also engage in efficiency-wage worksite interactions modeled as prisoner's dilemma games and evolve their worksite strategies over time based on the earnings secured by these strategies in past worksite interactions.

Distinction of this model from standard labour market model can be seen in three aspects. First, this model is a dynamic process model defined algorithmically in term of internal states and behaviour rules characterizing work suppliers and employers rather than by the system of demand, supply, and equilibrium equations. Second, agents (work suppliers and employers) try to learn the behavioural rules of other agents and these rules coevolve over time. Third, all events occurring in a path-dependent time line can be observed under given conditions. This is similar to a culture growing in a Petri dish and then the results can be observed by researcher without disturbance.

Market power for work suppliers and employers is determined by the degree of deviation of their welfare level from the average welfare level that they would obtain under a competitive market with the assumption of mutually cooperative worksite behaviour. The market power accrues to work suppliers or employers depending on job capacity and job concentration. Job capacity is measured by the ratio of potential job openings to potential work offers. In other word, this is measuring the total potential availability of job openings relative to work offers. Job concentration is measured by the ratio of work suppliers to employers. This is measuring the extent to which control over job openings is concentrated among relatively few employers. The experimental design of this study consists of the systematic variation from high to low job capacity and concentration.

The main finding is that job capacity consistently trumps job concentration when it comes to predicting the relative ability of work suppliers and employers to exercise market power. In addition, the study highlighted that the application of ACE model to the labour market framework contributes the systematic experimental investigation of behavioural and network formation processes. This provides better insights into the relationships between structure, behaviour, and market power of labour markets in reality.

Applications in agricultural economics

MAS approach is applied in the field of agricultural economics. The first exemplary example is Balmann (1997) which applied MAS to analyze policy impacts in agricultural structure change. The study of Balmann (1997) was initiated with the intention to investigate agricultural structural change as a path dependent. In addition, the study aimed to identify the conditions which induce emergence of path dependency. To investigate these circumstances, the MAS simulation technique was chosen to handle the high complex dynamic processes which are produced and depended on development of each farm in the system. The study model as the spatial and dynamic model had been developed. The model is based on a number of individual acting farms located at different points in an agricultural region.

The plots are spatially ordered in a fictitious and idealized region based on cellular automata approach which can become farmland and/or farmsteads. The farm agents have to compete to use the lands through a land renting market. This process takes place simultaneously with all individual farm planning.

Farm agent behaviour in planning and decision process was assumed to perform through linear programming (LP) to optimize their production activities in order to maximize their income. Decisions of agents are performed with consideration of interdependencies with their environment, other farm agents, production technologies, and market conditions. In addition, the model assumes adaptive expectations which the farm agents have to form expectations of their future development. The farms can close down or a new farm can be founded. They can rent and reduce their land. Also, they have to decide to invest in assets by comparing their situation with and without the asset.

The results showed that using this approach can confirm existence of the path dependencies and the conditions which contribute to it occurring. The investigation of path dependence existence is based on the importance of the initial situation in the development and the stability against later disturbances.

In the point of approach application, this study was not aimed to represent the full reality but rather to get a better theoretical understanding of the processes of change. The suggestion of this study in order to develop the model into a more realistic one is to consider modifications to the decision making processes regarding allocation mechanisms. This may require more empirical data used to support adjustments. Also, modification of the model can be performed by the introduction of technology progression, where the farm agents can decide to adopt such innovation in simulation.

For further development, the model can be easily modified and implemented to different fields of interest because of the modular structure. Additionally, the study pointed out that in principle this study approach has essential advantages compared to conventional approaches. That is taking consideration of individual behaviour and situations of a multitude of heterogeneous economizing agents. Also, the approach is useful for theoretical analysis especially here for investigating agricultural structure change issues and it is possible to apply it to other issues such as policy effects on farmers' income and its stability as well as on land use.

The second exemplary of MAS application is the study of Happe (2004) which is an extension of the MAS application from Balmann (1997). In this study, the spatial and dynamic simulation model called AgriPolis (Agricultural Policy Simulator) was developed as extended application from the Balmann (1997) model. The study investigated whether and to what extent policy change can induce structural adjustment leading to a more efficient and competitive agricultural structure. This investigation focuses on consideration of farm size change, factor use, technical efficiency, and income aspects.

The study model was based on a large number of individual farm agents interacting with each other and their environment. Farmers can perform agricultural production activities, invest in buildings and machinery, work as part-time farmers, or leave agriculture.

Extension of this work from the original work of Balmann (1997) is that adjustments of the model from previous work to more reality of the case study. The initial condition of the model was calibrated to the agricultural structure of the region Hohenlohe in Baden-Württemberg in the reference year 2000/2001. This calibration was carried out to capture the farming structure in the region and the variety of prevalent farms and production activities. This application also introduced the technique of Design of Experiments (DOE) as sensitivity analysis to investigate the AgriPolis model behaviour under the current condition. This investigation contributes a better understanding of the variation of the model's results to parameter changes. The technique is also helpful to find a robust configuration of the model and identify the significant factors and their interactions influencing the change of the target system.

Regarding farm agent behaviour, AgriPolis assumes that each farm agent maximizes farm family household income in the planning period. This is performed under the conditions of farm factor endowments, production activities, investment possibilities, and other farm restrictions. To do this, the mixed-integer optimization was applied.

The policy conditions which were involved in investigation were based on the policies that are expected to support agricultural development to improve efficiency and competitive agricultural structures. The consequences of this were analyzed in four perspectives which are structural development, efficiency, income, and budgetary effects. In addition, this extended work considered the agent's managerial ability which affects the agent's ability to use technology for cost savings. Also, under the policy condition agent behaviour of policy change expectations was introduced to the model for simulation.

The results of the study show that agricultural policies effect structural change in many ways. However, in the point of view of MAS approach application the results obtained from the AgriPolis are plausible from a theoretical and empirical point of view although the results are depended on assumptions influencing the farm agent behaviour. Adjustment of individual farm agent depends on the individual farm agent circumstances and the environmental conditions that the farm faces.

The third exemplary MAS application is a work of Berger (2001). The key concept of this application follows the pioneer application of Balmann (1997) to use farm-based linear programming within a cellular automata framework. This work aimed to assess policy options in the diffusion of innovations and resource use changes.

In the study MAS model, farm agent decision behaviour was based on optimization technique as in the previous two studies. The individual agent in the model has to decide among alternatives of available production, consumption, investment, and marketing. This is modeled through recursive linear programming (LP) models. Diffusion of innovations in the model depends on agent adoption condition. The adoption constraints were applied in the LP model in the form of network-threshold values that reflect the cumulative effects of experience and observation of peers' experiences. In addition, the study model had integrated hydrological components which contribute to the investigation of the consequences of using water for irrigation.

Application of this study was demonstrated two weaknesses of conventional approach. The first one is the inability to capture the interaction between individual farms. The second is the inability to consider the spatial dimension of agricultural activities which affects to the internal transport costs and immobility of land. In addition, the author argued the advantages of using a MAS approach. That are;

1) This approach is flexible as it is able to incorporate information from various sources such as agronomic experiment results, official and unpublished farm records, sample surveys, expert opinions, and direct observations on the field.

2) The significant constraints affecting technology adoption can be implemented at the individual farm level which is useful for predicting innovation diffusion and assessing the policy implications.

3) Under the approach, several individual farm models with different behavioural constraints can be solved simultaneously. This allows consideration of the heterogeneity of farm behaviour which facilitates to capture time lags in farmers' choosing among alternative technologies.

4) The approach allows interactions among farm households to be captured. This is useful for modelling of innovation diffusion phenomena which is affected by exchange information among agents which is considered as a kind of interactions.

5) The approach allows the exchange of available resources such as land and water through their markets with their endogenous price to be captured.

6) The approach can be used to conduct experiments in an artificial world in order to get insights for policy development and evaluation.

The author also highlighted advantages of applying a spatial cellular automata model. These are;

1) The approach is able to consider spatial dynamics of land allocation between farms which can realize the economies of scale of the farms.

2) The approach supports application of water usage for irrigation with particular role of spatial relations. This contributes consideration of technology and efficiency of irrigation affecting the farms.

3) The approach enhances the ability to investigate some issues such as the case of improved technology and policy intervention influencing land use systems.

Technically, the study conducted model calibration in two-steps. First, validation occurred at the micro level where the data obtained from the model agent was compared to real world farm data. Second, the macro level was examined to test the model aggregate representation. The process of calibration was repeated until the model fits at both levels. In addition, local experts were used to consider the plausibility of the model's predictive capacity. Robustness of the model was tested by observing the change of two variables under identical scenarios. The testing results can conclude robustness of the model when the values of both variables changed in these scenarios while the relative trends were uniform. Furthermore, the author pointed out that GIS based integrated MAS models can be a potential tool for policy analysis and natural resource management.

Another exemplary of MAS application in agricultural economics is Schreinemachers (2006). The study applied the MAS model with three objectives. The first is using the model to quantify crop yield gaps and yield gap dynamics at the farm household level and identify the significant factors affecting these. The second is using the model to assess the relationship between the width of the crop yield gap and farm household well-being and food security. The last is using the model to analyze how improved varieties with a higher yield affect incomes and food security at the farm household level.

The MAS model for this study was composed of three components. The first component is an economic model used to simulate farm household decision making. The second component is a biophysical model used to simulate crop yield and soil property dynamics. The third component is spatial layers of soil properties used to represent the physical landscape of the case study in two villages in southeast Uganda.

To simulate farm decision making, this study applied mixed integer linear programming (MILP) to capture decision making of individual farm agents incorporating with other components of the model. Each agent was assumed to maximize expected utility that later guides agents in the farm decision making process. The utility function was composed of three dimensions which are cash income from sales and off-farm labour, in-kind income from auto consumption of crop and livestock products, and the annuity of future expected income from investments.

The distinction of this study to other MAS applications is explicitly expressed in four ways. The first is application of agent parameterization for the survey data by using Monte Carlo techniques. The second is development of a non-separable three-stage decision model of investment, production, and consumption. This is a realistically representation of the economic trade-offs in resource allocation. The third is introducing a three-step budgeting system and an Almost Ideal Demand System to the mathematical programming model in order to simulate poverty dynamics in term of food energy consumption. The last is integration of agent coping strategies to food security.

In perspective of applying MAS, the author pointed out that the MAS approach can consider the heterogeneity of landscapes and farm households including their interactions and so is relevant to investigate the issue of poverty, inequality, and suitability which all relate to heterogeneity. In addition, the conclusion can be made from this study that the MAS approach can be applied to study sustainability and poverty circumstances.

Application in ecological and resource management

Application of MAS approach in ecological and resource management field is also gained from rapid expansion of the distributed artificial intelligence and MAS approach. The first selected empirical application is Barreteau and Bousquet (2000). The application was performed to investigate water resource utilization through irrigated systems in the Senegal River Valley. The key question was to consider the viability of the irrigation scheme which was currently under-utilized. The viability of the irrigation system was defined as its capacity to keep functioning under given initial conditions in a given context. Investigation of system viability is equivalent to checking the existence of a viability path under given initial situation. In addition, the influence of the existing social network on the viability of irrigation systems was examined.

To address this question, the MAS model as a virtual irrigation system was applied as a tool to extrapolate paths. This tool was used to capture interactions between farmers with their perception of reality.

Under the MAS approach, the study assumed that the viability of the irrigation systems depends on the component behaviour and interactions. Therefore, the study aimed to investigate the structure of the systems and activities performing within them. The application focused on behavioural rules in the system which included access to credit, water allocation, cropping season assessment, as well as organization and coordination among farmers.

Development of the MAS model for this study was alternated with modelling and simulation. From the field work, hypotheses about the functioning of the systems were formulated and subsequently were simulated with the model. Hence, each round raises new questions for further field study and so on. This cycle was repeated three times corresponding to three different questions on irrigation systems concerning: the importance of water management in irrigated systems; the importance of cropping season preparation and debt circulation in irrigated system dynamics; how the cropping seasons are assessed and follow on from each other. This process provided information about the way that all activities are enforced and about interactions among actors in the systems. These behavioural rules and interactions as well as all information found in the field were implemented into the MAS model named SHADOC (French acronym for hydro-agricultural simulator describing organization and coordination modes).

The model had two parts: a scheme model with its structure and dynamics, and a social organization with structure and dynamics. The model was written in an object-oriented programming language, SmallTalk, under the VisualWorks environment.

The authors showed that the model could be used as a research and experiment tool. Simulations of various scenarios of collective rules and individual behaviour are possible. The scenario choice was formalized as a triplet (C, I, E): C is a set of initial collective rules; I is a set of initial individual behaviours; and E is a set of relations to the environment. The model enabled the authors to study the evolution of an irrigated system in different frames of rules and alternative hypotheses.

The results can be classified into three groups. The first group consists of viability indicators. The second consists of factors affecting on viability. The third group consists of factors which possibly influence viability but they were not taken into account.

The researchers pointed out that the model allows the simulation the effect of collective rules with uncontrolled parameters. The expected results can observe the scope of variation. It is possible to enforce other design methods to limit this variation. In addition, the model showed the potential to examine the influences of social networks on the viability of irrigated schemes. This approach allowed "learning by simulating" rather than "learning by doing" which has been over-practiced in the field of irrigation development.

In Thailand, MAS approach has been applied to the issue of resource management. A first exemplary study is Becu et al. (2003). The study applied MAS approach to the issue of water management in the Mae Uam catchment. They focused on the impacts of upstream irrigation management on downstream agriculture viability. The hypothesis was that negotiation among stakeholders could resolve the conflict about competing water uses. Therefore, the model was structured to facilitate the stakeholder negotiation processes.

The MAS model of this study, named CatchScape, was developed under the CORMAS (Common-Pool Resources and Multi-agent Systems) platform (Bousquet et al., 1998). The model represented a virtual catchment. A companion modelling approach was used to develop the model which involved various stakeholders to find out appropriate solutions.

Modelling of CatchScape model focused on behaviour rules and methods similar to Barreteau and Bousquet (2000). The model architecture was integrative, spatially distributed, and individual based in order to cope with complex and adaptive issues of the system at the catchment scale. Therefore, the CatchScape is considered as an integrated model which consists of biophysical and socioeconomic aspects of the catchment. Biophysical modules were developed to capture features and dynamics of the hydrological system with its distributed water balance, irrigation scheme management as well as crop and vegetation dynamics. The socioeconomic aspects of the catchment were also captured. The social dynamics were described as a set of resource allocation processes regarding water, land, capital, and labour resources.

With this application, the author determined that the model provides the facilities to illustrate the evolutionary landscape patterns or to investigate specific stakeholder behaviour. In addition, to validate the model information of the system should be collected as much as possible. An authentication approach was suggested as a possible way to validate the model. This can be performed by crosschecking simulated results with actual and statistic data. Emergences raised from the simulation can be crosschecked with reality. The behavioural rules of the model can be directly confirmed with stakeholders. This recognition by the concerned actors is the best-known authentication.

For future studies, the author had pointed out that CatchScape could be modified to consider different system. With the simple CORMAS architecture, simulation can be done interactively with stakeholders. For examples, the issues raised by stakeholders can be captured during sessions and the rules or characteristics of the agents can be modified based on the suggestions of the stakeholders. Besides, the model can be used to help tackle changes produced from the decentralization processes. The model can be used by local stakeholders to explore the integrated impacts of prospective and alternative management options.

Another example of the use of MAS in ecological and resource management in Thailand is Promburom and Bommel (2005). The study aimed to develop a MAS model representing a highland agricultural system to study the processes and dynamics of decision making and its consequences for agriculture and land use under the current situation and when policies are implemented in the area.

The study area was the Mae Hae royal project foundation centre covering 14 villages in 3 districts: Mae Wang, Mae Chaem, and Sa Mueng district. The study model was designed based on an object-oriented modelling approach. The standard language, Unified Modelling Language (UML), was used to depict the model structure and detail. The model structure presented all elements in different classes and their relationships were presented in the class diagram. The model was composed of two object categories: objects representing stakeholder agents (e.g. farmers, village community, government agencies) and objects representing biophysical elements (e.g. crop, plot, watershed, climate, etc). Activities performed by agents and the sequence of model simulations were presented in model activity and sequence diagrams respectively. In the biophysical model, GIS was integrated in the model representing the environmental space. In addition, the authors cited that the study model can be used as a tool to support decision making for stakeholders in the study area regarding land and resource management.

Application to sustainability assessment

MAS approach has been applied to assess sustainability. Examples are study of Daniell et al. (2005) and Daniell et al. (2006). The applications aimed at assessing sustainability of housing developments. Also, these studies provided a decision making tool that can be used by policy makers, governments, and planning authorities. The MAS approach was used to model holistically the complex urban systems.

To assess sustainability, the studies introduced a new methodology known as sustainability scale for indicators that were derived from percentiles of a population with resource use above a predetermined sustainable level. The sustainability scale was based on a probability of exceeding the ultimate sustainability threshold level for each resource. Individual sustainability scale ratings (SSRs) for indicators were based on the cumulative probability distribution of the current resource uses at a larger system scale exceeding the sustainability threshold level. This technique allows comparison between sustainability indicators.

The study was illustrated to be operational in the case study of the Christie Walk housing development in inter-city Adelaide, Australia. The study showed that modelling relying on MAS approach can capture systems with many subsystems and their interrelations. In addition, the effects of human behaviour could be captured in both spatial and temporal dimension. This is useful information for decision makers and planers to get better insights into the complexity of urban system.

The simulation results showed that housing development favorably compared to the rest of the Adelaide metropolitan area. In addition, scenario analyses were conducted to explore the effects of changes in behaviour and community interaction as well as development infrastructure and location. This is considered as the greatest advantage of MAS approach which has the capability to carry out “What if” scenario analysis. Scenarios focused on waste production, recycling, water and energy use. In each case, high, moderate, and low levels of resource behaviour were initialized for all residents in the model. The results show that changes in behaviour could significantly influence sustainability.

From the scenario analysis, it was concluded that good infrastructure and design are preferable to reduce the impacts of human behaviour on sustainability. The study pointed out the importance of good design and infrastructure in order to reach sustainability in built environments. This could be more effective policy to improve sustainability than the policies with attempts to change occupant behaviour. The authors also highlighted that this methodology which integrates sustainability assessment with an MAS modelling technique will provide the basis for a solution to many of the challenges of researchers, policy makers, as well as planning authorities concerned with sustainability and the urban environment. The MAS approach allows consideration of the relative importance and effects of all subsystems in urban area on overall system sustainability which is important to the design and selection of policy development options and plans.

Furthermore, the authors suggested further application under this framework including;

- further analysis of methods to model occupant behaviour based on more complex decision theory, game theory, or other sociological and psychological theory

- further analysis of the impacts of resource pricing on usage and behavioural change

- studies of behaviour relating to the uptake of sustainable technologies and practices, and how policy makers can better work with communities to ensure a successful uptake of such technologies and practices

- expansion of the methodology to assess the sustainability of rural systems, companies, countries, or any other complex system, potentially with the integration of Geographical Information Systems (GIS).

2.4.5 Applications of Multi-Agent Systems approach to this study

The present study is an application of MAS approach to the issue of sustainability assessment. The application was conducted for the case study of Bor Krai village, Mae Hong Son province where sustainability of the subsistence farming systems is questioned.

To assess and extrapolate the area's sustainability situation, a virtual farming systems model for the study area was developed following the MAS modelling approach. Modelling of the system relied on a bottom-up approach and intended to capture the complexity of the case study's farming systems. Therefore, heterogeneity and interactions of system elements including local farm households and their environment were taken into account.

Modelling in the present study focused in more detail on the behavioural rules and dynamic conditions of the stakeholders. Hence, the decision making processes applied in this study were structured following behavioural heuristics presented in the decision tree diagrams based on existing farm household behaviour. However, in situations where information on behaviour and dynamic processes did not exist or cannot be obviously concluded, theoretical or plausible assumptions were made and introduced into the model.

The behavioural heuristic approach has been selected among an alternative option, the optimization approach, with arguments as follows.

Firstly, the approach is flexible as it can include qualitative aspects which are influencing the farm households' decision making especially in this study e.g. behaviour about subsistence, leaving fallow land and performing off-farm activities which are difficult to apply in the way of optimization (Schreinemachers and Berger, 2006; Becu et al., 2008).

Secondly, the heuristic approach obviously reflects the limited ability of farm households to make decisions with bounded rationality characteristic (Schreinemachers and Berger, 2006). This limits the capability of farm households to collect and compute information. It is considered as the search cost which can be in the form of cognitive or finance which restricts the ability of decision making. To obtain decision making processes, calibration and validation are performed by considering how the decisions are made by searching limited cognitive capacity of human mind internally produced from the farm households. This investigation enhances comprehension in detail about decision making processes which induces not only the comparative real-world results but also generates a good reproduction of the system containing reasonable processes to obtain outputs. The concept of bounded rationality considered in the heuristic approach is different from the perfect foresight of the households supposed by optimization approach whereby decision making is performed with fully multifaceted knowledge and powerful computational decision. The process of calibration to the real situation is also different to the heuristic approach. Calibration is performed by considering external limitation of the farm households opposed to considering the farms' internal limitation in the heuristic approach. This process is achieved by the adjustment of opportunities and constraints which induce inefficiency external to the farm households. With this, the actual objectives and decision factors which are different in each decision circumstance are neglected. Therefore, even if the obtained results are close to the real-world situation there are still questions about how the modelling decision process matches existing behaviours.

Thirdly, decision making processes are structured in a decision tree diagram which is a more understandable form for the people with various levels of knowledge. Therefore, the behavioural heuristic approach is more flexible to involve people as stakeholders in the various stages of study and modelling e.g. model development and model validation etc. This enhances not only the understanding and model validity but also improves participation and cooperation between the researcher and the area’s stakeholders (Becu et al., 2008).

Fourthly, the behavioural heuristic is more flexible to model the agent’s environmental perception and communication within their society. These aspects are important and should be captured as it will influence decision making processes and social emergence through interactions and individual actions (Becu et al., 2003). These aspects are rather difficult or impossible under an optimization approach.

Lastly, as an integrated model, the decision tree structure is more flexible and able to integrate with other models which are structured in different time step interval of simulation. For example, in the case of Becu et al. (2003) the decision making processes of agents were modeled in heuristic way. The agents’ decisions structured in the decision tree are compatible with biophysical sub-models –crop model, water balance model, hydrological model– with a 10 day time step interval. Decision making processes can include the dynamic aspect of biophysical environment into agents’ consideration. For example, the suitable time to plant crops can take into account seasonal and rainfall conditions. In addition, the process can capture dynamics of economic parameters e.g. seasonal labour and price conditions during the year.

Even though the heuristic approach shows some advantages as explained above the approach is still weak in taking complete economic trade-off among alternatives of resource use into account which this can be completely captured by optimization approach. With the heuristic approach, this weakness can be improved by introducing testing conditions in the decision tree structure but a number of nodes to test the conditions are required. This complicates the decision structure and may make it difficult to adjust. However, there is a promising way that can overcome this problem which is the use of a modelling and programming technique. The architecture of the decision processes can be designed to test conditions at various stages. This technique was applied to this study, for example, crop alternatives were separately tested to select the best one when considering the expected revenue and yield, labour needed and availability of supports. After that, the selected alternatives were weighted by decision maker preference to choose the best one. The best alternative was later tested to determine whether it is possible to do by considering the constraints such as labour, cash, weather suitability, etc. Therefore, in this case modelling using a heuristic approach can take resource allocation trade-offs into consideration to some extent.

The scope of the MAS model for this study covers the extent of the target farming system which was defined based on the farming system approach explained in the section 2.2.

The study model was based on CatchScape3 model (Becu et al., 2003) which was developed on the CORMAS platform by using SmallTalk programming language. The CatchScape3 model has been chosen because the model structure has the potential to serve the objectives of this study. Also, the CatchScape3 model provides several important biophysical modules to represent the farming systems in the study area. This contributes to the modelling capacity and it is flexible enough to be applied to the case study. For the socioeconomic component, the CatchScape3 model was adjusted to represent socioeconomic aspects of the study area. The modules for sustainability assessment were implemented to capture and quantify the area's sustainability situation in order to address the research questions. In addition, the MAS model of this study was further used to carry out scenario analyses in order to investigate the potential impacts under specific events and policy interventions.

3. Application of agent-based modelling to study framework

3.1 Study area description

This chapter gives an overview of the study area, Bor Krai village. It covers the socioeconomic and biophysical conditions of farm households including village's institutions as well as collective natural resource management.

3.1.1 General information about the study area

The study area, Bor Krai village, is located in the north of Mae Hong Son province in the northwest of Thailand close to the border of Mynmar (approximately 150 kilometers from the border) (Figure 4). Administratively, it is located in Muh 11 (sub-district) of Pang Ma Pha district, Mae Hong Son province. It is connected to the center of the district by the public road number 1095 with a distance of 6 kilometers. Additional, this area is situated in the National Reserved Forest area.

It is located between 19º 53´ and 19º 57´ North latitude and 98º 20´ and 98º 25´ East longitude. The village borders Mae La Na village (Shan), Ja Bo village (Black Lahu), and Ya Pa Nae village (Black Lahu) to the north, Tham Load village (Shan) and Sob Pong village (lowland Thai) to the east, Tha Krai village (lowland Thai), Baan Rai village (Black Lahu), and Baan Sam Lang village (lowland Thai) to the south, Luk Kao Lam village (Black Lahu) to the west (Figure 4).

The average elevation of the area is approximately 863.70 meters above mean sea level. The area is composed of steeply sloped mountains with an average slope gradient of 17.59 %.

The total area of the village is 1,417.91 ha whereby the rainfed upland cultivated area occupies 338.83 ha, collective livestock stall 1.85 ha, residential area 4.89 ha, village's conservative forest area 44.72 ha, and forest and scrub occupy 977.62 ha.

The average temperature is 23.67 ºC, with the highest temperature in April of 37.18 ºC and the lowest in January of 5.68 ºC. The average humidity of area is 92.90% and average precipitation is 1,207.17 mm per year. The month of August has the highest rainfall with 227.97 mm.

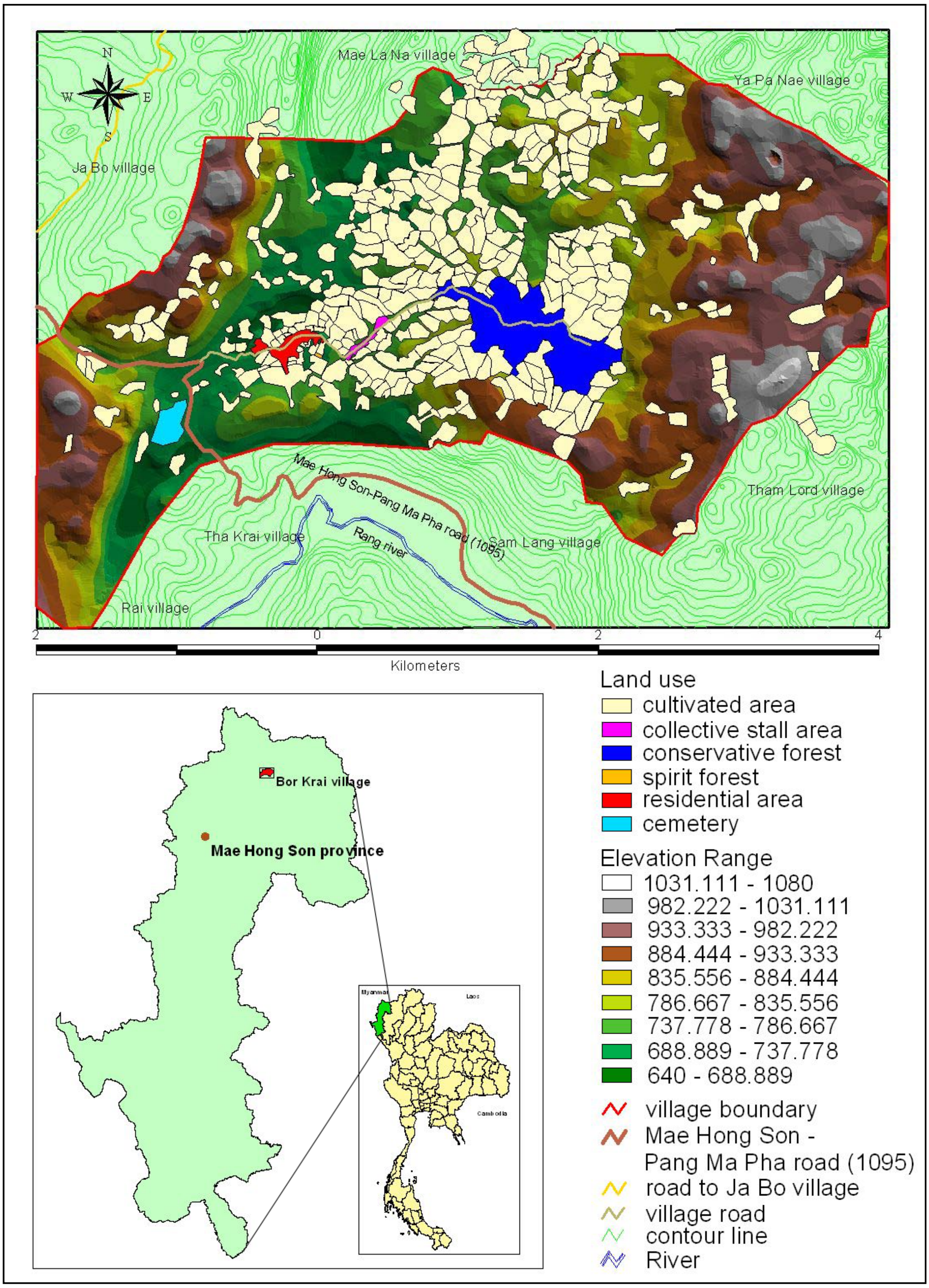


Figure 4: Study area, Bor Krai village, Pang Ma Pha district, Mae Hong Son province

Source: Land Development Department, 2005

In 2005, the village had a population of 61 households or 264 persons who are hill tribe, Black Lahu 95% and Red Lahu 5% of total respectively.

The villagers pursue their livelihood by farming, that is crop and livestock production. The major crops are upland rice and maize which are grown as a mixed crop pattern with local vegetables e.g. pumpkin, local bean, local melon, chili etc. In livestock production, piglets, pigs, cows, buffalos are commonly raised, especially piglets which are most important for household cash generation and are also used in ceremonies. For these purposes, each household requires 5-10 piglets. In addition, this village is recognized as the largest piglet production in the district and supply to traders and villagers of other villages.

Besides these activities, the villagers do off-farm activities such as hire out labour in farm and non-farm activities, and gathering forest products e.g. mushrooms, bamboo shoots, wild vegetables and fruits, etc. Also, because there is a local market away from the village around 1 km on the main road 1095 which is the main route connecting Pang Ma Pha district and Muang district (main district) of Mae Hong Son province, some villagers sell their products in this market. Also, there are some other villagers acting as traders by gathering local products from Bor Krai and other villages to sell to local customers and tourists.

3.1.2 History of the village’s establishment

The history of settlement started from migration of ethnic minorities including Black Lahu people from Myanmar to Thailand dated back around a century. The main reason for the migration was the search for arable and grazing land. At first, they moved to the area near the border and later to other areas which were large enough for household subsistence and more suitable for cropping and raising livestock. The first settled group of Bor Krai village moved from Ja Bo village which is located to the north of the present Bor Krai village area. Initially, the intention was only for a temporary stay whereby they left their home in Ja Bo village to carry out cropping and raising livestock activities in what is now called the Bor Krai village. However, four households permanently settled in the area. In the meantime, Bor Krai village was unofficially established as village following the beliefs of Lahu culture whereby a village can be established if there are 3 complementary persons –leader, shaman, and iron craftsman. After that, more households gradually moved to Bor Krai village and acquired agricultural land. Since agricultural land is now fully occupied, migration to the village has been decreasing except for those who move due to marriage.

Currently, the population of the village is increasing because the villagers normally get married at a young age, 14-16 years old, and knowledge about birth control is limited. Consequently, population statistics show that during the last 5 years after population growth by migration has stopped the population increased by a growth rate of 1.7% while the average growth rate of Thailand was 0.82% in 2005 (National Economic and Social Development Board, 2006). Also, statistics show an unbalance of age structure whereby approximately 47% of the total population are less than 20 years old (Figure 5). Since this area is located in the National Protected Forest area, an expansion of the cultivated area to meet consumption needs is not allowed and is controlled by forest officers. Consequently, the existing agricultural lands are intensively used and this is observed by a reduction of the fallow period from conventionally 4-5 years to 2-3 years. This pressure is leading to land degradation and environmental problems which will effect resource management in the future.

Additionally, the village’s current interior administration is still in development since the conventional village administration has been arranged into the same structure as the statute of the Ministry of Interior. The village’s leader is equivalent to the village headman in the Ministry’s administrative structure. Since the current village leader is accepted and there is no divergence of opinions, he takes charge as village headman and is recognized as the Ministry of Interior officer at village level. However, there is a development concerning the administrative opinion according to some positions e.g. two positions of village’s representatives in Tambol (sub-district) Administrative Office (TAO). These two representatives are selected by the villagers by election. In the past, those who had more relatives tended to be elected and because of this, some of the village developments which were to be carried out through TAO by these representatives were not fulfilled. This is partially because the representatives elected did not have the knowledge and understanding of the role of village representatives and only pursued their family fame. Nevertheless, in the last election of 2005, the villagers were more cautions in regard to these positions and only elected new and younger generations who had more knowledge and capability regarding village development.

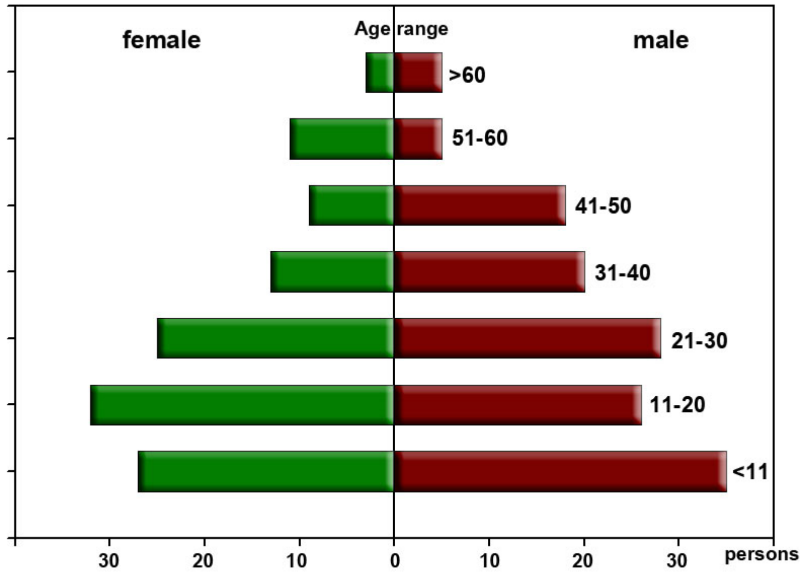


Figure 5: Age structure of Bor Krai village's population in 2005
Source: Field surveyed data, 2005

3.1.3 Internal institutions of Bor Krai village

Formally, the administration of Bor Krai village was carried out through a village committee under the leadership of the village headman. The village committee is arranged according to recommendations of the government office and consists of six sections i.e. welfare, monetary, security, education, health, and culture sections. However, the villagers practically manage village circumstances e.g. conflicts in land use, violence in relation to cultivated plots, collective mission, etc. through village meetings whereby all households have their representative. Most of the problems relating to conflicts and violence are solved through compromises relying on existing experiences and conventional rules and custom. At the same time, governmental obligations and announcements are also announced to all villagers through these meetings.

Further, Bor Krai village has many groups which are established under the supervision of several government offices. These groups include:

- Youth group whose purpose is to prevent involvement in drugs by participating in sports

- Saving group

- Touring service group which is established to arrange and promote traveling of village area to tourists

- Housewives group is intended to arrange and encourage weaving among the women

- Water source area conservation group is established to arrange and prevent encroachment of village's conservative forest areas

- Village rice fund which is established for collecting rice from all households and lending to villagers who are suffering from rice deficit

- Monetary groups which are established based on policies introduced to the village with the support of government officers. The most famous of these groups is known as one million baht fund and Kor-Khoe-Core-Jor fund (solving poverty fund).

However, there are some groups which are currently not active and some are operating using different approaches towards meeting their goals especially monetary funds. At first, the monetary funds were established to provide money towards villagers' agricultural productions but those who obtained loans used them for other purposes such as household consumption, re-crediting, buying of household equipments, etc.

3.1.4 Collective management of resources

Water resource

In Bor Krai village, 99% of the agricultural land is rainfed. There are some few plots, about 1%, which are irrigated in the wet and dry season[1] through two ponds, which were created by the research project, the Uplands Program, which conducted experiments of crop production in the dry season. The ponds are supplied by Sam Ya and Tong Tueng springs respectively. However, irrigated production in dry season was not successful in the first and second year because crops were damaged by low temperature during the months of December to February.

Though most of the village area is rainfed area there are other natural sources of water from 16 springs which are 1) Kong Pag, 2) Nam Kued, 3) Tong Tung, 4) Kok Muh, 5) Na

[1] Wet season covers around May – October and dry season covers around November to April

Pag, 6) Pa Bue, 7) Ja Ka Nae, 8) Hang, 9) Ja Yor, 10) Sam Ya, 11) Pi Ta, 12) Baan 13) Kau, Rai, 14) Ja Nae Toy, 15) Bor Krai, and 16) Sattha tributary.

These springs supply the water to its tributary which is around 50-250 meters long varying with the springs and after which it disappears into the natural hole. Almost all the springs are not important to the village's crop farming but only for raising livestock. This is because of the location of the agricultural plots thus limiting irrigation and also due to an inadequate amount of water even in wet seasons. Irrigation of this area needs development of ponds to store water such as those established by the Uplands Program research. However, there is a need for further research to find out the consequences of such developments on social, economic, and environmental perspectives.

The villagers use the water from the springs for domestic use and consumption especially from Nam Kued spring which originates from the village's conservation forest area. The villagers have created concrete ponds for storage. They have also used the mountain water supply system to distribute water to a public outlet in the village for domestic use and consumption. The villagers cannot use the water from this source throughout the year because of water shortage in the dry season. When this outlet is dry, the villagers turn to other springs which have temporary ponds. However, if these springs do not have adequate water the villagers fetch water from Rang river which is located around 3 kilometers south of the village.

Forest resource

In Bor Krai village, villagers have determined the forest areas around the village according to their utilization purposes. The forest area is separated into the area of village's conservative forest. This area is originated area of Nam Kued spring which is the most important water source for consumption. This area is used by villagers for gathering forest products, for gathering forest wood, and as a cemetery. In addition, there are collective obligations and penalties regarding encroachment and forest product exploitation and there is a collective role of the villagers in conservation and protection of the forest area and forest products.

Land resource

In Bor Krai village, 85% of the total cultivated area is utilized for annual crops and 15% for perennial crops. The perennial plots are used for fruit trees i.e. mangoes, peaches, jack fruits, apricots, and citrus. Seeds of these fruit crops are supplied and supported by the government officers and NGOs. The annual plots are rotating use known as shifting cultivation by usually two years of cropping followed by three years of fallow.

In the first year after fallow, the plots are used to grow upland rice mixed with either local beans, melons, or vegetables such as chili, parsley, and local lettuce. In the second year, the plots are used to grow maize which is mixed with either local bean or pumpkin. In the third to the fifth year, the plots are left in order to recover their structure and fertility.

However, some households may use the land intensively by taking shorter fallow periods (1-2 years) because of their limitation of land and due to the fact that expansion of cultivated land is not allowed. Expansion of land is controlled by forest officers and the village's collective obligations of using the area. Consequently, intensive cultivation under this pressure can be observed mainly because of increasing population and limited availability of land. Because of this increasing intensity of land use, land degradation tends to occur in the long run (Gypmantasiri and Amaruekachoke, 1995; Ratanawaraha, 1995).

3.1.5 Socioeconomic characteristics of households

In this section, socioeconomic characteristics of the 32 households sampled in the survey are discussed.

Household members

Based on the surveyed data, all the 32 households sampled are Black Lahu of which 97% are animism and the remaining 3% are Christians. The average age of the household head is 36 years old and about 56% of the total are illiterate and non-educated. The main source of cash for the households is from livestock production, crop production, and gathering of forest products (Table 2 and Table 3).

About 79% of the sampled households migrated from Ja Bo village which is located to the north of Bor Krai village. They moved to this area in search of more agricultural land or due to marriage. About 75% of the sampled households settled in this area 20 years ago, the rest settled 20-40 years ago (Table 4).

The average number of household members is five persons. The average number of household members within the labour age, that is, between 15-60 years old is three persons, non-labour age (less than five years old) is one person, between 6-14 years old is one person while those who are more than 60 years old is also one person. In addition, the average number of members who work on-farm is two persons while an average of one person either works in on-farm or off-farm activities (Table 5 and Table 6).

Table 2: Education of Bor Krai village household samples in 2003

Items	%
Education	
- Illiterate	56.25
- Primary school (foundation stage)	9.37
- Primary school (orientation stage)	25.00
- Secondary school	9.38
Total	100.00

Source: Praneetvatakul and Sirijinda, 2005

Table 3: Occupation of Bor Krai village household samples in 2003

Occupation	**Main occupation**[2]	**Secondary occupation**[3]
1) Farmer (annual crop production)	6.25	37.50
2) Farmer (fruit tree production)	3.12	-
3) Off-farm hiring out labour	9.38	-
4) Raising livestock	62.50	18.75
5) Trading	6.25	3.13
6) Gathering forest products	9.38	34.37
7) Tourism	3.12	-
8) Weaving	-	6.25
Total	100.00	100.00

Source: Praneetvatakul and Sirijinda, 2005

[2] This is determined by source of cash obtained
[3] This is determined by source of cash obtained

Table 4: Settlement information of Bor Krai village household samples in 2003

Items	**%**
1) Settlement duration	
- less than 21 years	75.00
- 21 – 40 years	25.00
Sub total	100.00
2) Migration to this area	
- no migration (born in this area)	12.50
- less than 21 years	75.00
- 21 – 40 years	12.50
Sub total	100.00
3) Original place before migration to the area	
- Ja Bo village	78.58
- Luk Kao Lam village	3.57
- Mae Say district in Chiang Rai province	3.57
- Pa Ka Noi village	3.57
- Union of Myanmar	3.57
- Huy Hier village	3.57
- Huay Sang Nai village	3.57
Sub total	100.00
4) Reason of migration to this area	
- induction by relatives or friends	9.38
- marriage to a person in this villager	18.74
- acquisition to agricultural land	31.24
- to work as hired labour	6.25
- accompanying with family	25.00
- getaway from an out break	3.13
- location of this area near district center	3.13
- to raise livestock	3.13
Sub total	100.00

Source: Praneetvatakul and Sirijinda, 2005

Table 5: Number of household members of Bor Krai village household samples in 2003

Items	Persons/household
Total number of members	4.50
Number of members aged 15-60 years old	2.75
Number of members aged less than 5 years old	0.78
Number of members aged 6-14 years old	0.84
Number of members age more than 60 years old	0.13

Source: Praneetvatakul and Sirijinda, 2005

Table 6: Working characteristics of household members of Bor Krai village household samples in 2003

Items	Persons/ household
1) Number of members working only in household agricultural activities	1.91
2) Number of members working in household agricultural activities and as on-farm hired labour	0.09
3) Number of members working in household agricultural activities and as off-farm hired labour	0.34
4) Number of members working in household agricultural activities and as on-farm and off-farm hired labour	0.16
5) Number of members working in household agricultural activities and trading	0.22
6) Number of members as non-workers	
- child	0.75
- student	0.91
- old members	0.12

Source: Praneetvatakul and Sirijinda, 2005

Land holding and utilization

The average size of land holdings among the households sampled is 4.13 ha with residential area occupying 0.28 ha and agricultural area 3.86 ha. About 94% of the land used by the households belongs to them while the remaining is borrowed from relatives or neighbours but is provided free of charge (Table 7).

Most of land, 89% of total, was acquired during the last 21 years. The rest has been owned for longer, about 21-40 years. About 56% of the total land was acquired during the settlement while approximately 40% was through inheritance, borrowing (3%), and buying (1%). However, since this area is located in the National Reserved Forest area, there is no land title for all types of land holding (Table 8).

About 99% of the land holdings are rainfed and therefore cultivation depends on the rain conditions. About 76% of total land is farmed through shifting cultivation including fallow period which is done year by year while 24% of total land is permanent plots without fallow period with fruit tree or annual crops. In the land which is farmed using shifting cultivation, 64 % had 1-3 years of fallow, 11% had 4-5 years while only 1% had more than 5 years of fallow.

Land under shifting cultivation is cropped for the first 1-2 years and then followed by 1-3 years of fallow depending on the available land. In the first year after fallow, the plot is cultivated with upland rice mixed with local beans, local melons, and sometimes different varieties of vegetables. Normally, cultivation is done during May to July (wet season) since the land has to be cleared and prepared in February or March. Harvesting is done in November to December depending on crop maturity. In the second year, the plot is used for growing maize mixed with local beans and pumpkin. After that, the plot is left for fallow (Table 9).

About 63% of the sampled households allocated agricultural land to annual crops and fruit trees, 28% allocated the land to only annual crops, 6% to annual crop together with fruit tree and vegetables while the remaining 3% allocated the land to annual crop together with vegetables (Table 10).

Table 7: Land holding characteristics of Bor Krai village household samples in 2003

Items	**Amount**
1) Total land holding size	4.13 ha
- Residential area	0.28 ha
- Agricultural area	3.856 ha
2) Land ownership	
- Farmer own the land	94.38%
- Rented from others free of charge	5.62%
Sub total	100%

Source: Praneetvatakul and Sirijinda, 2005

Table 8: Land attainment and title of Bor Krai village household samples in 2003

Items	**%**
1) Land attainment	
- acquisition	55.62
- buy	1.68
- inheritance	39.89
- borrowing	2.81
Sub total	100
2) Land attainment duration	
- less than 21 years	89.89
- 21– 40 years	10.11
- more than 40 years	0.00
Sub total	100
3) Land title	
- no title	100

Source: Praneetvatakul and Sirijinda, 2005

Table 9: Land utilization of Bor Krai village household samples in 2003

Items	Amount
1) Percentage of agricultural land utilization	
- shifting cultivation with 1-3 years fallow	63.96 %
- shifting cultivation with 4-5 years fallow	11.39 %
- shifting cultivation with more than 5 years fallow	0.63 %
- permanent cultivation by crop rotation	5.06 %
- permanent cultivation by mono cropping	18.99 %
Sub total	100 %
2) Agricultural land utilization	
- shifting cultivation with 1-3 years fallow	2.47 ha
- shifting cultivation with 4-5 years fallow	0.44 ha
- shifting cultivation with more than 5 years fallow	0.024 ha
- permanent cultivation by crop rotation	0.20 ha
- permanent cultivation by mono cropping	0.73 ha
Sub total	3.856 ha
3) Season of using agricultural land	
- wet season[4]	87.34 %
- wet and dry season	12.66 %
- dry season	0.00 %
Sub total	100 %
4) Source of water	
- rain	99.37 %
- rain, mountain supply and irrigation	0.63 %
Sub total	100 %

Source: Praneetvatakul and Sirijinda, 2005

[4] Wet season = May to October
Dry season = November to April

Table 10: Number of Bor Krai village household samples in 2003 as classified by crop grown

Items	Number of households	Share of household (%)
Only annual crop	9	28.12
Annual crop with vegetables	1	3.13
Annual crop with fruit trees	20	62.50
Annual crop with vegetables and fruit trees	2	6.25

Source: Praneetvatakul and Sirijinda, 2005

Note: vegetables consist of garlic, local lettuce, coriander
annual crops consist of upland rice, maize, corn
fruit trees consist of mango, pomelo, avocado, peach, apricot, coffee

Crop product distribution

In annual crop production, 41% of the products were stored for household consumption, 37% were used for feeding livestock, 3% were used as seed for the following year while the remaining 18% were sold to local people, customers and tourists on the local market (Table 11).

For vegetable products, 78% were sold in the village and on the local market, 15% was used for household consumption while 7% was used as seed. In the case of fruit products, 77% was sold in the village and on the local market and the remaining 23% was consumed by the households.

Table 11: Distribution of crop products of Bor Krai household samples in 2003

Items	Annual crops	Vegetables	Fruit trees
1) Number of samples (household)	32	3	22
2) Total income (Baht[5]/household)	16,531.93	3,403.33	4,303.38
3) Net income over cash cost (Baht /household)	15,837.00	3,239.00	3,213.15
4) Distribution of products (%)			
- consumption	41.45	14.36	22.58
- seed	3.27	10.45	0
- sell	17.96	75.19	76.55
- raising livestock	37.26	0	0.87
- storing	0.06	0	0
Sub total	100	100	100
5) Place of sale (%)			
- at the plot (farm)	1.14	0.00	22.73
- at the house	14.77	57.14	36.36
- local market	65.91	14.29	31.82
- Pang Ma Pha distict market	3.41	0.00	4.54
- Mae Hong Son province market	3.41	0.00	0.00
- at the plot and local market	2.27	0.00	4.55
- local and Pang Ma Pha district market	9.09	28.57	0.00
Sub total	100	100	100

Source: Praneetvatakul and Sirijinda, 2005

[5] Thai currency with 1 Baht equivalence to 0.02 Euro

Table 11: (continued)

Items	Annual crops	Vegetables	Fruit trees
6) Buyer (%)			
- villagers	26.14	85.71	22.73
- tourists	18.18	14.29	4.54
- traders in village	4.54	0.00	0.00
- traders from Pang Ma Pha district and Mae Hong Son province	10.23	0.00	40.91
- villagers and tourists	38.64	0.00	27.27
- tourist and traders of Pang Ma Pha district	2.27	0.00	4.55
Sub total	100	100	100
7) Transportation (%)			
- by farmer	71.59	42.86	22.73
- hire	3.41	0.00	0.00
- by buyer	25.00	57.14	77.27
Sub total	100	100	100
8) Total transportation cost (Baht[6]/household)	122.76	75.00	6.92

Source: Praneetvatakul and Sirijinda, 2005

Household income

The average net household income per year was 12,258.88 Baht. Net farm income was 11,519.79 Baht which was calculated from total farm income (36,531.26 Baht) minus total farm cost (25,011.47 Baht). Net household income comprises net farm income, net off-farm income (21,288.75 Baht) and private household expenditure (20,549.66 Baht) (Table 12).

[6] Thai currency with 1 Baht equivalence to 0.02 Euro

Table 12: Net household income of Bor Krai household samples in 2003

Items	Baht[7]/household
1) Total farm income	36,531.26
2) Total farm cost	25,011.47
3) Net farm income	11,519.79
4) Off-farm income	21,288.75
5) Total household private expenditure	20,549.66
6) Net off-farm income (4. – 5.)	739.09
7) Net household income (3. + 6.)	12,258.88

Source: Praneetvatakul and Sirijinda, 2005

Loan

About 84% of the sampled households had loans. 96% of them obtained the loan from financial institutions which are mainly the village funds and 4% from non financial institutions mainly neighbours and local financial companies. The average loan borrowed from financial institutions was 26,770 Baht. The most important sources are the village fund (one million Baht fund) and Kor-Khoe-Core-Jor fund (solving poverty fund). The main reason for borrowing is for the capital of livestock production. Usually, borrowing as a group instead of an individual assures the loan is repaid.

In the case of borrowing from non financial institutions such as neighbours and local financial companies, the average loan was 4,259 Baht. The reasons for borrowing from non financial institutions were to buy farm equipment and to use the funds for household consumption. In case of borrowing from neighbours, collateral is not required in contrast to borrowing from financial companies where borrowing as a group of persons is required to assure the loan is repaid (Table 13).

[7] Thai currency with 1 Baht equivalence to 0.02 Euro

Table 13: Loan characteristics of Bor Krai village household samples in 2003

Items	Amount
1) Number of household borrowing (households)	27
(Percentage of households borrowing)	84.38
2) Sources of loan	
2.1 Non-financial institutions	
(Percentage of household borrowing)	3.64
- neighbours (%)	50.00
- local finance company (%)	50.00
Sub total	100
2.1.1 Reason of borrowing	
- to buy farm equipment (%)	50.00
- for household consumption and expenditure, paying back existing loan, housing (%)	50.00
Sub total	100
2.1.2 Collateral	
- No collateral (%)	50.00
- group of persons (%)	50.00
Sub total	100
2.1.3 Amount of loan (Baht[8]/household)	4,259.26
2.1.4 Interest rate (% per year)	7.50
2.1.5 Interest payment (Baht/year/household)	222.22
2.1.6 Loan remaining (Baht/household)	3,518.52

Source: Praneetvatakul and Sirijinda, 2005

[8] Thai currency with 1 Baht equivalence to 0.02 Euro

Table 13: (continued)

Items	Amount
2.2 Financial institutions	
(Percentage of households borrowing)	96.36
- One million Baht fund (%)	43.39
- Kor-Khoe-Core-Jor fund (“solving poverty fund” in English) (%)	39.62
- TAO fund (%)	1.89
- Youth fund (%)	1.89
- Village fund (%)	3.77
- Rice bank fund (%)	1.89
- Her royal highness fund (%)	1.89
- OTOP fund (%)	5.66
Sub total	100
2.2.1 Reason of borrowing	
- For household consumption (%)	11.32
- To buy farm equipment (%)	5.66
- For emergency (%)	3.77
- For livestock production (%)	64.15
- For household expenditures, returning back exist loan, housing (%)	5.66
- To invest in trading (%)	7.55
- For crop and livestock production (%)	1.89
Sub total	100

Source: Praneetvatakul and Sirijinda, 2005

Table 13: (continued)

Items	Amount
2.2.2 Collateral	
- no collateral (%)	7.55
- group of persons	92.45
Sub total	100
2.2.3 Amount of loan (Baht[9]/household)	26,770.37
2.2.4 Interest rate (% per year)	
- one million Baht fund (% per year)	2.00
- Kor-Khoe-Core-Jor fund (solving poverty fund) (% per year)	0.00
- TAO fund (% per year)	0.00
- Youth fund (% per year)	0.00
- Village fund (% per year)	5.00
- Rice bank fund (% per year)	10.00
- Her royal highness fund (% per year)	0.00
- OTOP fund (% per year)	0.00
2.2.5 Interest payment (Baht/year/household)	403.70
2.2.6 Loan remaining (Baht/household)	26,325.93

Source: Praneetvatakul and Sirijinda, 2005

[9] Thai currency with 1 Baht equivalence to 0.02 Euro

3.2 Sustainability assessment and indicator determination

Application of the sustainability assessment in this study is performed through indicators representing the area's sustainability proceeded and captured in a Multi-agent systems (MAS) model. In this section, the sustainability assessment procedure and indicator determination are described. Also, the assumptions in relation to the study are presented.

3.2.1 Application of sustainability assessment

Application of sustainability assessment in this study is performed through indicators representing the sustainability of the study area. First and foremost, the sustainability situation corresponding to each indicator is individually assessed at a household level. After that, the overall sustainability evaluation at a village level is carried out relying on the consequences of the results at the household level. At the village level, the sustainability situation is presented by individual issue through each corresponding sustainability indicator. Also, the sustainability situation can be presented in the economic, social, and environmental condition which the groups of indicators under respective condition are used to assess sustainability for each condition. Besides, the sustainability situation of the area can be presented by using all defined indicators to assess the area's overall sustainability.

The concept and procedure of sustainability assessment applied here is relied on the collaboration research of Praneetvatakul and Sirijinda (2003) and Praneetvatakul and Sirijinda (2005) who carried out collaborative research between the Uplands Program of the University of Hohenheim, Germany and Kasetsart University, Thailand. Sustainability assessment application is adopted and based on Land Development Department (1998) whereby sustainability assessment and indicator determination are based on the International Framework for Evaluating Sustainable Land Management (FESLM) of FAO (Smyth and Dumanski, 1993).

After defining the indicators (detail in the section 3.2.2) and structuring the model, during simulation the corresponding data regarding the sustainability assessment are recorded and at the end of the year the sustainability assessment process is launched. At first, the process starts by considering the farm household performance at a household level and afterwards the sustainability situation at a village level is presented as an emergence of the area's farming systems. Results are emerged from the complexity of the system containing interactions between biophysical and socioeconomic components. Particularly, interactions can potentially occur between elements from either different components or the same component. For example, cultivation of crops on farm household plots represents interaction between elements of biophysical and socioeconomic components while passing information and acquisition of resources between farm households is considered as interaction of elements within socioeconomic component. The detail of sustainability assessment at the household and village level is described below.

Assessment of sustainability at household level

At the household level, the performance of individual households in regard to each corresponding indicator is evaluated. For each indicator, the household is scored and classified into 3 sustainable classes which are Sustained (S), Conditional sustained (C), and Non-sustained (N) depending on the defined threshold value. Then, the score corresponding to the class which the household belongs to is given to the household. In this study, the Conditional sustained (C) is considered as the sustainable class whereby the sustainability situation is likely to change to Non-sustained class (N) if performance in the future becomes worse (Praneetvatakul and Sirijinda, 2005). After scoring and classifying the household in all indicators, the summation of scores obtained by each household is calculated. The total score is used to assign the household into either Sustained (S), Conditional sustained (C), or Non-sustained (N) class in regard to all indicators. In order to classify them, threshold values are identified based on the sustainable score previously given for each indicator class which can be expressed as;

$$\text{MinValue} = \sum_{i=1}^{n} \left(SC_{N\max}^{i} + SC_{C\min}^{i} \right) \Big/ 2$$

$$\text{MaxValue} = \sum_{i=1}^{n} \left(SC_{C\max}^{i} + SC_{S\min}^{i} \right) \Big/ 2$$

where;

$SC_{N\max}^{i}$ = Maximum score of Non-sustained classes of indicator i; i = 1, 2, 3,…, n

$SC_{C\min}^{i}$ = Minimum score of Conditional sustained classes of indicator i

$SC^{i}_{C\max}$ = Maximum score of Conditional sustained classes of indicator i

$SC^{i}_{S\min}$ = Minimum score of Sustained classes of indicator i

Classification can be made by considering the total score obtained by each farm household compared to these threshold values. A farm household is classified into the Non-sustained class (N) when the obtained total score is lower than MinValue while the farm household is classified into Conditional sustained class (C) if the obtained total score is between MinValue and MaxValue. And, if the obtained total score is above MaxValue a farm household is classified into the Sustained class (S). In addition, with long run simulation the number of households belonging to each sustainable class and its dynamic are extrapolated and used for sustainability assessment at the village level.

Assessment of sustainability at the village level

The results of the sustainability assessment at the household level are used for assessment at the village level. At first, the Sustainability index (SI) of each indicator is calculated in order to represent the situation of sustainability of the corresponding indicator issue. Afterwards, the SI of all indicators is used to identify the Performance index (PI) to represent the area's overall sustainability situation. In addition, the PI of economic, social, and environmental indicators is carried out so that representation of sustainability situation can be compared to different components of sustainability.

As sustainability of farming systems in this study is defined as "the capacity of farming systems to maintain or enhance their certain level of performance or output over time in order to satisfy the need of relevant stakeholders while quality or supply of resources and environment is maintained or improved", the sustainability situation of farming systems at the first year of simulation (2003) is set as a benchmark and is used to compare trends of change of system aspects representing area's sustainability over time. In addition, two assumptions regarding the reference year of observation based on the study framework and surveyed data are set up as;

1) The first year of simulation (2003) is considered as normal year under socioeconomic and biophysical normal condition

2) The household performance in the first year of simulation (2003) is at a normal level under normal conditions as assumed in the previous assumption.

The SI of each indicator is calculated which can be expressed as;

$$SI^i = \frac{SSC^i}{MPSC^i} \times 100$$

where;

SI^i = Sustainability index of indicator i

SSC^i = $\sum_{j=1}^{m}(SC_j^i \times NH_j^i)$

SSC^i = Sustainability score of indicator i; (i = 1, 2, 3,…,n)

SC_j^i = Sustainable coefficient of indicator i and Sustainable class j (j = 1, 2, 3,…,m)

NH_j^i = No. of households classified in Sustainable class j of indicator i

$MPSC^i$ = Maximum possible value of SSC^i

The SIs of all indicators are calculated which the values can be used to compare among indicators at each point of time in order to determine and rank sustainability issues which need to be improved. A higher value means that the issue under concern is relatively more sustainable at each point of time but it cannot be concluded that the farming systems is sustainable for this issue. However, this question can be addressed by the SI results observed over the entire period. As the procedure of SI calculation is carried out every year in the simulation, the dynamic of the SI of each indicator determines development of sustainability. The dynamic of SI determines also whether area's farming systems is sustainable concerning to corresponding indicator issue based on definition and assumptions of sustainability assessment of this study. Development of SIs over time is also compared to each other so that the priority of unsustainability issues can be determined. A SI which declines rapidly is recognized as an undesirable situation which potentially contributes to overall unsustainability of the system.

In order to figure out the overall area's sustainability situation, the PI of all indicators is calculated using the maximum score of indicators and SIs result. The expression is determined as;

$$PI^n = \frac{\sum_{i=1}^{n} PFV^i}{MPPV^n} \times 100$$

where;

PI^n = Performance index when considering all indicators (n) and indicators in each condition

PFV^i = $MSBS^i \times SSC^i$

PFV^i = Performance value of indicator i

$MSBS^i$ = Maximum sustainable score of indicator i

$MPPV^n$ = Maximum possible value of sum of Performance value of all indicators ($\sum_{i=1}^{n} PFV^i$)

In addition, using the same procedure the PIs of each indicator condition –economic, social, and environment– are also calculated. However, only the information regarding the issue under concern is considered in this calculation. The PI development can be used to determine whether the area's farming systems is sustainable. Declining development over time indicates unsustainability of the farm area performance in regard to all indicators representing economic, social, and environmental conditions. Moreover, unsustainable aspects will be severe if the decline is very fast. However, an increase or slow decline of PI is considered as an improvement of the area's sustainability. Particularly, the PI and its progression of each sustainability condition represent a comparative situation of sustainability in the three conditions. A relative high and increasing progression of PI shows a sustainable and preferable situation of the condition compared to the others. However, in this study since the assumption was that all indicators are considered of equal importance of the sustainability issue, a change of one indicator will potentially affect the overall area's sustainability.

The simulation results under current conditions of the study area are set as the results of baseline scenario. These results are later analyzed as support information in order to develop the policy scenario which is intended to improve the area's sustainability. The policy scenario is simulated and the result will be compared to the baseline scenario to indicate and support prospective achievement of the policy. Furthermore, the baseline scenario results will be used for comparison with the other scenarios that assume changes of the economic and biophysical factors.

3.2.2 Sustainability indicator determination

Framework of indicator determination

Sustainability of farming systems of the area is assessed through defined indicators. Therefore, these indicators are determined in order to represent a sustainable situation. In this section, the framework to guide the determination of indicators is developed. The indicators representing sustainability of the study area are developed and selected within the framework. An important consideration in the selection of indicators is to ensure that there are sufficient indicators to represent the area's sustainability. In addition, other important factors used to determine the indicators in this study are the significant circumstances of the area sustainability, applicability to study framework and objectives, data availability and management, scientific quality, selected literatures, as well as stakeholder participation (Becker, 1997; Segnestam, 1999; Maglinao, 2000; van der Werf and Petit, 2002). The details of these are presented as follows.

1) Representation of area's sustainability:

The indicators should represent the area's sustainability situation relying on the concept and definition which as proposed in Bundland report (United Nations, 1987) that sustainable development should not only consider economic progression but should take environmental and social conditions into account. Thus, the indicators should cover all 3 dimensions –the economic, social, and environmental dimensions. Furthermore, agricultural land is the most important resource of farming systems and it is the critical issue of the study area that is located in the National Protected Forest area where the land resource is limited. In future, land resource use is under risk of intensive use due to population growth. Management of land towards sustainability should therefore be a concern. Consequently, this study will also consider the concept of an International Framework for the Evaluation of Sustainable Land Management (FESLM) of FAO proposed by Smyth and Dumanski (1993). This will involve development sustainability indicators based on 5 pillars which are:

i. Productivity; maintaining or enhancing production/services

ii. Security; preserving balance between a land use and prevailing environmental conditions and reducing the risks of production

iii. Protection; protecting soil and water resources and conserving priorities such as the need to maintain genetic diversity or preserve individual plant or animal species

iv. Viability; considering being economically viable

v. Acceptability; concerning being socially acceptable.

2) Significant circumstance of the area’s sustainability:

Farming systems of the study area are performed in mountainous areas. Therefore, cultivation or land utilization on this slope land potentially induces leaching and soil erosion. In addition, the slash and burn technique is also typically applied in the area. After burning the land, it is left bare and this leads to severe erosion at the beginning of rainy season due to heavy rains. Therefore, the issue of soil erosion needs to be considered in order to monitor change over time which indicates the trend of erosion on sustainability in study area.

In addition, as the farming systems of the study area subsistence based, the growth of population under limitation of land means that the land resource tends to be more intensively used to meet consumption. Intensive land use with a shortened fallow period does not allow recovery of soil fertility and can lead to serious problems of land degradation (Gypmantasiri and Amaruekachoke, 1995) and this in turn affects land productivity and household income. Accordingly, the issue of fallow period should also be investigated to illustrate the change of fallow period on land use over time. In addition, with increased household consumption needs, food security is important to the well being of the villagers.

Since sustainability of the study area is affected by many factors, the farm household is also affected. The performance of the households is important because they are the center of farming systems. Therefore, it is crucial to examine household income and farm income so that the trend of the households’ welfare and economic viability can be observed over time.

3) Applicability to study framework and objectives:

The objective of this study intends to evaluate the sustainability of the study area through the MAS simulation model which takes into account the heterogeneity and interaction of the elements in farming systems. To assess sustainability, the application method in this study is proceeded by an evaluation of the global or village sustainability situation through household performance. Results of household performance in all potential issues are evaluated and then performance percentage at global or village level known as Sustainability index and Performance index are determined. In addition, these results are extrapolated over time to show the dynamic of the area's sustainability. To support the methodology, the potential indicators are developed using a bottom-up approach at the household level. Moreover, in order to fit well with the evaluation of the area's sustainability, the dynamic and explicit cause-effect of indicators will be taken into account.

4) Data availability and management:

The application of this study is part of a interdisciplinary research. Integrating all aspects or indicators to represent and evaluate sustainability under all disciplines is ideally perfect and preferable for this study. However, to do so a huge amount of data and information as well as field experiment time are required. Due to limitations of time and data availability for this study, only the significant aspects are selected and incorporated into the integrated model. In addition, to determine indicators data management issue is also taken into account (Becker, 1997). In this sense, uncomplicated measurement and interpretation of the available data is desirable. Further, indicators should be quantifiable, acceptable, and transparent. Also, the defined indicators should be relevant and appropriate with the users, mainly the researcher and the stakeholders.

5) Scientific quality:

The scientific quality of the indicators is also taken into account. The defined indicators will be invented explicitly and unambiguously to measure the aspects and issues that they are supposed to be detected. (Becker, 1997).

6) Selected literatures:

Selected literatures of sustainability assessment through indicators in mountainous area of Thailand are reviewed, including: Gypmantasiri and Amaruekachoke (1995), Santasombat (1995), Pushparajah (1995), Land Development Department (1998), Praneetvatakul et al. (2001), Praneetvatakul and Sirijinda (2003), Praneetvatakul and Sirijinda (2005). International literatures of sustainability assessment through indicators include the selected studies of Müller (1997), Carney (1998), Segnestam (1999), Division for Sustainable Development (2001), van der Werf and Petit (2002), Osuntogun (2002), Segnestam (2002), Shyamsundar (2002), North and Hewes (2003), and Mathijs and

Wauters (2004). These literatures will be reviewed and all indicators of these will be listed and selected by considering their relevance to criteria set above. In addition, the concept of indicator measurements of these literatures can be used and applied to develop the indicators which are the best fit and most suitable to measure sustainability in this study.

7) The stakeholder participation:

This study will also involve participation of all stakeholders who are involved and have potential to influence and determine changes of farming systems in the study area. The farm households are considered as the most important element of the systems and therefore their suggestions and perspectives are taken into account. In addition, the government agencies, local organization, NGOs, as well as the researchers playing an important role in the area are also considered as stakeholders whose suggestions will be considered to develop the indicators. Through interview from field survey, group session discussion carried out during the study period, and observation of the researcher, the suggestion from many perspectives will be considered in order to determine sustainability indicators of this study.

Defined indicators

Based on the framework of sustainability determination, in this study sustainability indicators are selected and developed which cover economic, social and environment condition as follows.

Condition	**Selected indicators**
Economic condition	1) Household income (Baht/household/year) 2) Net farm income (Baht/household/year) 3) Household capital (Baht/household/year) 4) Household saving (Baht/household/year)
Social condition	1) Food security (Kg/year)
Environmental condition	1) Top-soil erosion (ton/ha/year) 2) Fallow period (years)

Determination of these indicators is based on the conceptual framework of indicator determination explained previously. The objectives, implications, and interpretation of these indicators are described as follows.

Economic condition

For the economic indicators, household income indicator is presented in Baht per year. The indicator is determined to represent and capture economic viability of the household in all on-farm and off-farm activities. In each year of the simulation, household income is calculated and can be expressed as;

Household income = Net farm income + Net off-farm income

The net farm income is determined by summation of net income from crop and livestock activities. For each activity, calculation of net income can be expressed as;

Net income = total revenue – variable cost – fixed cost

Total income of each crop activity is obtained by multiplying crop price by the quantity of crop products. Crop prices are the monthly prices which vary in each month based on the statistical average percentage change of price in each month compared to the average price for the corresponding year. In addition, average crop price of each year will be adjusted by price regression trend estimated from statistic data. Detail of each crop price determination will be presented in section 3.3.4. For livestock prices, the animal which is sold or consumed is calculated based on the livestock age. The price for each animal age is determined based on the surveyed data. The total income of farm activities will be deducted from its cost. The cost consists of variable costs which are input cost and hired labour cost and fixed costs which are interest cost of money as well as repairs and depreciation costs. Each cost item will be increased over time based on the trend of the Producer Price Index (PPI) of the relevant cost item. The detail of cost determination is explained in the section 3.3.4 which deals with assumptions.

The net off-farm income of the household is calculated by summing all the net income obtained from off-farm activities which is the hire of labour and the gathering of forest products.

In each year, household income is calculated and then the household will be scored and classified into sustainable classes relying on their performance. After that, Sustainability index (SI) of this indicator is quantified based on the performance of all households of the area. The SI will present sustainability situation of the study area for this issue. Increases over time of the number of households in a higher sustained class and increase of SI of household income indicator shows a preferable economic sustainability situation. In contrast, a decline in these aspects will be interpreted as being a more unsustainable situation for this item in the study area. In addition, to analyze and interpret about sustainability situation the detail of related factors and information that have caused the change in the sustainability situation and household behaviour are taken into account.

The second indicator of economic condition is net farm income which is defined to capture and represent economically sustainable aspects. Also, this will show viability of households who pursue their livelihoods by farming. The farming performance is therefore important and interesting in indicating sustainability situation of study area. During simulation, net farm income of the household is calculated in Baht per year. Calculation for net farm income is a partial calculation of household income which considers only farm household activities. Therefore, the calculation will be the same as calculation of net farm income of household income indicator. After that, sustainability evaluation process is pursued in the same procedure as household income indicator. All households will be scored and classified into sustainable classes relying on their net farm income. The SI will be calculated from the number of households in each sustainable class. After long run simulation, the results will be shown where a preferable outcome is an increase over time of the number of households in a sustainable class and increasing of SI of net farm income indicator. If the reverse occurs this is defined an unsustainable situation in relation to net farm income.

For the household capital indicator, an indicator is used to determine situation of household capital which is a significant aspect of area's subsistence farming. Having more capital stock leads to a more secure situation that tends to be sustainable in long run. In each year of simulation, the capital of household will be captured and calculated from the household's agricultural goods which can potentially be used as capital goods in production processes and as the sources of cash generation. The goods consist of crop products which are rice and maize stored in the household product store and livestock products which are adult of pigs, cows, and buffalos remaining to the household. The monetary value of these products is based on their amount and prices determined at the precise time when sustainability evaluation is taking place. Positive progression over time of number of household in higher sustainable class and the SI indicate a sustainable situation regarding the household capital while a decline in these two figures show an unsustainable situation for the area.

The last indicator of economic indicators is household saving indicator. The indicator is used to evaluate sustainability of a household's cash acquisition over a considerable time period. Calculation for this indicator is based on the net cash household income and executed in the end of the every year of period. Items and detail of calculation are very similar to the calculation of household income but for this indicator the household cash income will be deducted by household private expenditures which consist of cash expenses for household consumption, interest of borrowing money, and returning debt borrowed before simulation period. Calculation of this indicator can be expressed as;

Household saving = Household cash income – Household private cash expenditure

while;

Household cash income = Net cash farm income + Net cash off-farm income

All items required for calculation are determined based on the same concept and assumptions of the household income indicator. In addition, interpretation of this indicator will be made in the same way as the three previous indicators of this condition. The positive progression over time of the number of households into a sustainable class and of SI value indicates a more sustainable situation for the study area for this issue. Change of these values in a negative way through the time period illustrates increase in unsustainable situation which is rather similar to interpretation of the other indicators for economic condition.

Social condition

The food security indicator is only the indicator used to represent sustainability situation of the area's social condition. Sufficient rice for consumption by the household is the most significant aspect of the subsistence farming system. Sufficiency in this case means that the amount of production can serve consumption needs of the household. Especially, farming system of this study area is rather limited and most of the farm activities are production for consumption. At the same time, production of cash crops is limited by land fertility and suitability limitation. Therefore, household consumption relies mostly on farm products where rice is the main food crop. Capturing an increase over time of a lack of the total amount of rice can be interpreted that the farm households are in a unsustainable situation and they have to acquire rice from the other sources such as borrowing and buying rice to consume. As so, the result will show a decrease over time of household number in a sustainable class and the SI value of food security as consequence of lacking rice. In addition, an increasing lack of rice will raise a signal to the households to re-allocate their resources in agricultural lands and therefore there will be increasingly use of agricultural land in rice production. Production of the competitive crop of maize will be limited with a reduced cropping area. The consequence of limited maize production also affects livestock production especially piglet production which is the most important source for cash for the households in the area. Therefore, an increase in the non-sustainable food security probably tends to generate the impacts on other activities of the household and other elements of farming systems. In contrast, a decrease in lack of rice increases the ability of the farm households to produce food crop to meet their consumption needs. And, the farm households can pursue their livelihood in subsistence way as long as the technology of farming systems is still not changed.

Environment condition

Two indicators which are top-soil erosion and fallow period are used to indicate the sustainability in terms of environmental conditions. The top-soil erosion indicator applied here is obviously important because the farming systems are performing on slope land where leaching and soil erosion potentially occurs. Capturing and monitoring the amount of soil erosion therefore are useful and can increase consciousness in the area which can be promoted to get common point of views between stakeholders in order to avoid future land degradation. In each year of the simulation, the amount of top-soil erosion of each household is quantified at a plot level from all plots used through the Universal Soil Loss Equation (USLE) model (Wischmeier and Smith, 1978). The result is in the tones per hectare per year which determines the amount of soil erosion generated by farm activities all year round. By implication, the household which is farming on the land which has a relatively higher slope and poor soil erosive resistance will potentially generate higher amount of erosion. Having positive development of a number of households in the sustainable class and of SI over time results in a more sustainable situation at village level regarding soil erosion. In opposition, generating more top-soil erosion in general will lead to an unsustainable situation of the area where the number of households in a sustained class and SI of top-soil erosion indicator are declining. With this situation in long run, the area is under risk of land degradation which potentially affects productivity in the future (Place and Dewees, 1999; van Noordwijk, 1999; Szott et al., 1999).

The other indicator of this condition is fallow period indicator. The average time period of households leaving their land fallow is captured and evaluated. A long fallow period will induce recovery and improvement of soil physical structure and fertility (Szott et al., 1999). However, agricultural land in study area is being used under pressure of population growth. Intensive use of land by shorten fallow period tends to occur and this will potentially bring about soil degradation and decrease of productivity (Place and Dewees, 1999; van Noordwijk, 1999). With simulation, results of agricultural land use and behaviour of farm household in regard to leaving land fallow are observed. The result of long average fallow period is considered as a preferable aspect contributing to sustainability situation of the area. At the village level, an increasing number of households in the sustainable class and SI value over time are considered as indicators of a sustainable situation. In the contrary, declining over time of these values indicates an unsustainable situation in the long run.

Sustainable class determination

To classify the farm household into sustainable class, the threshold values are set as reference values to illustrate how far is the area’s sustainability and sustainable situation (Müller, 1997). Identification of threshold values is substantial as there are no standard threshold values representing a sustainable situation for all aspects. In addition, in some issues, for example the household income, the threshold values are set by not only the area sustainability but also by the concept of the indicator application to serve particular purposes of research. However, there are alternatives for setting threshold values that are critical values, target values, historical values, norms, tendencies, and average values (Müller, 1997).

The critical values or threshold values of indicators are scientifically defined which are less subjective. The observed value which is higher than the critical value is expected to generate negative impacts influencing sustainability of the whole system. However, the threshold values for some aspects e.g. tolerable soil erosion, tolerable level of substances in water and air are still under scientific discussion. Therefore, there is limitation in deriving the values which are scientifically proved and can be used to serve as indicators for particular research. Thus, it is often that these values are politically determined as target values.

The target values are identified as certain standards setting by the government. These values are developed and supposed to be accepted and represent balance between interests of different various groups. However, these values cannot guarantee achievement of a sustainable situation especially for environmental issues where probably the powerful interest groups can prevent identification of the significant limits.

Historical values are politically determined by setting the values in some year in the past to be limit values. For instance, the Dutch Government uses the year 1930 as reference values to monitor the quality of water in the North Sea. However, there are some arguments as to whether the values in that year represent a sustainable situation.

The threshold values probably are defined based on norms by the legal international organization such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO) or other institutions. However, for some socioeconomic indicators e.g. wages, the normative threshold values are set based on basic needs of people and are normally varied by country. Sometimes, this concept of setting falls in the category of target values.

Tendencies are an option provided in case that there is no available threshold value from the previous options. However, this alternative is not based on the evaluation concept and cannot give information as to whether the system is sustainable. This gives only a rough idea of a systems' position relative to past development and relative to similar system, for example, tendencies in soil loss, tendencies in income level and distribution, etc.

The last option to set the threshold values is using average values of similar systems. This option is also possible and useful in the case where there is an absence of other threshold values. The average values in relation to the indicators of similar systems will be used in order to compare the system's sustainability situation to the similar one. For example, the net farm income of northern Thailand is compared to the net farm income of the entire region of Thailand.

For this study, identifying of the threshold values is based on the purposes and assumptions of the study in determining sustainability aspect of the study area. The criteria applied to identify the values are different for each indicator. Also, for each indicator different sustainable scores will be set for different sustainable classes whereby the higher score will be given to the class which is in a higher sustainable class. In the simulation, the households will be classified into defined sustainable classes and given scores corresponding to their performance relative to the corresponding indicator. However, for this study the importance of all issues represented by relevant indicators is given equal weight with the highest score of all indicators for Sustained class (S) set as 10. And, for the other lower sustainable classes they will be given a lower score respectively. Details of sustainable class and threshold value determination are described as follows.

Economic indicators

1) Household income indicator:

This indicator is determined in order to monitor the economic viability of farm households in the study area. Since this indicator is applied to the subsistence farming system area, the threshold value identification is intended to represent and observe the earning of income by the household to cover their living cost expenses. Therefore, the concept of poverty is applied to determine the threshold for this indicator. Absolute and relative poverty line concepts (Duclos and Araar, 2006) are employed in order to determine sustainable classes. At first, the target value option of setting threshold values is applied. The absolute poverty line concept which is normally applied to determine the minimum cost of living standard in Thailand is used to determine the threshold value of the sustained class. This means that a household which has the ability to generate income to reach the minimum cost of living standard shows a sustainable situation. This threshold value is set by using the official secondary data of the Thai government agency, National Economic and Social Development Board of Thailand (2003), which presents the minimum cost of living standard or absolute poverty line of Lahu ethnic minority in northern Thailand in 1999 adjusted by trend of change of statistic official poverty line to estimate the absolute poverty line of Lahu in 2003.

For the other sustainable classes, the concept of relative poverty line is applied. Household income distribution from simulation results of the first year (2003) are used to determine the threshold values in regard to their income distribution. The threshold value for Non-sustained class (N) will be first determined and then for Conditional sustained class (C). The threshold value of Non-sustained class (N) is set by using the relative poverty line value.

For this study, the simple way of determining relative poverty line is used which it can be determine at the half of median of household income of all households (National Economic and Social Development Board of Thailand, 2004). The household that obtains their household income lower than this value are considered as poor as compared to other households within the same village. They only generate a low level of income compared to the relative minimum living standard cost of the same household in a similar environment and living conditions. Therefore, these households will be considered into Non-sustained class (N) which shows an unviable economic situation. Further, between the threshold values of Sustained (S) and Non-sustained (N) classes the median income value of household income of all households is set as a threshold value which divides the differences of these two values into two intervals. The households obtaining income between these two intervals are classified into Conditional sustained class (C). The households with higher household income than the median income value will be given higher sustainable score than the one obtaining household income lower than the median income value. By these criteria, the threshold values and sustainable score can be identified as follows.

Household income (Unit: Baht[10]/household/year)	Sustainable score	Sustainable class
< 35,105	0	N
35,105 – 45,000	4	C
45,001 – 56,621	6	C
> 56,621	10	S

In addition, these threshold values are adjusted at each point of time during simulation to be consistent with the change over time of prices and costs taken by households. Thus, the thresholds are adjusted by the trend of Consumer Price Index (CPI) which represents the rate of change of goods and services bought by the consumer. The trend of CPI is estimated based on statistic data of CPI from 1990 to 2006 of the Bureau of Trade and Economic Indices, Ministry of Commerce of Thailand. Adjustment of these thresholds intends to adapt the threshold values to represent change of living standard cost over time while the household income is adjusted over time as prices and costs change.

[10] Thai currency with 1 Baht equivalence to 0.02 Euro

2) Net farm income indicator

This indicator is used to monitor economic viability of the household's net income especially from farm activities. As they are mainly pursuing their livelihood by agriculture, the performance of farming and its dynamic are rather interesting as this is the main activities to generate household income and consumption.

At the beginning, the concept of average values to set the threshold value of Sustained class (S) is applied. The available data of average net farm income of farmers in northern Thailand in 2004 of the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives of Thailand, is set as the threshold. If the household in the study area obtains higher net farm income than the value from the Ministry, then their performance in farming is preferable as compared to a farmer living in the same environmental conditions of the region. For the other sustainable classes, the concept of relative income is applied based on the first year (2003) net farm income simulation result of all households. The simple way of determining relative poverty line is adopted with the value at half of the median of net farm income of all households used. The households with lower performance in generating net farm income than this will be considered into Non-sustained class (N). This means that they have low performance of farming compared not only to the farmer in the whole region, northern Thailand, but also within their village. Between the threshold values of Sustained and Non-sustained class, the median of net farm income of all households is set to divide the Conditional sustained class (C) into two classes with different sustainable score whereby the class with higher sustainable score represents having a more sustainable situation. Relying on these criteria, the threshold values can be presented as follows.

Net farm income (Unit: Baht[11]/household/year)	Sustainable score	Sustainable class
< 13,000	0	N
13,001 – 25,000	4	C
25,001 – 42,000	6	C
> 42,000	10	S

Furthermore, during simulation these threshold values are adjusted by trend of inflation rate estimated by statistic data from 1996 to 2006 of the Bank of Thailand.

[11] Thai currency with 1 Baht equivalence to 0.02 Euro

Adjustment is applied here in order to eliminate the illusion of getting better net farm income sustainability situation over time due to an increase in prices.

3) Household capital indicator

The household capital indicator is defined to capture stored capital farm goods of the farm household. Generally, a subsistence farm household will store farm products which can be considered as capital goods that can be used in the production process and can also be used to generate cash for the household. In the case of subsistence farming, having higher stored capital farm goods is a preferable aspect which implies being in a more secure situation in case the stored goods are required. So, situation and dynamic over time of capital goods is quite interesting especially for subsistence farming system.

Unfortunately, under this issue there is no available sustainability threshold value. Therefore, for this study a relative concept is applied to classify sustainable class based on the relative situation of all households. The first year (2003) simulation household capital result of all households are arranged in ascending order. The threshold values will be set by using the capital value of these households at each 20% of households which is about 12 households each. The first interval is considered as having lowest sustainability situation compared to all households while the further intervals are respectively considered as having a higher sustainability. By this criterion, the threshold values of this indicator are set and given a sustainable score for each sustainable class which can be summarized as follows.

Household capital (Unit: Baht[12]/household/year)	Sustainable score	Sustainable class
0 – 15,700	0	N
15,701 – 27,000	2	C
27,001 – 42,500	5	C
42,501 – 64,500	8	S
> 64,500	10	S

Threshold values are also adjusted by the trend of inflation rate to take into account increase in prices over time.

[12] Thai currency with 1 Baht equivalence to 0.02 Euro

4) Household saving indicator

This indicator is determined to monitor the situation and dynamic of net cash income which the farm household generates in each year. Having high positive net cash income not only indicates having a good balance between household's cash incomes and expenses but also it can also imply that the household is at a lower risk of being in an unsustainable situation from cash deficit in the future. In addition, positive cash household income situation indicates a higher potential to invest in profitable activities. However, this depends on the household behaviour and restrictions at the time the decision making takes place. This indicator is in the same situation as the household capital indicator because there are no available standard defined threshold values. The concept of relative situation is again applied but details of criteria used are different from the household capital indicator.

At first, the threshold is determined at 0 whereby the households having negative net cash household income are considered into the Non-sustained class (N). In this case, they have risk of being in an unsustainable situation in the future. For the other sustainable classes, the threshold values are set based on the simulation results at the first year (2003). The one threshold value is defined at the average level of net cash household income that represents the general situation of net cash income of the village. And, another threshold value is set by ordering the results of net cash household income. The value is then defined as the value where 50% of the households which are above average. Relying on these criteria, the threshold values are identified and sustainable scores are also defined and given to each sustainable class. Details of defined threshold values and sustainable score for each sustainable class are shown as follows.

Household saving (Unit: Baht[13]/household/year)	Sustainable score	Sustainable class
< 0	2	N
0 – 10,500	6	C
10,501 – 23,600	8	S
> 23,600	10	S

In addition, the concept is the same as the previous three economic indicators where the threshold values will be adjusted during the simulation. Adjustment will use the trend of

[13] Thai currency with 1 Baht equivalence to 0.02 Euro

inflation rate which is estimated based on statistic data. Dynamic of threshold values applied here with the intention to take dynamic of prices into account.

Social indicator

5) Food security indicator

The food security indicator is the only indicator determined to represent and monitor sustainability in social conditions. The indicator is defined to present the area's sustainability concerning rice sufficiency for consumption. This issue is important especially for this area with subsistence farming systems. Continually suffering from a rice deficiency is not preferable for farm households that mainly produce for their own consumption and this leads to an unsustainable situation for the area. For this study, the threshold values to determine sustainable classes are set based on the amount of rice deficit in kg/year. A deficit of rice less than 40 kg/year, which is the amount that the household can borrow from the village's rice bank, is considered as Sustained class (S). This amount is considered as security level which at least every household in the village can ask to borrow rice when facing shortage. But, for the further deficit amount the household has to borrow or buy from other sources. The other two threshold values are set at 150 and 300 kg/year which are considered as facing deficit of approximately 26 and 51 days/person/year respectively. In other words, this means that the household has produced less than the household consumption requirement. If this condition continually occurs, then it shows a sign of unsustainability. After the threshold values have been set, each sustainable class is given its sustainable score which can be presented as follows.

Amount of rice deficit (Unit: kg/year)	Sustainable score	Sustainable class
<= 40	10	S
41 – 150	7	C
151 – 299	3	C
=> 300	1	N

Environment indicators

6) Top-soil erosion indicator

This indicator is determined as a one of the indicators representing an area's sustainability in regard to environmental conditions. The indicator is defined by considering the amount of top-soil erosion and its dynamics caused by doing agricultural activities on steep slope land. Consequently, having a huge amount and increase over time of erosion indicates an unpreferable situation which leads to the area's environmental unsustainability. In the simulation, the amount of top-soil erosion produced from the household's agricultural activities is annually estimated through the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The indicator is used to represent the potential occurrence of the environmental hazards such as soil degradation and downstream sedimentation by erosion. The negative effect depends on the degree of erosion.

To determine sustainable classes and the threshold values, the concept of target value setting is adopted and the level of erosion is referred to the soil loss tolerance rate of Thailand as proposed by the Thai government agency, Land Development Department (2002). The soil loss tolerance classes consist of 5 soil loss levels which are slight, moderate, severe, very severe, and extremely severe corresponding to soil loss amount levels that are less than 12.50, 31.25, 93.75, 125, and more than 125 ton/ha/year respectively. These values are currently used to identify the soil loss tolerance classes and are spatially presented on the soil loss map of Thailand as supporting information for policy recommendations. For this study, the Thailand's soil loss tolerance classes and their corresponding soil loss values are applied and can be summarized as follows.

Amount of top-soil erosion (Unit: ton/ha/year)	Sustainable score	Sustainable class
0 – 12.50	10	S
12.51 – 31.25	6	C
31.26 – 93.75	3	N
93.76 – 125	1	N
> 125	0	N

7) Fallow period indicator

This indicator is identified to capture the characteristic of the farm households leaving land as fallow to let the lands recover their fertility. This issue is quite interesting because of the constraints of lands to meet household consumption production under high population growth. The lands are intensively used by shortening the fallow period to reach the required consumption levels. Consequently, land degradation coupled with low productivity, high weed density, low soil water content, and high soil acidity potentially brings about environmental and social unsustainable conditions (Place and Dewees, 1999; Szott et al., 1999; van Noordwijk, 1999; Wangpakapattanawong, 2002). Thus, for this study this issue is observed and the threshold values are determined based on the relative concept of setting the threshold value. The average length of fallow periods found in the survey is set as normal behaviour generally performed for a long time by the households. Therefore, taking 3 years or more is considered as the threshold value to reach the sustained class as it is the general level and current practice in the area. For the other sustained classes, the threshold values will be set at every one year less than 3 years and the sustainable score corresponding to the sustainable classes are assigned. The threshold values and sustainable score corresponding to sustainable classes are presented as follows.

Fallow period (Unit: years)	Sustainable score	Sustainable class
0 – 0.9	1	N
1 – 1.9	3	C
2 – 2.9	7	C
=> 3	10	S

3.3 CatchScapeFS model description

Relying on the study framework and surveyed information, the conceptual model is developed and afterwards implemented on the computer to carry out simulation results for sustainability assessment and scenario analysis. This chapter provides an explanation of the conceptual model development which is designed based on the defined system and the study objectives. Details of the biophysical component embedded by biophysical models represented and required for capturing biophysical characteristics of study area in order to assess sustainability are also described. The socioeconomic component in the part of determination of farm household agent characteristics and their behaviour are explained. Further, implementation of conceptual model and model validation are considered in this section.

3.3.1 Development of conceptual model

At first, farming systems of Bor Krai village is defined by considering definitions of farming systems which consist of farm households in the farm community. Farming system is centered by the farmer who is making decisions regarding allocation of household resources –land, labour, capital, and management– to farm and off-farm activities for achievement of household goals (Norman, 1986; Doppler, 1999). In other words, farming systems are considered as a set of elements or components interrelating and interacting between themselves which is centered by farm household elements whose decision making to allocate their resources to reach the objectives is affected by other elements.

Therefore, farming systems of this study are defined as a system which consists of interdependent elements or components that are centered by farm households who are making decisions on allocation their resources to farm and off-farm activities that contribute to achievement of household objectives.

Additionally, consideration of elements involved in farming systems are based on elements that affect and relate to farm household decision making in either farm or off-farm activities. Relationships of farming systems to other systems in vertical and horizon dimensions are also considered. Furthermore, element determination of this study also takes some important issues into account which consist of;

1) theoretical and practical possibility with respect to compatibility of integration and availability

2) research question which needs elements to support assessment and determination of sustainability through defined indicators

3) taking into account the application to further study in the way of object-oriented modelling approach and interdisciplinary research which can be implemented in other areas and integrated other disciplines of consideration

4) time limitation which taking more advance and complex needs time and skill for development

Depending on defined farming systems, their elements and behaviours are identified. Considering element descriptions of systems follow explicitly interdependence of farm households and their environment, either social and/or physical environment. In the model, farm households and other operational elements e.g. agricultural product market, labour market, village committee, traders, government agencies, etc who are effected by others and the environment, are considered as agents. The social environment is considered as the agent community and network realized as the farm community and network with interrelations and communication. The physical environment is considered as the physical space represented as the landscape and its attributes e.g. fertility, slope, moisture, vegetation, etc. which can be situated and modified by agents or objects.

Therefore, descriptions of models are structured and explained depending on various dimensions of spatial interdependence. These dimensions are human actors and communication networks, behaviour, perception, and cognition of human, land use/cover, farmsteads, land resource and ownership, soil quality, and water resource. This is described as follows (Figure 6).

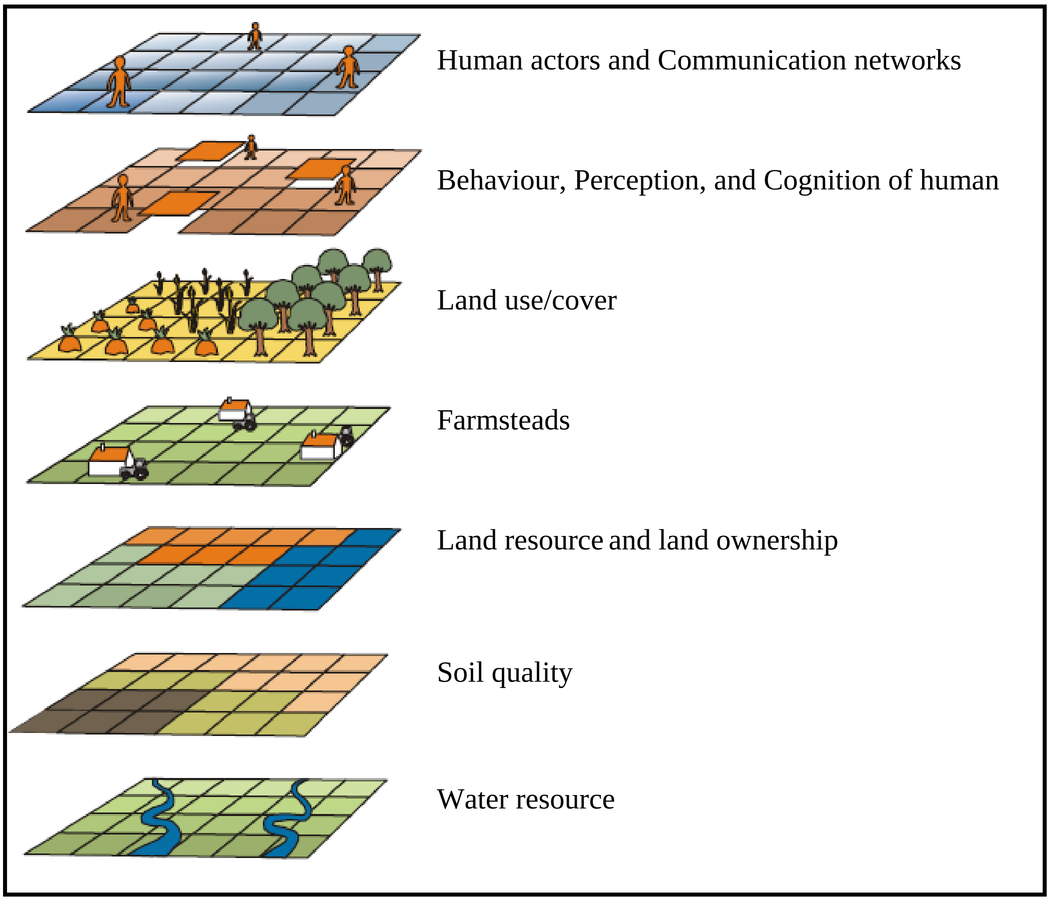


Figure 6: Spatial representation and interdependencies
Source: modified from Berger and Ringler, 2002

1) Human actors and Communication networks

In the model, farming systems consist of agents represented as farm households whose resource endowments, land, labour, capital, and management are different based on empirical data. Agents of farm samples are used to generate an agent population represented as a farm population by application of the Monte Carlo technique. With this technique, the population agents are generated by using probability functions which contributes consistent with survey agents (Schreinemachers, 2006). In addition, within their community communication in order to exchange information and enquire for additional resources is captured. Also, agents, village committees, as well as village institutions and institutions outside the village which obviously affect to decision making and farming e.g. agricultural extension officers, forest officers, NGOs, agricultural product traders, livestock traders, crop product markets, livestock markets are involved.

2) Behaviour, Perception, and Cognition of human

Based on the agents defined above, their behaviour and ability of perception to environment and cognition influencing their decision are embedded to agents. Differences amongst them in such characteristics is defined and applied.

3) Land use/cover

The landscape's characteristics and location which are the most important factors in agricultural production are generated and implemented in the model as a part of the physical environment. Land use and land cover data is derived from GIS analysis for several spatial aspects which are land use, land slope, land elevation. Important factors of land are considered and provided for integration with other biophysical elements and sustainability assessment. Furthermore, elements situated on the land and interacting with land are identified for examples crops, spring, tributary, forest, forest products, water etc.

4) Farmsteads

The farmsteads are defined for each household as the place where the farm and forest products are stored.

5) Land resource and land ownership

The agricultural land is allocated to farm agents based on survey data and the Monte Carlo technique is employed for the allocation of farm land to agent population.

6) Soil quality

Soil quality is considered as an attribute of land is derived from analyses based on the soil map contributed by subproject B1.2 of the Uplands Program, the University of Hohenheim (Schuler et al., 2006). The quality of soil also includes soil fertility, soil texture, and soil depth as these aspects provide for other elements interacting with the soil e.g. crops and soil erosion.

7) Water resource

Water resources from all sources are considered and the two sources are rainfall and springs. Also, the dynamics of water resources in the area is structured to consider the transfer of water and effects of water on other elements and factors e.g. crop and soil erosion.

With determination of farming systems consisting of several related elements and the criteria for determining the system described above, the conceptual model is constructed in the way of agent-based modelling and named “CatchScapeFS” model. This technique of modelling considers all elements in the system as objects which can be either passive or abstract objects. The model consists of two components containing of objects, the biophysical and socioeconomic components interacting and linked by specification of interdependencies captured from the study system. To illustrate the model structure, Unified Modelling Language (UML) is used as a standard language contributing to understanding of overall conceptual model as shown in Figure 7.

The figure shows an abbreviated class diagram of the conceptual model. Each rectangle is a class representing a type of object or entity defined by its name at the upper part of a rectangle. In addition, in the complete version of the conceptual class diagram the middle part of each class rectangle will be determined by a set of specific attributes characterized for each class. In the lower part, the set of specific methods that each class can be asked to perform is also indicated.

The lines linking all classes present the relationships between classes. The transparent arrow shows a one-way association indicating a relation or role where one relates to the other. For example, the Household class knows their own village committee, indicated by a one-way association to VillageCommittee class. A line linking classes presents a two-way association e.g. Household class has plots represented by the line connecting to Plot class while Plot class belongs to the Household class in the way round. Another kind of association is represented by the line with a diamond that shows aggregation association among them e.g. GroupInfo class (Group information) is composed of information represented as Info class. The triangle arrow shows generalization and specification between classes. For instance, Trader class is generalization of CropTrader and LivestockTrader class while both are specification of Trader class.

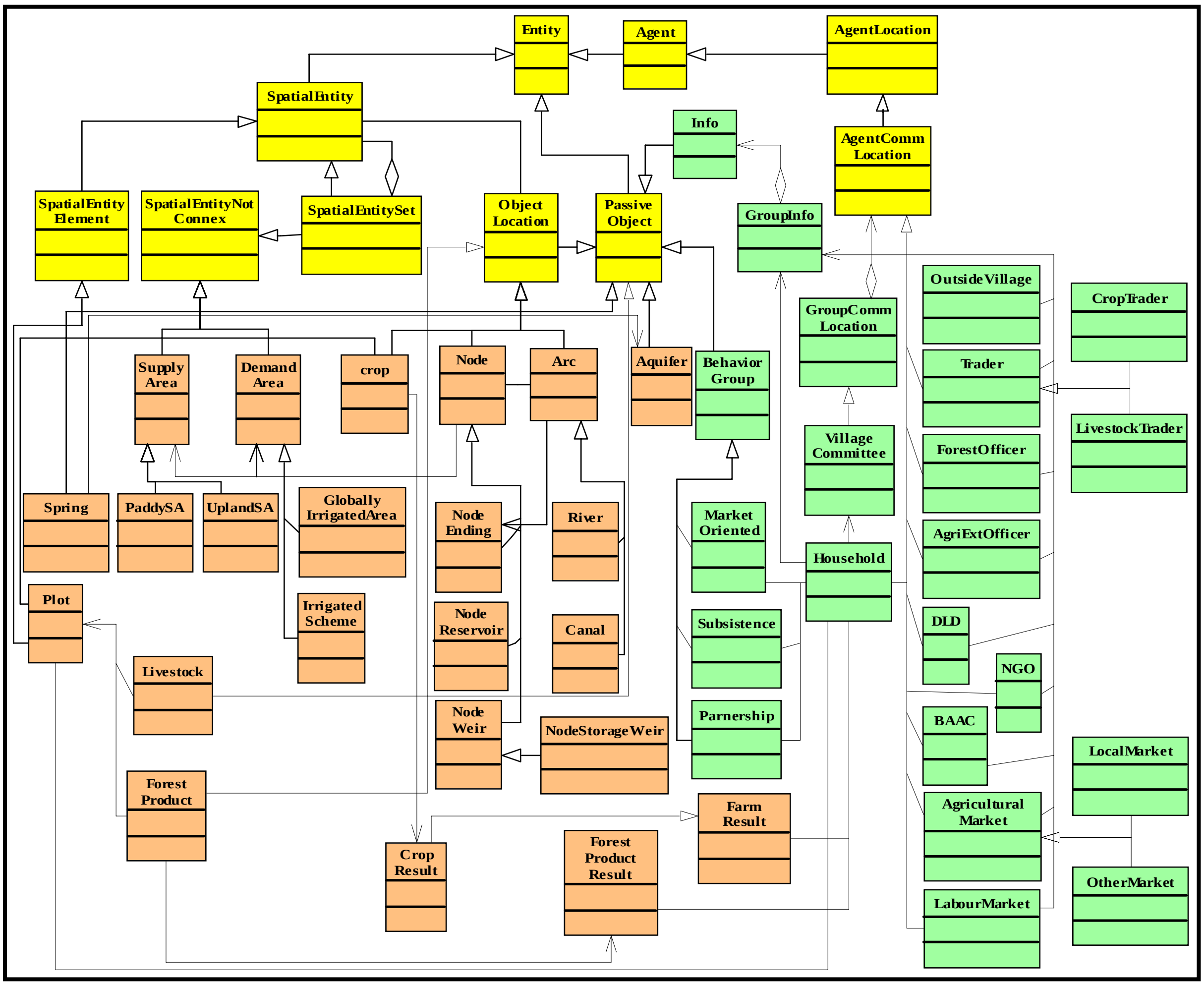


Figure 7: Summarized class diagram of CatchScapeFS model
Source: Potchanasin et al., 2006

This conceptual model is designed based on the selected platform, Common-Pool Resources and Multi-Agent Systems: CORMAS, which is selected as a capable tool for simulation of the interacting systems with specification of interdependencies between socioeconomic and environmental elements. For explanation, the rectangles of the classes are coloured by their category. The yellow rectangles are standard pre-defined classes inherited from the CORMAS platform that considers all the elements in the model as entities that can be classified into three principal classes –Agent, PassiveObject, and SpatialEntity. All classes related to those three principal classes consist of the brown rectangles which are classes in the biophysical component category and the green rectangles which are classes in the socioeconomic component category. The details of each principal class composition are explained as follows.

1) Agent class; It mainly consists of AgentLocation and AgentCommLocation which are specializations of agents in the model by specific ability aspect of locating and communicating. The classes which are considered as agents that can situate in their environment and can behave upon survival or satisfaction function subject to their resources, environment perception, and skill (Ferber, 1999). Almost all classes in socioeconomic component are specializations under this principal class. These include classes of Household (representing farm household), AgriExtOfficer (representing the Agricultural Extension officer), ForestOfficer (representing the Forest officer), DLD (representing the Department of Livestock Development officer), Trader (representing trader that is generalization of crop and livestock trader), CropTrader (representing crop traders), LivestockTrader (representing livestock traders), AgriculturalMarket (representing agricultural market that is generalization of local and other market), LocalMarket (representing local market), OtherMarket (representing other market), LabourMarket (representing labour market), NGO (representing the Non-governmental organization), BAAC (representing the Bank for Agriculture and Agricultural Cooperatives), OutsideVillage (representing source of information from outside village), and VillageCommittee (representing the internal village institutions including village committee, village rice bank, and village fund).

2) PassiveObject class; It consists of one pre-defined standard class from CORMAS platform which is ObjectLocations class and two classes of socioeconomic component which are Info class (representing information) and BehaviorGroup class. The BehaviourGroup class is composed of specific behaviour classes of farm household and include MarketOriented (representing behaviour taken by market oriented farm household group), Subsistence class (representing behaviour taken by subsistence farm household group), and Partnership class (representing behaviour taken by partnership oriented farm household group). Additionally, PassiveObject class also is also composed of three classes from the biophysical component which are Aquifer class (representing abstract reservoir obtaining deep drainage of water from each supply area), Spring class (representing natural springs in area) and Livestock class (representing livestock raised by the farm household).

ObjectLocations class is composed of four classes with their specializations from the biophysical component which are Crop class (representing vegetation covering area including crop grown by farm household), ForestProduct class (representing forest products comprising mushroom, bamboo shoot, wild vegetables and fruits), Node class (representing junctions of water tributaries in the area and water reservoirs), and Arc class (representing tributaries in the area).

3) SpatialEntity class; It is a pre-defined standard class according to spatial entities of the model. The class is composed of three significant standard classes from CORMAS which are SpatialEntitySet, SpatialEntityNotConnex, and SpatialEntityElement representing each specific spatial class relying on its aspects. In addition, the classes of biophysical component related to spatial elements of model are designed as specializations of pre-defined standard classes of SpatialEntity class. SpatialEntityElement class consists of Plot class (representing each unit of land in the model) while SpatialEntityNotConnex consists of SupplyArea class (representing aggregated area defined as area contributing water to its node) and DemandArea class (representing aggregated area defined as area enquiring for water).

In the simulation process, the model is designed running of each time step corresponding to 10 days in reality with achievement of six principal phases including eight phases of the farm agent household activities (Figure 8 and Figure 9). Both diagrams show categories of activities in each successive phase which are all scheduled and will be carried out in each time step. Each column of the diagram represents the model’s elements and the boxes represent activity categories which are in a different colour depending on where its successive phase is. Location of each activity category box in column of the Figures indicates the model’s elements which involve and perform the activity. In addition, the arrows show interactions between the model’s elements occurring during the activity process.

At each phase, some modules in the activity category are executed and some are skipped depending on the pre-defined condition. For example, in phase III crop decision module is not executed if the plot is already cropped or the farm agent perceives that it is a dry season which is not suitable for cropping. The details of each phase are explained in details as follows.

Phase I: Parameter Updating is the attribute dynamic process of biophysical elements e.g. age of crops, livestock and forest products, state of plot based on the cropping decision of the previous time step, fallow period of the plot, farm agent’s cropping knowledge base for their plots, as well as the season of the model. The attributes of the biophysical elements are updated based on rules and actions of the previous time step which directly affect the elements' attributes of the current time step.

For example, in the time step when activity of planting crops on a plot is taking place the farm agent will decide which kind of crop to plant on the plot. Technically, the information of the intended planted crop is put in the plot attribute which is defined as the buffer crop attribute of its crop. Also, at this step the plot is prepared for planting and the farm agent will spend out the required resources for land preparation. For the next time step, the crop attribute of the plot will be updated by using information in buffer crop attribute. Therefore, the crop type will change to be the crop which the farm agent intended to plant. This will consequently affect other elements e.g. the decision making of farm agent to plant on this plot will not occur because there is a crop planted, the agent will spend household resources depending on the new crop planted, the parameter of crop water balance model is updated depending on the new crop, and so on.

Phase II: Biophysical dynamic is the process where part of the biophysical modules are activated (Becu et al., 2002). Based on conditions and parameters updated from the previous time step, the water balance model, crop model, and hydrological model are achieved. In addition, the forest product attribute of the forest plot is updated as in some seasons some kinds of forest products maybe appear or disappear.

Phase III: Farm household activities consist of all farm and off-farm activities of farm household as well as analyzing and updating the knowledge base with new information. Farm crop activities include the entire process of cropping which starts with the cropping decision and is followed by planting, harvesting, and selling respectively. For each activity, the process is designed to model the schedule of the activity which the farm agents will individually perform depending on such schedule and their own conditions. For the farm livestock activities, the farm agents will carry out decisions about raising livestock, maintenance, and selling of livestock. In addition, the farm household agent activities include off-farm activities that the farm households are doing in reality. The off-farm activities consist of gathering forest products, hiring out labour, selling household products, household consumption, financial and resource acquisition activities e.g. borrowing money, exchange and hiring labour, borrowing and buying rice for consumption. According to all activities, the information of the farm agents in their knowledge base is used and new information e.g. crop price, crop support information, amount of rice and feed stuff lacking, amount of feed stuff used, borrowing information is updated into the knowledge base.

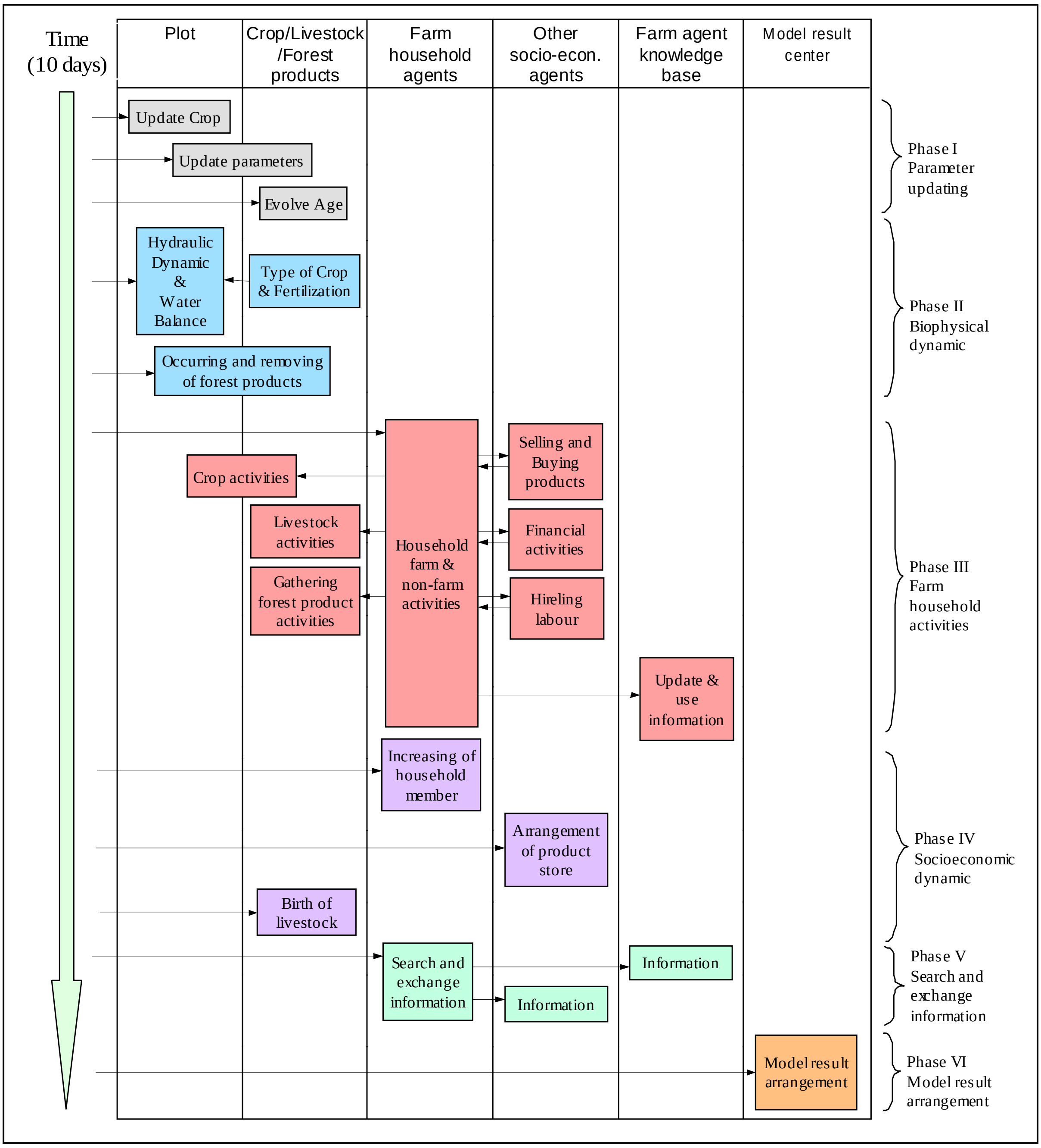


Figure 8: Summarized schedule diagram of CatchScapeFS model
Source: adapted from Becu et al., 2003

Phase IV: Socioeconomic dynamic is the process which the model elements in socioeconomic component perform. The processes include the dynamic of number of livestock and household members. These dynamic processes depend on the pre-defined conditions which are the population growth rate and number of mature livestock holding respectively. Additionally, the arrangement of the product store of the other socioeconomic agents is involved as the process which the agents sell or clear old products and update their demand for the new products for the next step.

Phase V: Search and exchange information is the communication processes where all farm household agents exchange crop information between themselves during the year. This aspect represents the situation in reality where the farm households have talked to each other and discussed through village meetings which are frequently held for all villagers. With this, the farm agent will get information from the others and then update in his own knowledge base. Furthermore, searching for information by the farm household agents from other sources such as from the government agencies, NGOs, traders, and publication media is performed. However, this depends on the behaviour of the farm agent with some groups needing more information to use for decision making than others. But, for some groups they do not want to take risks from change unless it has been proven by the other farm agents that it is the way to get better situation e.g. getting higher yield, price, and support.

Phase VI: Model result arrangement is the process where all information which is required to be used and supported for study analysis is organized and recorded. During the simulation at the end of each year, this information is calculated and the results are arranged and exported for analysis and explanation.

Further, for phase III about on-farm household activities the process schedule can be extended into more detail which is divided into eight successive phases of farm household agent activities. Figure 9 shows that at each time step of 10 days in reality the farm household agents will perform activities as detailed below.

Phase I: Knowledge base updating is the process of arrangement and analysis of the information obtained. With this, the information about crop and livestock in the farm agent knowledge base is updated with new data which is obtained from the previous time step.

Phase II: Household resource updating is the process where the resources which are available only for each particular time step are updated. For example, the full household labour for each time step is updated before carrying out any activities. In addition, the products which are stored in farm agent product store are updated their storage period whereby those which have reached perishable stage are removed.

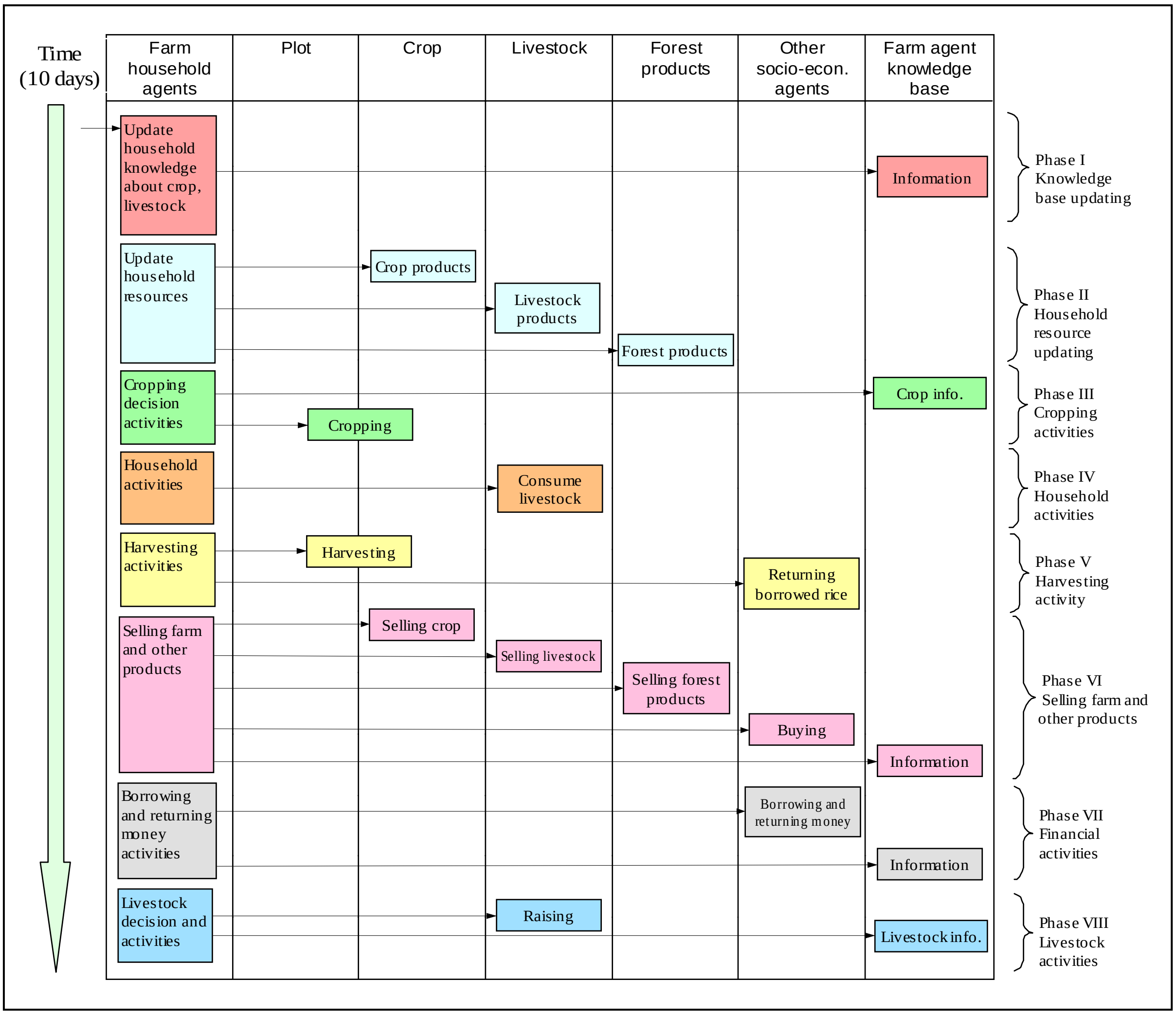


Figure 9: Summarized schedule diagram of farm household agent in CatchScapeFS model

Phase III: Cropping activities consist of the crop decision making activity and planting of the crop on the plot. The details and activity diagram of crop decision making will be explained in the section 5.3.3. Decision making activity of the farm agents is individually based on information in their knowledge base where they have different information and experiences about the crops. In addition, depending on the crop which has been planted the farm agent resources e.g. labour, cash, and other inputs are spent for doing the crop planting activity.

Phase IV: Household activities are household non-farm activities which include household consumption and spending on private living cost expenses. With this process the farm agent attributes on the amount of rice in the store and household cash are updated which affects the farm agent element itself. In this process, the livestock consumption activity of the farm agent is also performed which affects not only the livestock attribute of farm agent but also the livestock elements which leave the system due to them being consumed. In addition, if there is a rice deficit this is recorded as information for cropping decisions in the next production year.

Phase V: Harvesting activity is the process where the farm agent harvests his crop when it has reached the harvesting stage. The process also includes transporting the crop products to the agent product store and returning borrowed rice to village rice bank which has to be performed after harvesting.

Phase VI: Selling farm and other products is an attempt by the farm agent to sell his products from the product store. The farm agent will ask the traders who come to buy the products in the village or offer the product in the other markets and the local village market. Information of products which have been sold are recorded and updated in the agent knowledge base to use as information in other activities.

Phase VII: Financial activities consist of decisions to borrow and pay back money. In case where the farm agent has a shortage of cash, the process of borrowing money to other agents which include other farm agents, village fund, and the bank is executed and information regarding the borrowing is recorded and updated in the agent knowledge base. In addition, at the end of year the farm agent will perform decisions of repaying the loan which depends on the financial situation of the farm household agent at that time.

Phase VIII: Livestock activities consist of decision making on livestock raising activities including maintaining and spending household relevant resources for the activities. Also, consequent information on livestock performance are arranged and updated in the knowledge base which will be used as information in other performing processes.

3.3.2 Description of biophysical component

The biophysical component of CatchScapeFS model is based on CatchScape3 model (Becu et al., 2003). The landscape of the study area, Bor Krai village, is divided into spatial grid cells as plots of one rai[14] (0.16 ha) in reality (Figure 10) and the total number of plots is 8,855 rai or grid cells. Each cell is embedded by a set of attributes e.g. land use, soil type, slope, fertility, fallow period, etc which are required for related biophysical modules. The spatial attributes are generated based on Geographical Information Systems (GIS) of the study area and the important characteristics are land use, soil type, and slope as shown in Figure 10.

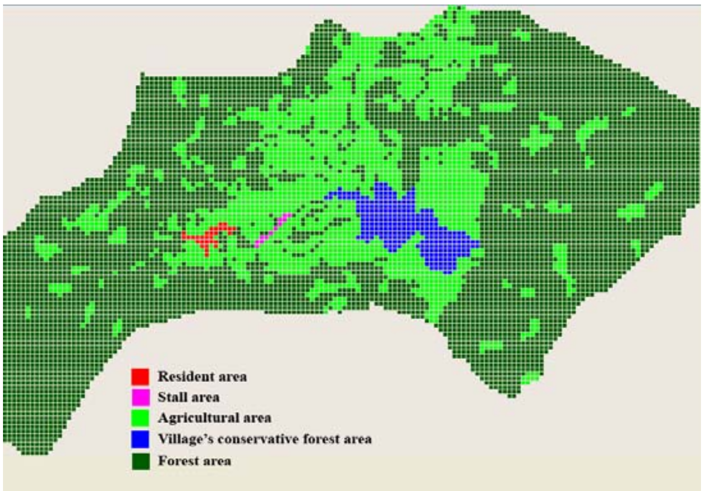
In addition, the biophysical component of the model is embedded with hydrological, crop, water balance, and soil erosion models as detailed below.

Water balance model

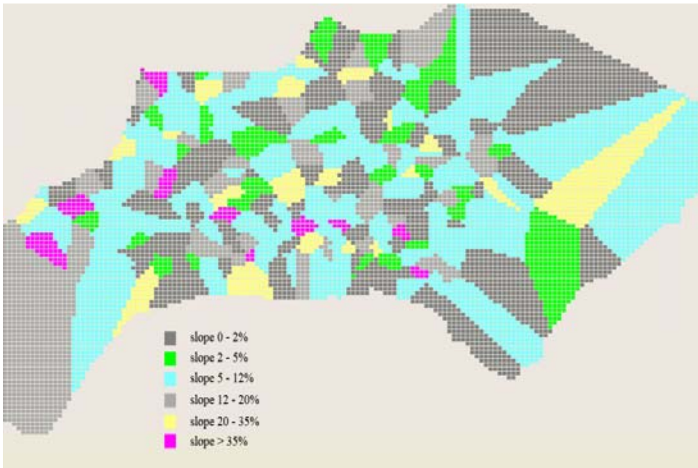
At each time step, in order to quantify the amount of water output released from each plot as runoff and deep drainage, the water balance model is structured. The released water is then used in another biophysical model which is the hydrological model. In the process of the water balance model, calculations are done with the crop model as complement of one another.

The water balance model was developed using the concept of double reservoirs of Perez et al. (2002) which are root zone and soil layer reservoir (Figure 11). The soil layer reservoir is supplied by water input as infiltration and irrigation and releases water outputs as deep drainage and evapotranspiration. The soil layer reservoir covers the root zone reservoir which can increase depending on root growth at each time step while soil layer reservoir is constant. At each time step of the simulation, overall sequence of activation of the water balance model is sequentially executed as follows.

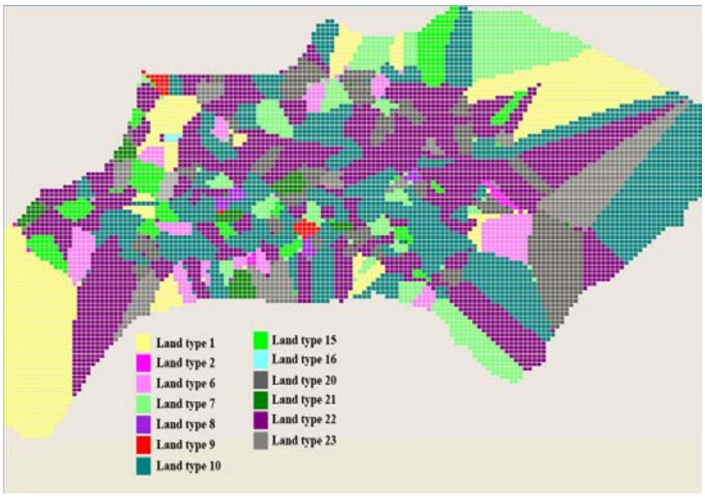
[14] area unit which is commonly used in Thailand and approximately corresponds to minimum area used for cropping in the study area



Grid cells representing land use of the study area



Grid cells representing the slope of the study area



Grid cells representing land type of the study area

Figure 10: Spatial grid cells of study area presenting each important attribute
Source: CatchScapeFS model

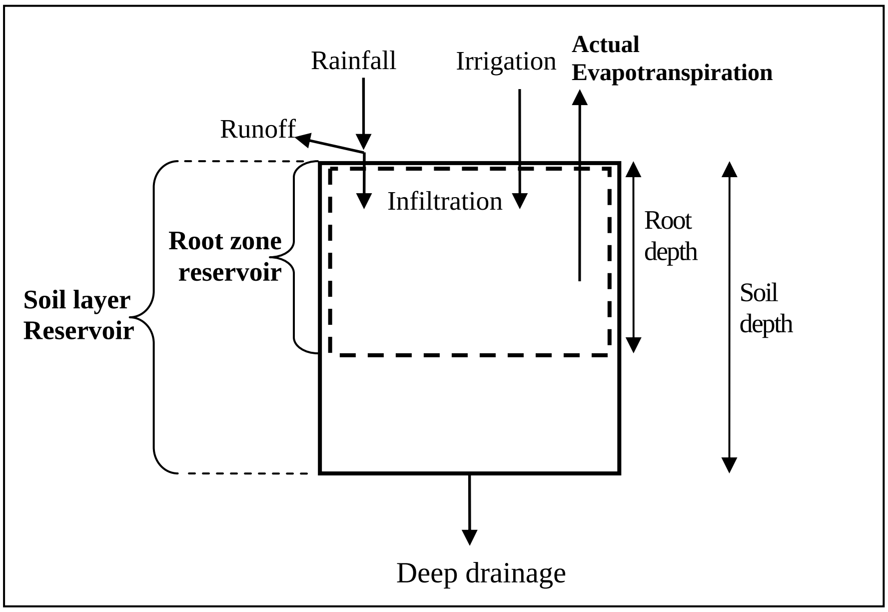


Figure 11: Concept of water balance model
Source: Becu, 2005

1) the plot is supplied with water through rainfall and irrigation

2) the production function calculates runoff and infiltration

3) the crop model calculates new root depth

4) moisture content of the soil layer and root zone reservoirs are updated and deep drainage is calculated according to soil layer reservoir capacity

5) the crop model calculates crop actual evapotranspiration according to potential evapotranspiration and crop characteristics

6) amount of crop actual evapotranspiration is removed from the soil and root reservoir

7) moisture contents of the soil layer and root zone reservoirs are updated (Becu, 2005)

In the water balance model, runoff at each time step (10 days) is calculated by SCS equation (Becu, 2005) which is;

$$sro = NDRi.ro_i$$

When;

sro = amount of runoff during 10 days (mm)

ro_i = amount of pseudo-daily average runoff (mm) of the 10 days period i; i = 1, 2, 3,…, n

NDR_i = number of rainy days (mm) at the 10 days period i

while;

$$ro_i = \frac{rr_i - 0.2(IS.CS.CC)^2}{rr_i + 0.8(IS.CS.CC)}$$

when;

rr_i = amount of pseudo-daily average rainfall of the 10 days period i; i = 1, 2, 3,…, n

IS = daily infiltration rate for a given type of soil

CS = slope correction factor reflecting the reduction surface detention with increasing steepness

CC = crop management correction factor

where;

$$rr_i = \frac{RR_i}{NDR_i}$$

where;

RR_i = amount of rainfall of the 10 days period i; i = 1, 2, 3,…, n

NDR_i = number of rainy days (mm) at the 10 days period i

In addition, at each time step the daily infiltration rate is added as a correction factor which reflects the soil impermeability after heavy rain, then, infiltration rate represented as;

$$IS = IS - IK + 1.5$$

where;

IK = soil impermeability which is updated at each time step through;

$$IK = IK + \left(\frac{RR_i + m}{m} \right) e^{-0.5}$$

where;

m = yearly average rainfall during 10 days which is set to 100 mm

Water content of soil layer and root zone reservoirs is calculated according to simple mass conservation equations. Deep drainage is calculated as a surplus of water content in the soil layer reservoir which depends on the soil depth. The deep drainage released is then passed to the aquifer reservoir for the hydrological model representing the overall hydrological structure of the study area.

Crop model

Crop model is employed for calculating evapotranspiration that determines the actual yield of crop at each time step of the growing period. Model calculation process is based on CropWat model (Smith, 1992) of FAO. The actual yield can be estimated by methodology proposed by Doorenbos and Kassam (1979) that actual yield is linearly related to the evapotranspiration deficit which is determined by ratio between cumulative values of actual evapotranspiration (ETA) and maximum evapotranspiration (ETM) during the growing period. The equation can be expressed as;

$$Yield = YM.\left(1 - KY.\left(1 - \frac{SUMETAi}{SUMETMi}\right)\right)$$

where;

$Yield$ = actual yield (kg)

YM = potential or maximum yield of the crop (kg)

KY = water stress coefficient reducing potential yield

$SUMETA_i$ = cumulative value of actual evapotranspiration (ETA) at the time step i of growing period (mm); i = 1, 2, 3, …, n

$SUMETM_i$ = cumulative value of maximum evapotranspiration (ETM) at the time step i of growing period (mm)

In the calculation process, evapotranspiration (ETM) at each time step is determined by crop coefficient (KC) which varies for each vegetative period of the crop (Doorenbos and Pruitt, 1984) and potential evapotranspiration (ETO) obtained as input data from CropWat for windows program version 4.0 of FAO. As so, ETM calculation can be express as;

$$ETMi = KCi.ETOi$$

where;

$ETOi$ = potential evapotranspiration at the time step i; i = 1, 2, 3, …, n

KCi = crop coefficient at the time step i

The actual evapotranspiration (ETA) at each time step is quantified by the expression as;

$$ETAi = KSi.ETCi$$

where;

KSi = water stress coefficient where;

KSi = 1 when water content in root zone reservoir is above threshold (Pi) that is $P_i = P_{factor} + 0.04.\left(5 - \frac{ETCi}{10}\right)$ (Doorenbos and Pruitt, 1984; Allen et al., 1998)

and $KSi = \frac{CRi}{(1 - Pi).CAWi}$ when water content in root zone reservoir is less than threshold (Pi)

where;

CRi = actual root zone reservoir water storage at time step i

$CAWi$ = maximum root zone reservoir water storage at time step i

P_{factor} = crop root suction capacity varying by crop

The corrected evapotranspiration (ETC) is expressed as correction of ETM at time step i by coefficient of depletion (KF) which depends on level of fertility of the plots and the level of fertilizer supplied. As so, the expression is as follows;

$$ETCi = KF.ETMi$$

Hydrological model

The hydrological model is related to the water balance and crop model where both are structured at the cells or plots of the study area. The amount of water as runoff and deep drainage from the water balance model are used in the hydrological model representing propagation of such water through catchments' hydrographic network represented by arc-node structure (Becu, 2005). Dynamics of water proceeds as semi-distributed hydrological model which is an aggregation of water at intermediate level of spatial scale called supply area which is distributed through arc-node structure similar to water inputs and outputs and is propagated along upstream and down stream features. The concept of the structure is shown in Figure 12.

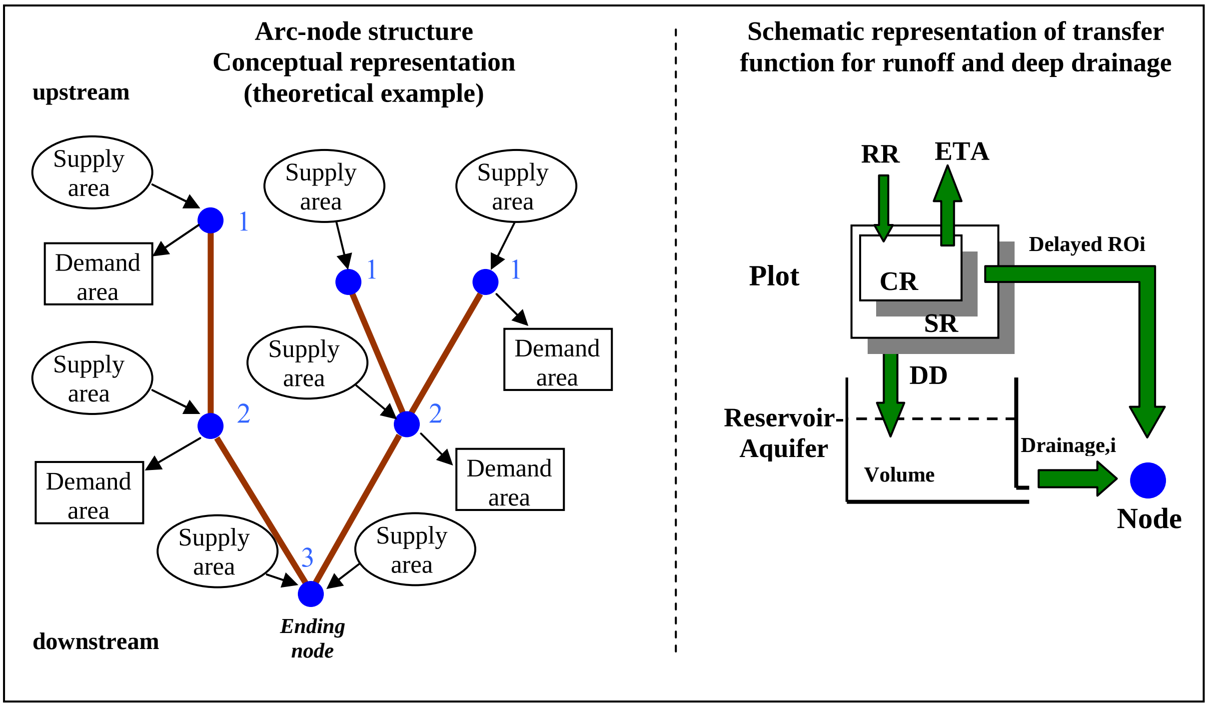


Figure 12: Concept of hydrological model
Source: Becu, 2005

From the figure, the supply area is a set of cells or plots determined by geographical aspect of the study area. In this study, hydrological analysis of ArcView GIS software is used for identification of supply area. After analysis, the entire study area is divided into several supply areas corresponding to sub-catchments of the area.

Nodes are represented as confluences of rivers and sub-catchment outlets while arcs are represented as river or stream linking between two nodes. A node is linked to one or more supply areas that may contribute water to it. Also, each demand area is determined as a set of cells or plots that can enquire for water as irrigated demand performed by farm agent. The demand area is identified to given nodes that can be possibly linked to none or many demand areas.

For the operation of hydrological model at each time step, the nodes are considered to launch scheduling sequences of the model's operation starting at the most upper nodes until the lowest node. The process of the model's operation is sequentially performed following operations which are;

1) Node 1 orders its supply areas to run water balance and crop model of their plots and afterwards to sum their runoff and deep drainage.

2) The total runoff is transferred to its node by using a delay function. Deep drainage of each supply area is added to the volume of its reservoir-aquifer of the supply area and then the reservoir-aquifer transfers a fraction of its total volume to its node.

3) Node 1 orders its demand areas to sum the irrigation demand of their plots needed by the farm agents to irrigate their plots and then node 1 allocates water to its demand areas depending on the amount of water demand and water availability.

4) The remaining water of node 1 is transferred to the downstream arc and then conveyed to the next node.

5) For the demand area of node 1 located at the downstream of node 1 but upstream as supply area of node 2, its water is allocated when node 2 asks its supply area (node 1 demand area) to execute water balance. Then, this process is turned to the same as operation 1 – 4 except ending node (node 3) operates only 1 – 2.

However, as the study area is a rainfed area and irrigation for agriculture from small natural water sources is not commonly used the water demand for irrigation is then considered as zero. The amount of water that node obtained from corresponding supply area is totally transferred to next node until ending node following the operation process as explained above.

Soil erosion model

In this study, the soil erosion model is based on the Universal Soil Loss Equation model (USLE model) proposed by Wischmeier and Smith (1978). This model is also applied for estimation of soil loss in Thailand by the government office (LDD 2000; LDD 2002). At each year during simulation, soil loss of the study area is quantified by USLE model expressed as;

$$A = R \times K \times LS \times C \times P$$

where;

A = amount of soil loss (ton/ha/year)

R = Rainfall Erosivity Factor (ton/ha/year)

K = Soil Erodibility Factor

LS = Slope Length and Slope Steepness Factor

C = Crop Management Factor

P = Conservation Practice Factor

For this study, all plots of the study area are classified into land types by three characteristics which are soil texture, soil depth, and land slope. To do so, there are 24 land types in the study area classified by existing combinations of these land characteristics. For the value of the model factor, the K and LS factor data varying by land type and the C and P factor data varying by the kind of crop are obtained from the literatures of the Land Development Department of Thailand, LDD (2000) and LDD (2002). Estimation of soil erosion for each plot is executed at the end of every year based on the factor condition at that time. The estimated values of the plots are then used to quantify average amount of erosion caused by individual farm activity which is providing information for the model's sustainability assessment modules.

3.3.3 Description of socioeconomic component

In this section, important procedures of the farm household agent which is the most important agent of the socioeconomic component and the farming systems are explained. As described previously, each time step of simulation corresponds to 10 days in reality and at each step the six principal phases as well as eight phases of farm household agent activities are achieved. All activities of farm agents are carried out which include updating knowledge base, updating household resources and commodities, doing household private activities, taking off-farm activities, etc. Some procedures are achieved in the manner of reflexive action corresponding to the environment e.g. spending money for household consumption is executed by simple procedure when all conditions are met. However, some procedures are more complicated and require the agent's capability and knowledge to carry out the activities. The decision making activity is one of them and the aspects of making decisions by the farm agent is the most interesting issue because this affects the other related elements in either socioeconomic or biophysical component of the farming system. The selected procedures presented here consist of using plot and choosing crop decision, consuming rice activity, and recovering themselves from a cash shortage activity. The details are described in the following section.

Agent decision making processes

<u>Using plot and choosing crop decision</u>

Within the eight successive phases which the farm agents have to carry out, there are some decision making procedures under complex situation involved. Based on the field survey and observation, the Unified Modelling Language (UML) activity diagram for each selected procedure is constituted. The diagrams are used to facilitate the representation of the complex software system corresponding to the considered activity. In the diagrams, the black circle shows the initial state or starting point of the overall activity. The black circle with transparent edge indicates the final state or ending point of the overall activity. The arrow shows action flow and the description of the activity is shown in the boxes with straight sides and rounded corners. The diamonds represent the point at which conditions have been tested or where decisions take place.

The first procedure is the activity of making decisions about using agricultural plots and choosing crops for cropping (Figure 13 and description of the "Using plot activity" programming code in the appendix). This decision will be made plot by plot for all plots of each agent. Before the agent reaches the starting point, he sorts in a descending order by considering the fallow period of the plots. After that, the agent will pick the first plot with the longest fallow period and starts making decision relying on the activity diagram presented in the Figure 13. Initially, if the plot has already been used then the process will stop and the agent will go to the next plot and start process again until the last plot. In the case where this plot is not decided to be used yet and during the previous year it was left as fallow, the plot will be brought to the process of choosing crops. But, in case where this plot was used for planting upland rice in the previous year the agent will take this plot into planting other crop decision process. This corresponds to reality that farm households leave their plots to let them recover themselves. The first year after fallow the plot will be usually used for planting upland rice. And, then for the next or probably next two years this plot will be planted with other crops but in case of the farms experiencing land limitation using this plot for cropping upland rice again is also possible.

After plot conditions are met, choosing crop decision will proceed. Choosing to plant upland rice happens when the net household rice needed is on the positive. Here, the farm agent will roughly estimate net rice needed based on current information and knowledge. The net household rice needed can be expressed as;

Net household rice needed = rice consumption needed – expected rice obtained – current household rice remaining + rice borrowing – rice being borrowed

The rice consumption needed is calculated based on common sense of the farm agent. This is based on field surveyed data where 1 person consumes 1.3 Kg un-milled rice per day. The term of expected rice obtained is calculated by multiplying the number of plots which are occupied by upland rice with the average upland rice yield which is information from their knowledge base. This information is updated year by year after the crop production year is achieved. Therefore, in that the situation where the agent suffers from low rice yield production from the previous year then a low yield is expected. The net amount of borrowed rice is taken into account. The rice borrowing term indicates having borrowed rice from others. In this situation, the agent has to produce more to cover this amount to return back which is assumed to occur in January of the corresponding year. With this expression, the net household rice needed is carried out. If it is positive, the plot will be used to plant upland rice. Here, one assumption has been set that the household has to plant upland rice anyways because of subsistence reason which the upland rice has a relative high opportunity cost and therefore the farm agent has to find the means to reach the conditions of other required resources i.e. labour and cash.

If decision making over current plot has been finalized through planting upland rice, the agent will consider the next plot. The process will start again from the initial point. If the requirements for household rice are met (negative net household rice needed), decision making will go to the next condition. The second condition is set as usual behaviour of farm household in the area which needs maize for livestock activities. The condition of maize is tested and the agent has to compare the amount needed and the amount expected. The needed amount is set as information from the agent's database which is recorded as the total amount of maize needed from last year. An assumption here has been made based on the empirical data that the farm agent will not immediately increase investment and production of livestock. Therefore, the dynamics of number of livestock indicating maize need of the current decision year is close to amount of previous year. For the expectation of agent about amount of maize obtained, agent expectation is in the same way of upland rice expectation. The farm agent will estimate by multiplying the number plots which are being planted maize by the average maize yield from the agent knowledge base. This average yield is also updated every year similar to upland rice yield information in knowledge base. After the maize condition is tested and if farm agent still needs maize the current decision plot will be used to plant maize and the next plot will be brought into consideration. At this point, the subsistence reason is also applied for the case of maize as having a relative high opportunity cost which maize is importance for livestock. Therefore, maize will be planted and the agent has to find the required resources. In contrast, if the farm agent has enough maize the process of activity will be directed to cash crop decision which at first plot fallow period property is tested.

The plot with more than two years fallow has the potential to be used for cash crops. This manner is set based on behaviour found in the study area where the households had a lot of agricultural plots. The plots remaining after allocating to produce staple crops for consumption has potential to be used for cash crops. However, there are some conditions which have to be met depending on the household behaviour. The first condition is whether the agent has cash crop options. This condition represents having limitations of crop choice where frequently there are no other options than typical staple crops. In addition, the crop choices and the selected crop from the choice options are different between agent behaviour groups. The assumption has been made in this manner which the crop option information comes from 3 sources –within village, institution, and the outside village source.

Within village source is the exchange of information within village and this represents communication between farm households in reality. With this, we assume that all farm agents circulate information to all and obtain information from all.

The second information source is the institution source information. This information comes from the agricultural extension officers, forest officers, financial institution officers, traders, and NGOs. Depending on observed and surveyed information, the market and partnership oriented farm agent group (details of farm agent classification are explained in section 3.4) try to get information and potentially adopt and apply the information from this source in farming.

The last source of information comes from the outside village source e.g. public media, farmer from other regions etc. The market oriented farm agent group is assumed to try to get the information from this source. This setting is based on behaviour of farm agents in this group which is active and tries to get as much as information to make cropping decision. However, difference of crop options between farm agent groups probably occurs only in the first year of getting the new information. After some farm agent have adopted and applied if such crop option provided success return, then this crop option information will be circulated to all farm agents in the village in the next coming year as information from within village source.

Additionally, preference of farm household relying on the criteria used to select the crop is applied in the process of crop option selection. From the field surveyed data, the ranking of issues for all farm agent behaviour groups can be summarized as follows;

Rank order	Market oriented group	Subsistence oriented group	Partnership oriented group
1.	Market issue	Suitability of resource issue	Support condition issue
2.	Suitability of resource issue	Support condition issue	Market issue
3.	Support condition issue	Market issue	Suitability of resource issue

The market issue takes total income into consideration and roughly considers the gross income obtained from their cropping activity. For the case of suitability of resource issue, total yield representing land fertility suitability and amount of labour required are considered which corresponds to reality that the farm households are concerned about obtaining yields from cropping. This issue is considered because in the past the farms had failed in cropping some cash crop due to limitation of land fertility and suitability. In addition, the farm household is concerned about the amount of labour required for cash crop production as if it requires many hours of labour a household with limited labour resources cannot do such activity. The last issue is support condition which consists of input support, input and marketing support, and no support. These support aspects are generally found with extension or suggestion of cash crop to the area. Some kinds of support significantly stimulate adopting crop activity which affects some groups of households. All these issues are applied as different weighted preference score among crop choice options. The farm agent will then choose the crop with highest score to plant in the plot.

After availability of crop options is tested and the potential crop has been chosen, the second condition concerning the possibility of planting such crop in the time of decision taking place is examined. Using experience and crop extension information from the agent's knowledge base, the farm agent will know whether he can plant such cash crop option in that season. In the case where this condition is satisfied, the decision process proceeds to the resource availability condition testing. The availability and possibility to acquire labour and cash resources are tested and the selected cash crop will be planted if all conditions are satisfied. If any condition is not met, the cropping decision process is stopped and the next activity processes are executed.

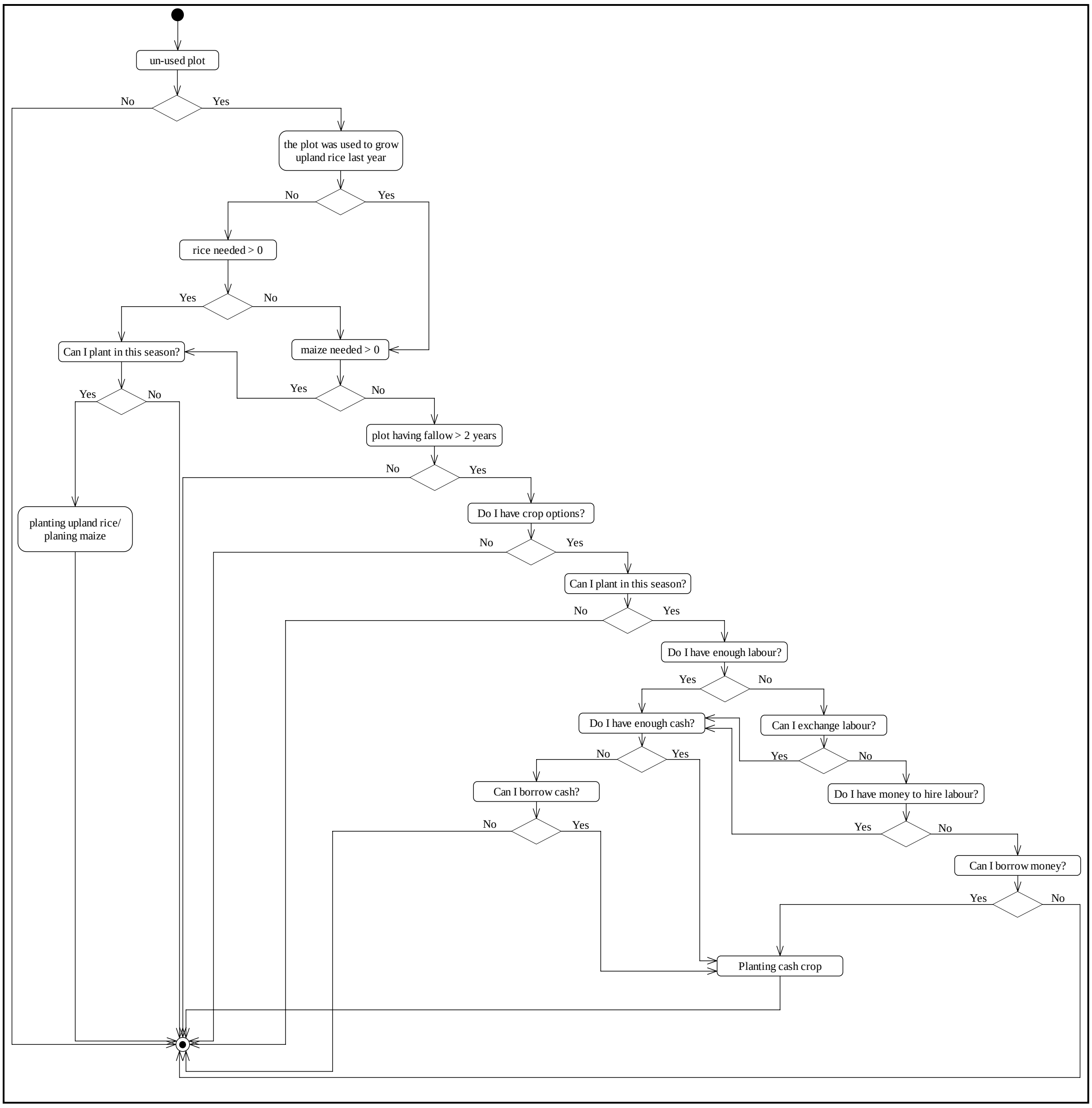


Figure 13: Using plot activity diagram

Consuming rice activity

The consuming rice and related processes are regular activities of farm agents corresponding to reality. The activity diagram of this process is presented in Figure 14 and description of the "Consuming rice activity" programming code in the appendix. The activity starts by assessing whether the agent has rice in the store. Testing is proceeded by comparing the amount of household rice in the store with the household rice needed (calculated based on the requirement of rice need per person, 1.3 Kg/day, multiplied by number of household members). The amount of household rice needed is deducted from the household rice store and if the amount needed is greater than the amount in store the farm agent will first request to borrow rice from village rice bank. The total amount of agent's requested rice is calculated by determining the total daily amount of household rice required multiplied by the number of days remaining until the next harvest period. If rice remaining in the rice bank is greater than request, the farm agent will borrow and consume the borrowed rice and if the remaining amount is not enough, then the farm agent will ask to borrow rice from the neighbours individually. Request from the agent will be considered by the first neighbour and if the neighbour's remaining rice is enough to consume until next harvest season, then, the neighbour will lend out the request amount. But, in a case where the request is declined the agent will ask another neighbour individually until the request is accepted.

If the farm agent cannot borrow rice from the neighbours, the farm agent will decide to buy rice from the trader whereby farm agent's money availability is tested. In a case where the farm agent money is enough, then the farm agent will buy the amount of required rice. But, in a case where the farm agent remaining money is not enough the farm agent will try to generate cash by selling farm products from the mixed crops or livestock. The mature mixed crops which are local bean, melon, and pumpkin will be harvested and sold to the market and if the money is still not enough the household animals which consists of chickens, piglets, pigs, cow, and buffalo is gradually sold out until enough cash has been generated. If the money from selling livestock is still not enough, the farm agent has to request to borrow money from many sources which include village fund and neighbours. However, in worst cases the Bank for Agriculture and Agricultural Cooperatives (BAAC) is assumed to serve as the financial institution which can offer a loan to the farm agent. When the farm agent finance situation is satisfied, the farm agent will buy and then use rice for household requirements.

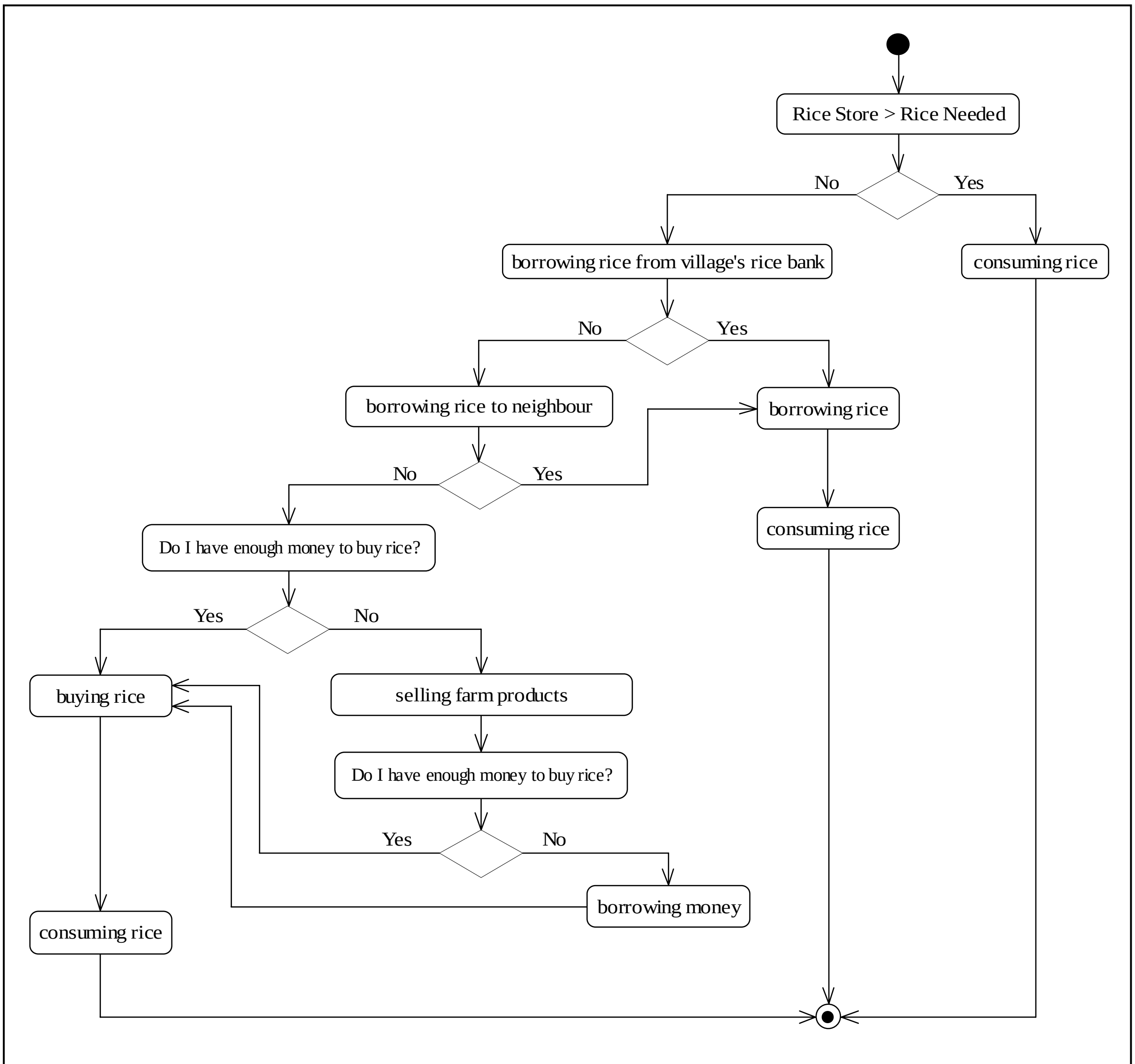


Figure 14: Consuming rice activity diagram

Recovering themselves from cash shortage activity

During time of doing activities in the simulation process, farm agent will look into his cash situation. Sometimes in doing some activities, the farm agent requires more money than what is available. In cases where farm household encounters money shortage his strategy options are based on farm household behaviour found in the study area (Figure 15 and description of the "Recovering themselves from cash shortage activity" programming code in the appendix). Selling farm crop and livestock products are the first two options. The farm agent will check availability of mature mixed crops (local bean, melon, and pumpkin) and livestock which can be sold out for cash. If there is still a shortage, going out of own farm to work as a hired labourer is another option for the farm agent. However, the possibility of getting the job depends on labour market conditions during that time. Sometimes, there is no available job in the market. The job condition represented by the number hours of labour needed in the market is set based on an assumption because of lack of data. At each time step of simulation (10 days), the labour needed in the labour market is randomly set between 100 to 300 hours. In case that these three options are not sufficient to recover from shortage, borrowing money from either village's fund, neighbours, or the BAAC is provided as the last option to recover from the cash shortage.

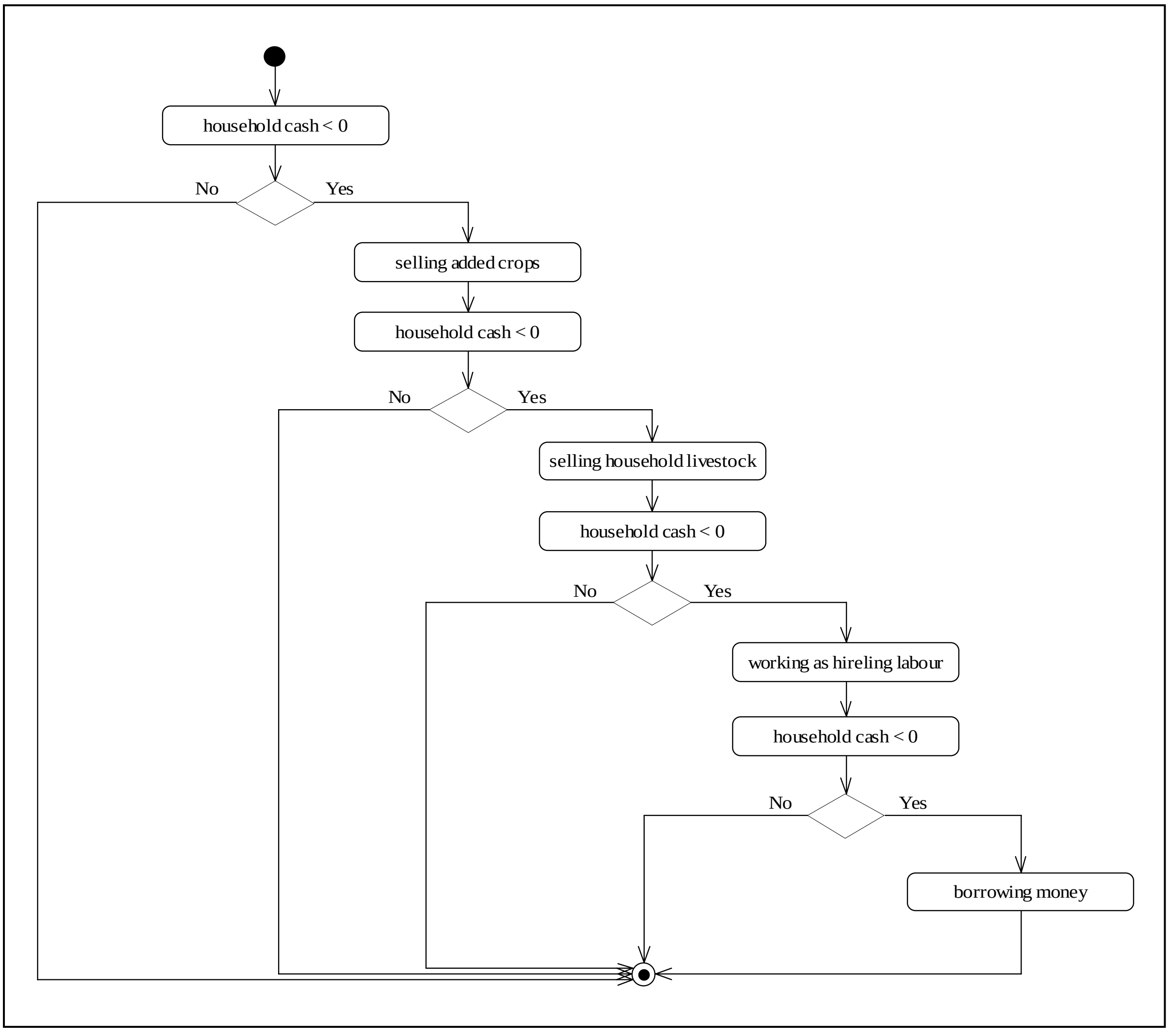


Figure 15: Recovering themselves from cash shortage activity diagram

Raising livestock decision activity

The raising livestock activity of the farm agents is assumed to be annually executed in December. This period is set because it is time after harvesting and doing other activities of farm agents. At this time they can raise more livestock based on their information collected from the whole year. In addition, deciding to raise livestock at this time relates with the time period that the agents need livestock for consumption which is assumed to be in June every year. Decisions considered include rearing pigs, cows, and buffalos which are the commercial livestock of the area.

The constraints of raising livestock which the farm agents take into account are based on surveyed data and observation information of study area. From the Figure 16 (see also the description of the “Raising livestock decision activity” programming code in the appendix), the decision activity of the farm agents to raise livestock starts by looking at their own household cash availability. Households with higher cash than private expenditures have the potential to raise some kind of livestock. Also, if the farm agent has some available household labour then the agent probably decides to raise livestock. This condition considers only farm household labour because in reality only farm household labour is used to raise livestock.

In the next step, the farm agents will order the kinds of livestock which the farm agent will consider to raise. Ranking is based on the condition of livestock price, initial cash investing requirement, farm preference, Annuity Net Present Value (Annuity NPV), and Payback period. All kinds of livestock are scored and descended ranked by the total score. After that, each kind of animal in the ranked options is individually tested to decide whether the agent will raise it.

The livestock price is taken into account as the expected income that can be generated under each kind of animal. This is taken account in the ranking process. The price of each animal which the farm will take to consideration is the price at which each animal can be sold. For pigs, the price is at 1.5 years old and for cow and buffalo the price is at 3 years old. The animal with higher selling price will be given higher score. For the initial cash investing requirement, the price of small animal bought for rearing is considered with ranking and scoring different between the farm agent groups. The market oriented group will rank and score by descending but the other two groups, subsistence and partnership oriented group, by ascending. This condition is determined with the intension of representing the farm behaviour which the market oriented usually take more risk more than other groups. The farm preference condition is included as the general preference of farm households in study area about the animal which they prefer. They prefer pigs and the lowest preference is given to cows and buffalos. With this, a higher preferred animal will be given high score than the lower one. For the last two conditions, the conditions consist of considering Annuity NPV and payback period of raising each kind of animal. This manner is set to represent economic consideration based on theoretical investment decision. The Annuity NPV represents comparing average present value return per year among animal options. The animal with higher value of Annuity NPV is given higher score than lower value. In case of the payback period value, theoretically short period of return back of investment cost is preferable. A lower value of payback period represents faster returns to cover the investment cost. Therefore, a lower value is given a higher score as preference aspect.

From these conditions, the livestock options are scored and ranked. Next, each animal in the ranked options is tested. Depending on raising livestock behaviour in study area, usually raising more livestock is performed by replacing or keeping the offspring with the existing animals. Assumptions on the minimum number of animals required as the breeding animals are made for this study. For the market oriented group which is trying to get as much as cash they can, keeping higher number of breeding animal can potentially generate more cash for them through selling mature animals and the offspring. However, they have to be much more active because keeping high number of animal requires more feeds and cash for production and sometimes there are risks from disease hazards. The minimum numbers of animals are identified for this group which the minimum number of pigs is 4 while minimum number of piglets and cows is 1 animal each. For the subsistence and partnership oriented group, the minimum numbers of animals is lower. The minimum number of pigs is 3 and for piglets is 1 animal. For testing, the first animal option from the ranked animal options is considered. In a case where the farm agent has more animals than the minimum determined number, then the agent will decide to skip raising such animal option and the next options are picked up to consider. But, in case that the agent has less number of animals than minimum determined number then that kind of animal will be considered. The number of this kind of animal to be raised will be determined by household cash and labour constraints which all constraints have to meet.

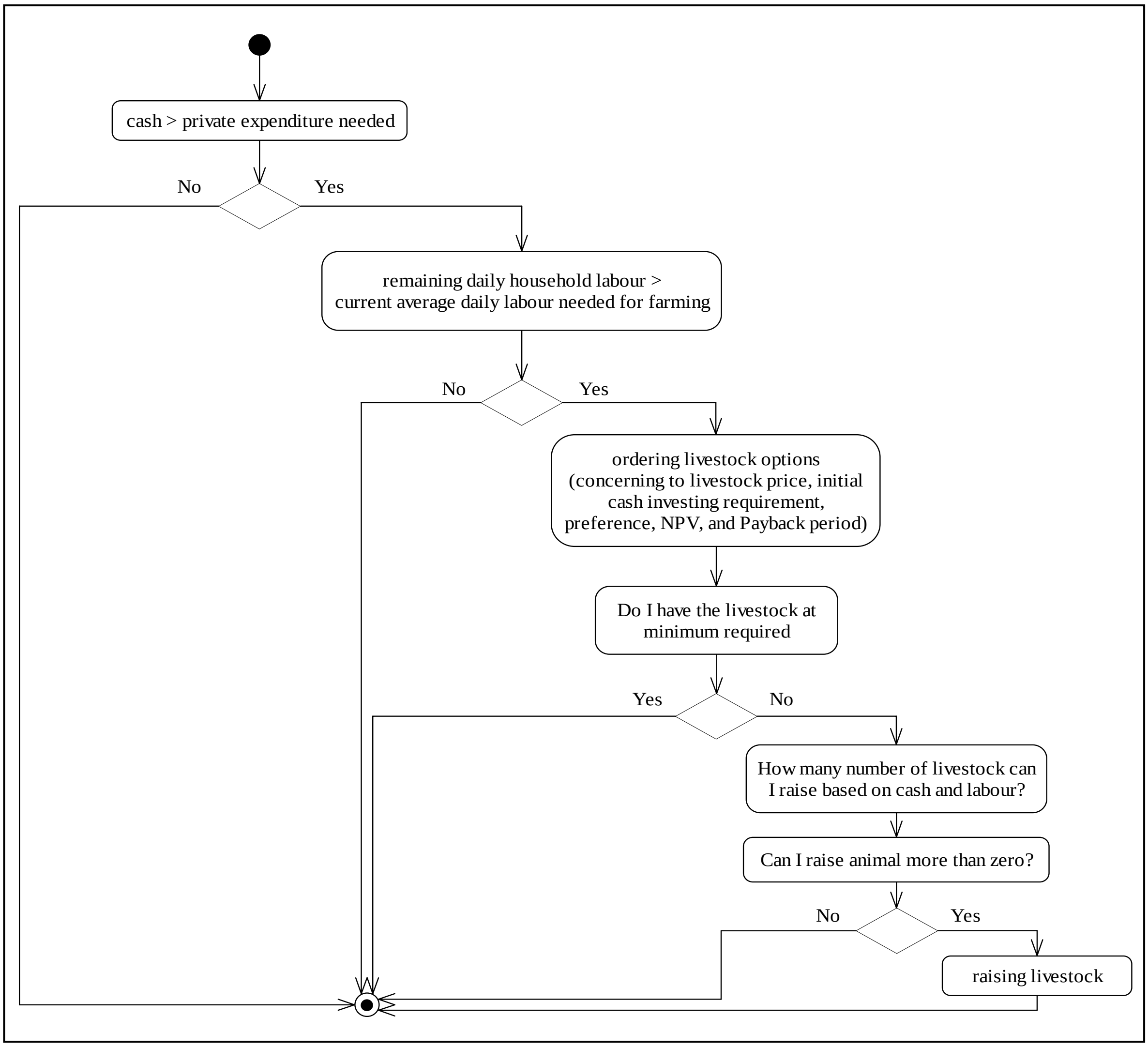


Figure 16: Raising livestock decision activity diagram

3.3.4 Model assumptions

The CatchScapeFS model is similar to other models which are determined based on the assumptions. Some assumptions are set and already explained at the point where they take place. However, there are some assumptions which are roughly explained but more details are needed so as to be clear on the model description. During the simulation process, economic parameters are determined for each time step and used by the agent as economic condition. Determination of these parameters is based on assumptions which are explained for each item as follows.

1. Crop price

Crop prices are determined monthly for all crops which in the current version of the model the crops consist of upland rice, maize, mango, local bean, local melon, and pumpkin. Each crop price is determined through the average price trend function which is estimated by using statistic data or/and surveyed data.

Upland rice price

For the upland rice price, the monthly prices during the year 2003 to 2006 are set from the existing statistic price data from the Office of Agricultural Economics (OAE), Thailand but the monthly prices for 2007 until 2018 are estimated. To do so, at first average price trend function is estimated based on annually statistic data from year 1990 to 2006 of the Office of Agricultural Economics, Thailand. Then, the average price for each year is identified. Based on the average price of each year, the monthly prices within each year are adjusted by percentage of changing from average price. The certain percentages of each month are the average percentages compared to average year price calculated from monthly statistic data of the Office of Agricultural Economics, Thailand from the year 1990 to 2006. With this, monthly prices of upland rice from 2007 to 2018 are determined and used in the simulation.

Maize price

The monthly statistic data of maize prices during the year 2003 to 2006 from the OAE is set as maize price parameter in the model. For the monthly prices from 2007 until 2018, the prices are determined through the average price trend function to determine each year average price and then adjusted by certain monthly percentage of changing price compared to average price of corresponding year. This is the same procedure of upland rice price determination. However, there are some differences in the case of upland rice in that the statistic data used to estimate the average price trend function and to calculate certain percentage of changing price within the year for maize comes from the year 1984 to 2006 of the OAE.

Mango price

In case of mango, the monthly statistic price data from 2003 to 2006 is used as the price in the model whilst the monthly prices from 2007 to 2018 are determined in the same way as upland rice and maize price determination. The average price trend function of mango is estimated by using statistic data from 1995 to 2006 of the OAE whereby the average mango prices for each year are identified. Then, the monthly price within the year is determined by multiplying the average price within the year with certain percentages of changing price of each month compared to the average year price calculated from monthly statistic data from 1995 to 2006. So, the monthly adjusted prices are determined for each month of simulation.

Mixed crop price (Local bean, local melon, and pumpkin)

As the local statistic data of all mixed crops does not exist, therefore the price from survey is used as the price of the year 2003 and as the price for estimation of the prices for other periods. At first, to obtain the average prices of the other years the statistic data of vegetable price index from 1985 to 2005 of the OAE is used to estimate the average prices of the year 1985 to 2002 and 2004 to 2005 for each crop. From the obtained average prices, the average price trend function is estimated and the average prices from 2006 to 2018 are determined. Because of absence of monthly price statistic data, therefore the average price of each year is set as constant price for the whole year.

2. Crop cost

During the simulation, variable and fixed costs of crop activities are determined. For variable costs, crop input cost is based on survey data. In addition, implementation over time of input cost throughout simulation is adjusted by the Producer Price Index (PPI) of each kind of input. The statistic PPI values of 2003 to 2007 of the Bureau of Trade and Economic Indices, Ministry of Commerce, Thailand are used to adjust the input cost in the corresponding year while the PPI values of 2008 to 2018 are estimated based on available statistic data from 1995 to 2007 for each kind of input. With these data, the PPI trend functions of each kind of input are estimated and the PPI values for each year are determined and used for crop input cost adjustment over time of simulation.

For the fixed cost, the cost items which consist of repairing cost, interest of borrowed money, and depreciation cost for each crop activity is set based on survey data. To implement the fixed cost during simulation, the fixed cost of each item is adjusted by inflation rate. The inflation rates to be used for 2003 to 2006 are the statistic data of Thailand's inflation rate of Bank of Thailand and the inflation rates which are used for 2007 to 2018 are estimated from inflation rate trend function. The function is determined by using inflation rate statistic data from 1996 to 2006 of Bank of Thailand and then the inflation rate of each year during 2007 to 2018 is identified through the function.

3. Livestock price

For the current version of the study model, livestock consists of 5 kinds of animals which are pig, piglet, cow, buffalo, and chicken. Their prices for each time step are varied depending on livestock age based on the area's livestock price data from the field survey. In addition, these prices are compared with the statistic data of the OAE for their consistency.

4. Livestock cost

The cost of livestock production is identified which variable cost comprising input cost of each animal raising activity is based on survey data. Throughout the simulation period, the input cost is adjusted by PPI of the corresponding input item. The PPI values for the year 2003 to 2006 are set as the statistic data of PPI for each input item of the Bureau of Trade and Economic Indices, Ministry of Commerce, Thailand. The PPI values for 2007 to 2018 are set through the PPI trend functions which are estimated for each input item from PPI statistic data from 1996 to 2006.

For the fixed cost, the cost items which consists of repairing cost, interest of borrowed money, and depreciation cost for each animal is set based on survey data. During simulation, the fixed cost of each item is adjusted by the inflation rates for the related year. For the year 2003 to 2006 the statistic data of Thailand's inflation rate of Bank of Thailand are used to adjust each cost item. For the year 2007 to 2018, the inflation rates are estimated through the inflation rate trend function which is identified based on statistic data of inflation rate from 1996 to 2006 of Bank of Thailand.

5. Forest product price

The forest products which consist of wild fruits, mushroom, bamboo, wild vegetables, and forest feed stuff are set in the model and occur in particular time period corresponding to reality. The statistic price data of all products is lacking, therefore, the prices determined in the model simulation are determined based on survey data. From additional information from interview and observation, the prices which the villagers individually obtained at local market are frequently changed with non system pattern of changing affected by external factors e.g. supply, demand, selling promotion, negotiation of buyer etc. The prices probably are high at the beginning of season but if there is no demand, then, the villagers will reduce the prices. Prices can also be reduced as the product quality gradually declines or as the buyer offers. Thus, in the model the prices of forest products are set based on survey data and randomly adjusted within the range of changing prices of each kind of forest product found in the study area.

6. Household private living expenditure

The household private living expenditure is set based on survey data and varies by number of household members. In addition, at each year during the simulation this expenditure is adjusted by the Consumer Price Index (CPI). For the year 2003 to 2006 the CPI statistic data is implemented. For the year 2008 until 2018, the CPI values are estimated through CPI trend function which is identified by using the CPI statistic data of Northern Thailand from 1990 to 2006 provided by the Bureau of Trade and Economic Indices, Ministry of Commerce, Thailand.

3.4 Classification and generation of farm agent

In this study, the CatchScapeFS model consists of 60 farm household agents which approximately correspond to the area’s population in 2003. The farm agents are identified based on empirical data of farm household samples from the study area where they are different in characteristics –land holding size, member, labour, number of livestock, etc– and in behaviours regarding decision making of crop and livestock production activities, of off-farm activities, of investment etc.

At first, in order to obtain farm household agent population for the model the surveyed data of 32 farm household samples are independently analyzed by quantitative and qualitative methods. The analyses are performed and concluded to identify the farm household groups based on their characteristics and behaviour in the model. The farm household samples are then classified into these defined groups which lead to the next step of generating the farm agent population.

For quantitative analysis, the cluster analysis is employed to classify farm household samples into groups by considering their similarity. The important factors which influence farming and decision making of the households are selected and used to cluster the farm households into different groups. The factors consist of nine factors which are: age and education level of the household leader, number of household members, number of labourers, land holding size, net household income, net cash farm income, off-farm income, and amount of loan. These will be used as variables in the cluster analysis.

At the same time, a qualitative method is applied to classify the farm household samples relying on their behaviour. Analysis is performed by considering similarities in their behaviour which were recorded and observed during field surveys. The observed behaviour information can be classified in eight characteristic categories which are: decision making of crop and livestock activities, collecting information to support decision making, adoption new technologies, strategies for recovering themselves from stressful events, attitude to investment, attitude of land resource sufficiency and security, perception and adaptation to environmental change, and decision making of off-farm activities. After quantitative and qualitative analysis, the results are compared and concluded to identify farm household sample characteristics and behavioural groups.

3.4.1 Classification of farm household by quantitative analysis

In this analysis, hierarchical cluster analysis is applied. The unclassified farm households or cases from the survey data will be classified into distinct groups which have similarity within groups (Everitt, 1986). Under this analysis technique, the basic procedure of clustering known as agglomerative method is conducted. Generally, the procedure starts with the computation of a similarity or distance matrix between farm households or cases and finally ends with successive fusions of all cases which are achieved at the point so that all the cases are in one group. For this study, Ward's method has been selected as fusion method of union of all possible combination either between households, between households and group of households, or between groups of households. In addition, the similarity is measured by the Euclidean distance which can be expressed as;

$$d_{ij} = \sqrt{\sum_{k=1}^{p} \left(X_{ik} - X_{jk}\right)^2}$$

where;

X_{ik} , X_{jk} = the value responses to characteristic or variable k of household or case i and j respectively

k = the characteristics or variables of households; k = 1, 2, 3, …, p

As the values of characteristics have different units and scales which can affect the distance measurement, the Z scores by variable is engaged to standardize the data to preserve relative distances (Everitt, 1986; Field, 2000). With performing of the Wald's method, the distances of all possible household union are calculated. At each step of clustering, the union will consider all possible combinations and the one which its fusion makes minimum increasing of the error sum of squared deviations will be combined (Everitt, 1986). The procedure will be repeated until the households are in one group and this will be presented in a dendrogram.

From the analysis, the results show that farm households of study area are clustered into four possible clusters (see also dendogram in Appendix figure 1). However, there are only three clusters which are reasonable to represent the profile of farm households in this area and the rest should be considered as outliers. These three clusters are shown in Table 14 under column named cluster 1, 2, and 3 and the outlier is in column cluster 4. For this 9, 10, and 12 household samples are classified into the clusters respectively.

From the results, cluster 1 has characteristic of the young active farm households who are beginning their farm establishment. These farm households are encountering relative limitation of land and labour because they are new farmers separated from their original families. They have only an average of 2.68 ha and couples are the main source of labour in farming. However, since they are younger and have higher education that is primary school, they try as much as possible to generate cash to fulfill their consumption needs by either selling crop farm products or off-farm activities such as hiring, trading, or selling forest products. In addition, this cluster has a higher proportion of cash crop income than other clusters. Income from these sources is comparatively high and can also be compensated by high household private expenditures. This can be explained by the amount of net household income whereby this cluster generates more cash from farming but at the same time uses more cash in household private expenditure.

The contrary cluster with cluster 1 is cluster 3 which represents traditional farm households with the largest number of household members. The household head is relatively older with an average of 44 years, no education but have more land holding area, 5.36 ha, and labour, 4 persons. They can generate relatively high net cash farm income and feel free to do off-farm activities to increase household income. Further, this cluster can also obtain cash from loan to use in farm and household consumption.

The last cluster is a combination of characteristics of young active and traditional farm household cluster shown as cluster 2. These households are in between the two previous clusters with average age of 35 years and higher land holding area than cluster 1 but less than cluster 3. They have average labour of 2 persons and can generate net cash farm income slightly closer to cluster 1. However, they keep away from off-farm income and this makes their net farm household income relatively low.

Based on this quantitative analysis, the results will be used for conclusion together with qualitative analysis results in order to determine farm household groups. The qualitative analysis and the results are presented in the next section.

Table 14: Result from cluster analysis of Bor Krai village

Items		Cluster				Total
		1	2	3	4	
No. of households	Valid N	N=9	N=10	N=12	N=1	N=32
Age (years)	Mean	26	35	44	51	36
Level of education	Mode	Primary school	No education	No education	No education	No education
Total land holding area (ha)	Mean	2.68	4.02	5.36	3.68	4.13
No. of household members (person)	Mean	3	4	6	4	5
No. of labour (person)	Mean	2	2	4	4	3
Off-farm income (Baht[15])	Mean	20,400.00	6,228.00	13,613.33	272,000.00	21,288.75
Net household income (Baht)	Mean	7,319.32	-5,589.75	10,595.38	266,708.39	12,258.88
Net cash farm income (Baht)	Mean	14,884.80	12,371.78	24,871.38	44,154.73	18,704.10
Having loan (Baht)	Mean	22,114.29	29,285.71	24,833.33	180,000.00	31,029.63

Source: Own cluster analysis

3.4.2 Classification of farm household by qualitative analysis

In parallel, qualitative analysis is employed to classify farm households. The households will be sorted according to their behaviour, representation, as well as decision making aspects in farming and household circumstances.

To do so, the information from opened-end questions of eight household samples from the field survey conducted in 2005 is entered into spreadsheets. To simplify for the next step of the analysis, each column of the spreadsheet is set for each question and each row is set for each household. After setting the form, the data recorded from the field survey are entered into each question (column). According to this, some notes occurring on the survey are also put into noted column since they have useful and notable detail for further analysis.

After getting all information in the spreadsheet, the data for each question are used and interpreted in order to classify the households by their obvious similar behavioural aspects. The process of classification will be performed by analyzing and considering the vertical dimension through all data from all households in each question. Interpretation of each response will take into account the field observation and survey in order to correct the analyzed results. For each question, the data which is likely to be close to each other are coloured as the same group and the procedure is continued until the last question (Figure 17).

[15] Thai currency with 1 Baht equivalence to 0.02 Euro

Next, the questions will be interpreted and categorized into eight behavioural categories which are: crop and livestock production, seeking information, technology adoption, strategies dealing with stress, investment issues, representation about sufficiency of land and land tenure, environmental perception, and off-farm activity performance category. For example, the category of crop and livestock production are composed of questions regarding cropping aspects, selecting crop and livestock to produce, and determination of amount of the crop and livestock to produce. The category of off-farm activity involves questions about behaviour of hiring, and gathering forest products. In addition, the question under the same category will be placed close to each other to be convenient for analysis in the further steps.

In each category, the questions which are classified and placed close together in previous steps will be summarized by considering these questions through horizontal dimensions to find out the common aspects for each household under each category. The general profile will be summarized to represent the common aspects of this household in each category and placed in the new column for the next summary. The summarized data will be classified through vertical dimension again and the households which are rather close to each other in common aspects will be coloured as the same group (Figure 18). After that, the summarized data of all categories will be used to classify households and summarize the common aspects for the groups. The farm households which can be classified in the same group will be done and coloured the same (Figure 19).

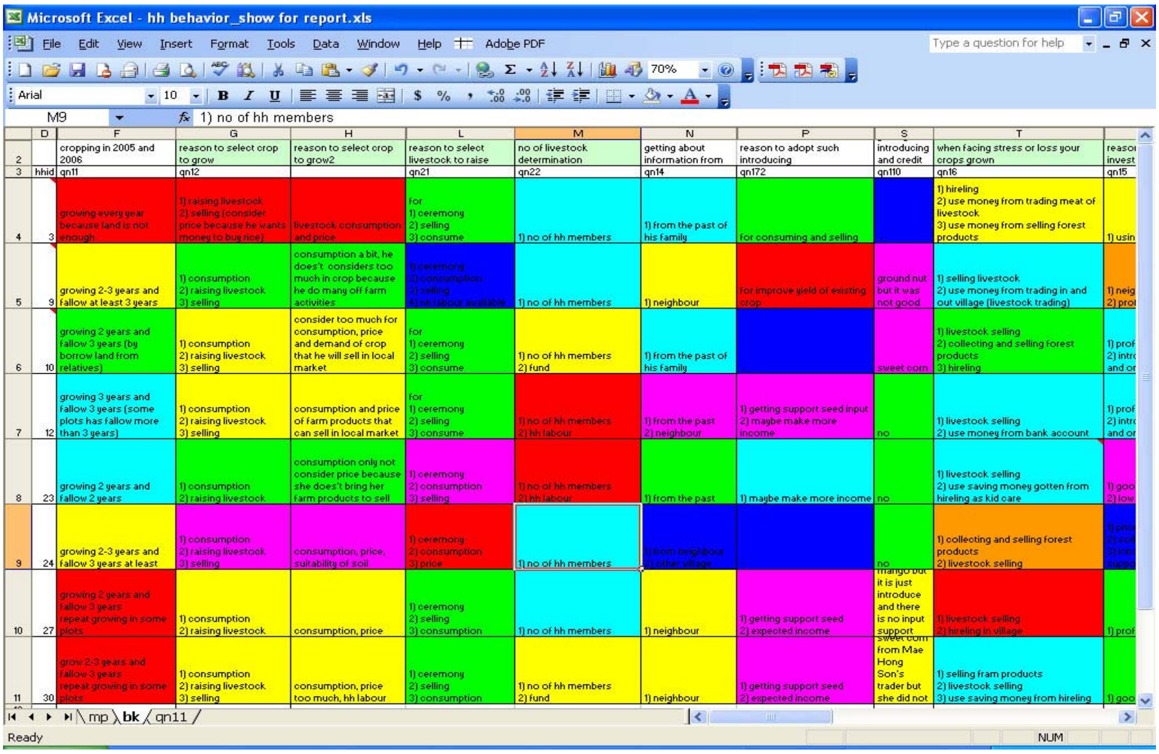


Figure 17: Classification of households in step of consideration of data interpreted from the survey through vertical dimension

Source: Own qualitative analysis

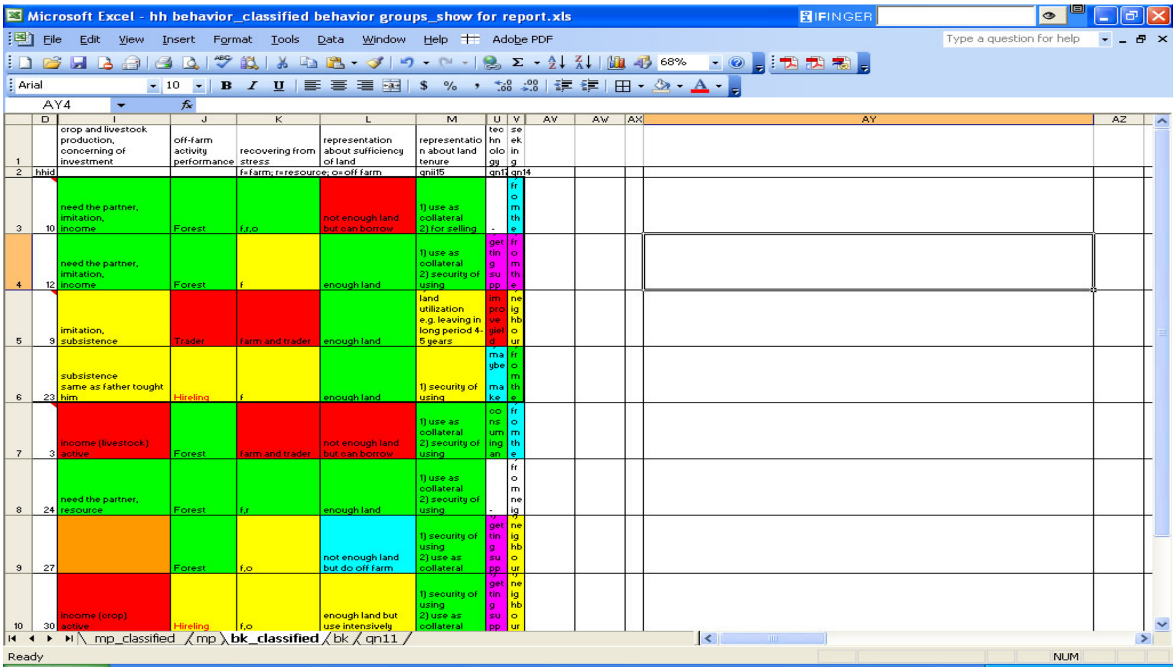


Figure 18: Classification of household in steps of consideration of common aspects under each category through vertical dimension

Source: Own qualitative analysis

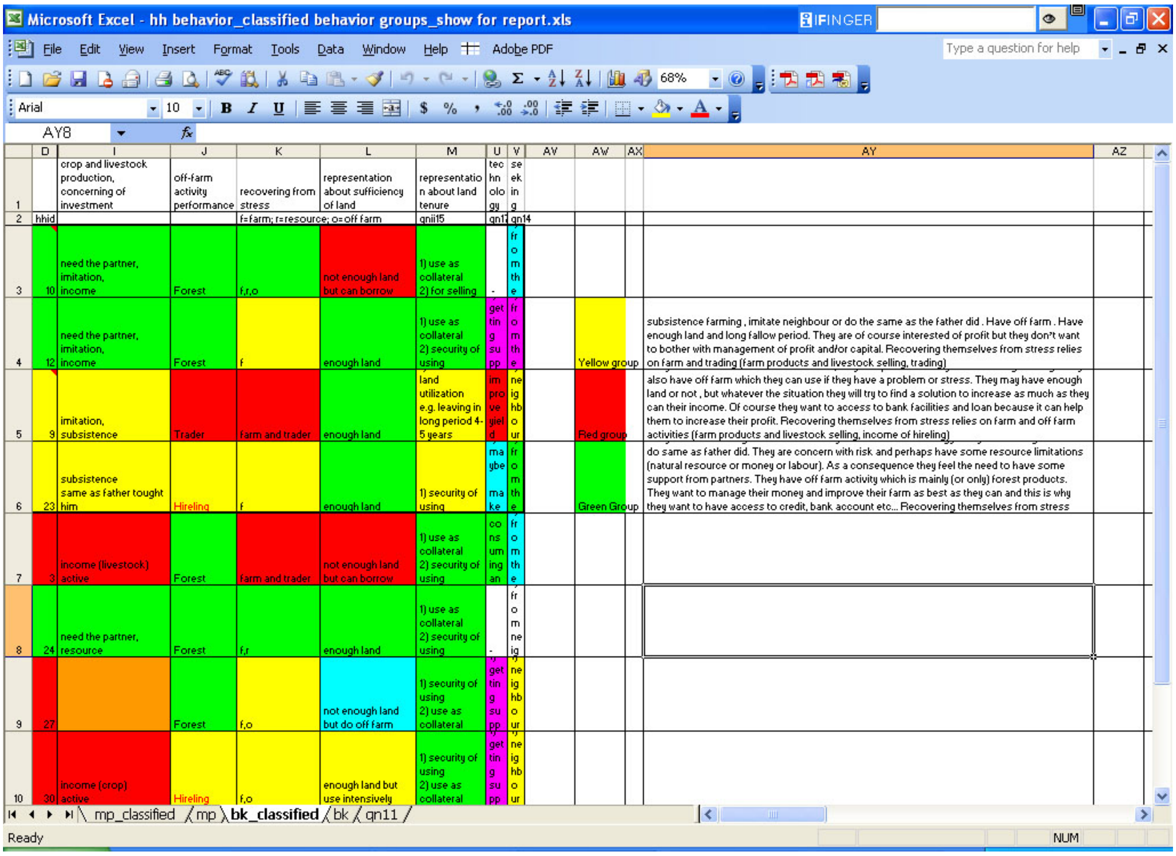


Figure 19: Classification of household in final step
Source: Own qualitative analysis

From this qualitative analysis, the results show that the farm households in Bor Krai village can be classified into three groups in regard to their behaviour, opinion, and decision making aspects in farming and household activities as shown in Table 15. The first group denoted by yellow colour in the analysis performs as subsistence farming and imitate their neighbours or do the same as their original family experience. Also, they occasionally do off-farm activities in order to fulfill their income needs. In their opinion, they have enough land which they can take long fallow period for cropping in plots. In addition, they are of course interested in profit but they do not want to bother with management of profit and/or capital. When facing stress, recovering from stress depends on farm and trading farm products and forest products.

Table 15: Result of qualitative analysis for Bor Krai village

id	crop and livestock production, concerns of investment	off-farm activity performance	recovering from stress	representation about sufficiency of land	representation about land tenure	technology adoption	seeking for information
10	need the partner, imitation, income	Forest	farm, resource, off-farm	not enough land but can borrow	1) use as collateral 2) for selling	-	1) from the past knowledge of his family
12	need the partner, imitation, income	Forest	farm	enough land	1) use as collateral 2) security of using	1) getting support seed input 2) maybe make more income	1) from the past 2) neighbour
9	imitation, subsistence	Trader	farm and trading	enough land	1) free for land utilization e.g. leaving in long period 4-5 years 2) security of using 3) use as collateral	for improve yield of existing crop	1) neighbour
23	subsistence same as father taught him	Hireling	farm	enough land	1) security of using	1) maybe make more income	1) from the past
3	income (livestock) active	Forest	farm and trading	not enough land but can borrow	1) use as collateral 2) security of using	for consuming and selling	1) from the past of his family
24	need the partner, resource	Forest	farm and resource	enough land	1) use as collateral 2) security of using	-	1) from neighbour 2) other village
27		Forest	farm and off-farm	not enough land but do off farm	1) security of using 2) use as collateral	1) getting support seed 2) expected income	1) neighbour
30	income (crop) active	Hireling	farm and off-farm	enough land but use intensively	1) security of using 2) use as collateral	1) getting support seed 2) expected income	1) neighbour

Source: Own qualitative analysis

For the second group which is denoted by red, they are more market oriented farmers who are also quiet active in farming. They also do off-farm activities to complement their income in case of facing problems or stresses. In addition, they may or may not have enough land, but, whatever the situation they will try to find a solution to increase their income as much as they can. In addition, they want to access bank facilities and loans because it can help them to increase their funds and potential to invest for income. Further, when they encounter problems or stress they will recover themselves from stress by doing farm and off-farm activities such as selling farm products and hiring their labour.

In regard to the last group denoted by green, the households are also looking for income but they have a different strategy and they need partners to support. In farming, they imitate neighbours and do what their original family (parents and grandparents) did under situation of limited resources such as natural resources, cash, or labour. They are concerned with risk and as a consequence they feel the need to have some support from partners who can support them in either input or marketing needs. Besides, they want to manage their money and improve their farm as much as they can and this is why they want to have access to credit and banking facilities. Further, they do off-farm activities which is mainly (or only) forest product gathering. In the case of problems or stress, they recover themselves through farm, off-farm, and the household remaining resources (farm products and livestock selling, hiring of their labour, and collecting forest products).

3.4.3 Summary of farm household agent classification

In order to classify farm households into the characteristic behavioural groups, the results from quantitative and qualitative analysis will be compared and concluded under empirical evidences. The analysis presented in the two previous sections allows us to know the common characteristics of farm households based on each approach. However, some evidences slightly correlate to each other even though the results come from independent analysis.

As previously explained, the results show us the matching between quantitative and qualitative analysis. The group indicated as cluster 1 from quantitative analysis results matches with market oriented group denoted by the red colour from the qualitative analysis. Those results could be summarized together indicating that cluster 1 performs as young active farm in the way of market oriented with high education. Also, they are active in farming and try to find some funds or loans to improve their income. They are also involved in off-farm activities which can improve their income sufficiency and be used as a means to recover themselves when facing stress. Further, by taking quantitative data the profile of the sample groups resulting from qualitative analysis can be shown in Table 16. In the table, the parameters illustrate that the red group is relatively young with high education. Also, they have limitation of land and labour as indicated by relatively low figures in both items.

Table 16: Profile based on first data set of farm households classified by qualitative analysis for Bor Krai village

Items		group			Total
		red	green	yellow	
No. of households	Valid N	N=3	N=3	N=2	N=8
Age	Mean	26	40	40	35
Level of education	Mode	Primary school	No education	No education	Primary school
Total land holding area (ha)	Mean	2.08	3.73	3.06	2.95
No. of household members (person)	Mean	4	4	4	4
No. of labour (person)	Mean	2	3	3	3
Off-farm income (Baht[16])	Mean	8,166.67	22,233.33	159,400.00	51,250.00
net household income (Baht)	Mean	4,169.87	15,706.50	153,689.41	45,875.99
net cash farm income (Baht)	Mean	21,924.28	10,825.67	33,536.03	20,665.24
Having loan (Baht)	Mean	56,266.67	85,000.00	464,500.00	169,100.00

Source: Own analysis

Thus, we can assume with reasonable accuracy that farmers in cluster 1 generally behave as market oriented farmers coloured in red in qualitative analysis. However, because of the small sample size and difference of classification approach the results in some items are different from the profile summarized by cluster analysis.

For cluster 3 which is considered as traditional farm households, it is similar to the yellow group in qualitative analysis. The matching aspect is that they are rather traditional farm households and doing subsistence farming with no education but have relatively high land and labour resources. That is why they behave in a traditional way and do not want to bother with management for profit purposes and imitate neighbours or their family experience. In addition, they have relatively high land holding area; therefore, they can take long fallow periods in plot rotation. This evidence can be observed as traditional farming by

[16] Thai currency with 1 Baht equivalence to 0.02 Euro

the relatively older head of households with low levels of education in Table 16. However, the correspondences in the Table 16 are not totally showing some characteristics in the same way as previous quantitative result because there is an outlier that makes some disturbance and the result in the Table 16 is calculated from a small sample size. But, after further consideration of both previous analyses and some reasonable parameters in Table 16 we can make an assumption that farmers in cluster 3 follows a subsistent behaviour as the group denoted by yellow in the qualitative analysis.

For the cluster 2 which has a combination of characteristics between the previous two clusters, the comparative correspondences between the groups in Table 16 are not clear which is probably because of the small sample size. However, the correlation is close to the group denoted by green from the qualitative analysis. The mixed characteristics of this cluster are reflected through behaviour of doing different strategies to acquire their income either in a traditional or income oriented way. These strategies may also come from imitating their neighbours or behaving in a similar way to their original family. However, they will try to find partners to support either input or marketing in doing innovative activities. In addition, limitations of labour and low income both off-farm and net household income from cluster analysis correlate to limitation of resources and the need to have greater access to banking facility for credit. Even from Table 14 we do not have as much evidence like the case of the red group but with the close correlation of both summaries in quantitative and qualitative analysis we can make the assumption that the cluster 2 behave as a green group in qualitative analysis.

Consequently, by considering the assumptions of correlation that have been explained previously we can make conclusions on the household behaviour groups of the study area. The groups consist of three types of farm household behaviour groups which are: the market oriented (young active farm), the subsistence oriented (traditional farm), and the partnership oriented (combination characteristic farm) farm group relating to cluster 1, cluster 3, and cluster 2 from quantitative analysis and behaving same as the red, yellow, and green behaviour group from the qualitative analysis respectively. Also, the characteristics of each agent type are determined by household aspects from the quantitative analysis which have been shown in the Table 17

Table 17: Characteristics of farm household sample groups of Bor Krai village

Items	Group of farm household samples		
	Market oriented group	Subsistence oriented group	Partnership oriented group
Age of household leader	26	44	35
Education	Primary school	Illiteracy	Illiteracy
Land holding size (ha)	2.68 ha	5.36 ha	4.02 ha
No. of household member (persons)	3	6	4
No. of member as agricultural labour (persons)	2	4	2
Off-farm income (Baht[17])	20,400.00	13,613.33	6,228.00
Net household income (Baht)	7,319.32	10,595.38	-5,589.75
Net cash farm income (Baht)	14,884.80	24,871.38	12,371.78
Amount of loan (Baht)	22,114.29	24,833.33	29,285.71

Source: Own analysis

From Table 17, the farm household samples can be classified into three groups which are market oriented, subsistence oriented, and partnership oriented group. The profile of their characteristics are also summarized and presented in the Table.

Regarding summarized description, the market oriented group somewhat pursues their agricultural practice as semi-commercial farming systems. Even when they produce for subsistence, their behaviour tends to rely more on their decisions to generate cash as much as possible. Their behaviour is partly determined by their characteristics and resource endowment conditions. The farm household samples in this group are the young active farm households which have just started their own farm enterprises. Also, they have limitations of land and labour because they are new farms separated from their original family. On average, they have only 2.68 ha and the couple is the main source of labour in the farm. Due to this limitation of resources to produce for consumption, they actively try to get cash to fulfill their consumption needs. The possible activities can either be selling crop farm products or off-farm activities such as hiring labour, trading, and selling forest products. Consequently, the profile table shows that cash acquisition for this group is relative high and this can partly cover household private expenditures. Besides, with relative high education they are smart and try to find as much information as possible to help them in their farming decision making. These attempts are devoted in getting better information about crop choice, price of crop and other products, need for off-farm labour, etc which the extent of searching is in both

[17] Thai currency with 1 Baht equivalence to 0.02 Euro

within and outside village. Furthermore, this group accepts greater risk taking in investment in order to generate cash and consequently they prefer to access borrowings to enhance their ability of investment.

The second group of farm household samples is identified as a subsistence oriented group which behaves as subsistence farming systems. Also, they are traditional farm households with a large number of household members. Because of high land and labour resources, they have the potential to generate high net cash farm income compared to other groups and are free to take off-farm activities to increase household income. Besides, this group has older household heads with no education hence decision making depends on their experience and confidence. They are risk averse and many times they keep away from investment in innovation. Accordingly, their decisions rely on their experience or even imitation from their neighbours. However, they need to access loans, mainly for consumption and some for farming.

For the last group, they have mixed characteristics of the previous two groups. The average age is 35 years old which is between the two previous groups while they have higher land size than the market oriented group but less than the subsistence oriented group. With limitation of labour, 2 persons, they perform well for net cash farm income which is slightly closer to the income of the market oriented group. But, they earn quite low off-farm income; therefore, it makes their net household income to be relative low. They are also active and consider the innovations to improve their income and need support from partners who probably provide them with input, loan, or marketing support. In farming, they imitate neighbours and do the same as their original family did under resource limitation situation. They are concerned with risk and accordingly they feel the need to have some support from partners who can support them in either input or marketing supports. Besides, they want to manage and improve their farm as best as they can and to do this they need access to the bank facilities. Further, they often do off-farm activities especially gathering forest products. In the case of stressful circumstances, they recover from stress through selling farm and other household resources as well as doing some off-farm activities.

At this point the results from quantitative and qualitative analysis all 32 sample farms have finally been revised again based on the key significant characteristics required for the generated agents. Accordingly, the conclusion can be made that there are only 30 farm household samples that are reasonable and able to be assigned as farm household agents in the model with the other two samples considered as outliers. The market oriented group consists of 9 samples while the subsistence and partnership oriented group consists of 11 and 10 samples respectively. However, for this study the framework is to model and extrapolate the farming systems of the area with the number of heterogeneous farm household population. Therefore, Monte Carlo technique is applied to generate another 30 more farm agents based on the samples' information (Schreinemachers, 2006). By this technique, in each sample farm group the number of generated farm agents which is equal to number of agents in the corresponding sample farm group are created and their initial attributes are determined through empirical cumulative distribution functions (Schreinemachers, 2006). The empirical cumulative distribution functions of the significant attributes concerning the conceptual model are estimated and used for the generated farm agents' initial attribute determination. These attributes consist of the farm's characteristics which are: number of members, cash, debt, amount of rice, amount of maize, number of livestock, and number of fruit plots. The functions are then estimated based on attributes of the sample farm households (Figure 20). For example, Figure 20 shows the empirical cumulative distribution functions for the number of holding plots for each farm sample group.

The Figure shows that, for instance, the first 44 percent of households in market oriented group have 11 plots while the following next 11 percent have 12 plots. In case of the subsistence oriented group, the first 18 percent of households have 14 plots and the following 9 percent have 17 plots. The estimated empirical cumulative distribution functions are used for all significant attributes of the generated farm household agents. The procedure starts with generating a random number between 0 and 100 and then the number of the attribute value (e.g. number of holding plots) is read from the y-axis of the corresponding attribute's cumulative function. This process is repeated for each attribute of each generated farm agent until all attributes of all agents have been assigned. All attribute values are then fixed as the initial state of the generated agents for simulation.

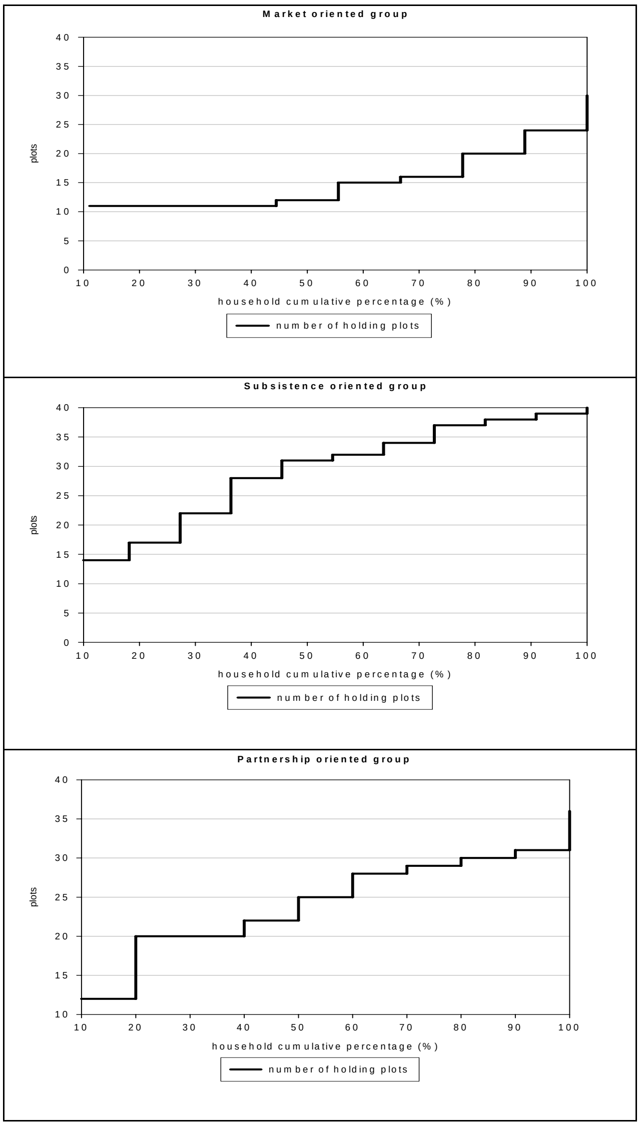


Figure 20: Number of holding plots empirical cumulative distribution functions of each sample farm household group
Source: Own calculation

In addition, consistency tests are conducted at two levels which are the cluster and population level to determine if the farm agents are realistic (Schreinemachers, 2006). The descriptive statistic values which are mean, standard error, standard deviation, variance, median, and confidence interval of the surveyed data and agent population are calculated. The tests are conducted by comparing the descriptive statistic results between the surveyed agent and agent population which are presented in the Table 18 as the test at the population level and the Table 19 – 21 as the test at the cluster level. The results of both levels show the good agent reproduction which the mean values of the agent population are within the confidence interval and very close to the mean value of the surveyed sample agents. In addition, the difference of the other statistic values which are standard error, standard deviation, variance, and median of agent population and surveyed sample agents is small. Therefore, a conclusion can be made that the agent population has a good replication which represents reality and similarity to the surveyed agent aspects.

Table 18: Agent population consistency test at population level results

Characteristics	Population	N	Mean	S.E.	S.D.	Variance	Median	Confidence interval	
household members	Survey	30	4.43	0.24	1.33	1.77	4.00	3.94	4.93
	Agent	60	4.43	0.17	1.32	1.74	4.00		
household cash	Survey	30	16,443.17	2,714.19	14,866.22	221,004,608.87	10,432.02	10,892.04	21,994.31
	Agent	60	16,220.54	2,005.35	15,533.35	241,284,882.71	10,815.35		
household debt	Survey	30	19,793.33	2,276.73	12,470.16	155,504,781.61	24,000.00	15,136.90	24,449.77
	Agent	60	19,303.33	1,683.05	13,036.82	169,958,632.77	24,000.00		
rice store	Survey	30	838.14	47.06	257.78	66,449.92	914.29	741.88	934.40
	Agent	60	835.72	30.53	236.48	55,921.92	897.49		
feed stuff store	Survey	30	370.67	4.76	26.07	679.43	370.67	360.94	380.41
	Agent	60	370.44	3.46	26.78	717.17	372.07		
number of plots	Survey	30	24.50	1.70	9.32	86.88	24.50	21.02	27.98
	Agent	60	24.42	1.24	9.58	91.70	25.00		
number of pigs	Survey	30	3.83	0.39	2.15	4.63	4.00	3.03	4.64
	Agent	60	3.72	0.28	2.17	4.71	4.00		
number of piglets	Survey	30	4.90	0.70	3.85	14.85	5.00	3.46	6.34
	Agent	60	4.78	0.51	3.98	15.87	5.00		
number of chicken	Survey	30	18.37	2.97	16.26	264.52	10.00	12.29	24.44
	Agent	60	18.87	2.28	17.62	310.59	10.00		
number of cows	Survey	30	3.73	0.76	4.18	17.44	3.00	2.17	5.29
	Agent	60	3.82	0.57	4.38	19.17	3.00		
number of buffalos	Survey	30	2.27	0.55	3.04	9.24	0.50	1.13	3.40
	Agent	60	2.25	0.39	3.01	9.04	1.00		
number of fruit plots	Survey	30	2.63	1.04	5.72	32.72	1.00	0.50	4.77
	Agent	60	2.52	0.72	5.60	31.30	1.00		

Source: Calculation

Table 19: Results of agent population consistency test at cluster level of market oriented group

item	Population	N	Mean	S.E.	S.D.	Variance	Median	Confidence interval	
household members	Survey	9	3.44	0.18	0.53	0.28	3.00	3.04	3.85
	Agent	18	3.39	0.12	0.50	0.25	3.00		
household cash	Survey	9	24,728.98	5,616.85	16,850.54	283,940,797.83	24,160.44	11,776.51	37,681.46
	Agent	18	21,362.98	3,981.57	16,892.36	285,351,771.32	17,018.76		
household debt	Survey	9	16,977.78	4,265.03	12,795.09	163,714,444.44	20,400.00	7,142.60	26,812.96
	Agent	18	14,233.33	3,080.67	13,070.17	170,829,411.76	20,000.00		
rice store	Survey	9	684.36	72.27	216.80	47,003.61	594.19	517.71	851.01
	Agent	18	661.04	43.91	186.30	34,707.58	567.34		
feed stuff store	Survey	9	348.77	6.29	18.86	355.83	344.11	334.27	363.27
	Agent	18	346.13	4.29	18.19	331.04	335.72		
number of plots	Survey	9	16.67	2.25	6.75	45.50	15.00	11.48	21.85
	Agent	18	15.72	1.53	6.51	42.33	12.00		
number of pigs	Survey	9	4.00	0.90	2.69	7.25	4.00	1.93	6.07
	Agent	18	3.56	0.64	2.73	7.44	3.00		
number of piglets	Survey	9	6.33	1.76	5.29	28.00	8.00	2.27	10.40
	Agent	18	5.44	1.29	5.47	29.91	6.00		
number of chicken	Survey	9	10.78	3.07	9.22	84.94	10.00	3.69	17.86
	Agent	18	9.11	2.18	9.25	85.63	10.00		
number of cows	Survey	9	2.89	0.48	1.45	2.11	3.00	1.77	4.01
	Agent	18	2.61	0.35	1.50	2.25	2.00		
number of buffalos	Survey	9	2.00	1.01	3.04	9.25	0.00	-0.34	4.34
	Agent	18	1.67	0.66	2.81	7.88	0.00		
number of fruit plots	Survey	9	1.00	0.50	1.50	2.25	0.00	-0.15	2.15
	Agent	18	0.83	0.33	1.38	1.91	0.00		

Source: Calculation

Table 20: Results of agent population consistency test at cluster level of subsistence oriented group

item	Population	N	Mean	S.E.	S.D.	Variance	Median	Confidence interval	
household members	Survey	11	5.82	0.26	0.87	0.76	6.00	5.23	6.41
	Agent	22	5.82	0.18	0.85	0.73	6.00		
household cash	Survey	11	16,117.39	4,944.44	16,398.85	268,922,327.00	10,048.69	5,100.49	27,134.29
	Agent	22	18,028.73	3,978.96	18,662.97	348,306,413.82	11,788.67		
household debt	Survey	11	21,818.18	3,263.62	10,824.22	117,163,636.36	25,000.00	14,546.38	29,089.99
	Agent	22	22,136.36	2,309.68	10,833.35	117,361,471.86	26,000.00		
rice store	Survey	11	899.62	85.25	282.75	79,948.68	1,013.89	709.66	1,089.57
	Agent	22	903.59	52.21	244.88	59,965.65	997.09		
feed stuff store	Survey	11	386.56	7.58	25.13	631.60	391.65	369.68	403.45
	Agent	22	386.94	5.28	24.75	612.51	394.44		
number of plots	Survey	11	30.18	2.71	8.99	80.76	32.00	24.14	36.22
	Agent	22	30.32	1.89	8.85	78.32	33.00		
number of pigs	Survey	11	4.18	0.69	2.27	5.16	5.00	2.66	5.71
	Agent	22	4.18	0.47	2.22	4.92	5.00		
number of piglets	Survey	11	4.09	1.09	3.62	13.09	4.00	1.66	6.52
	Agent	22	4.36	0.83	3.87	15.00	4.50		
number of chicken	Survey	11	23.55	6.06	20.11	404.27	20.00	10.04	37.05
	Agent	22	25.36	4.64	21.74	472.81	25.00		
number of cows	Survey	11	4.27	1.43	4.73	22.42	3.00	1.09	7.45
	Agent	22	4.59	1.09	5.11	26.06	3.00		
number of buffalos	Survey	11	2.55	1.15	3.80	14.47	0.00	-0.01	5.10
	Agent	22	2.64	0.81	3.77	14.24	0.50		
number of fruit plots	Survey	11	5.18	2.67	8.84	78.16	2.00	-0.76	11.12
	Agent	22	5.14	1.81	8.50	72.31	2.00		

Source: Calculation

Table 21: Results of agent population consistency test at cluster level of partnership oriented group

item	Population	N	Mean	S.E.	S.D.	Variance	Median	Confidence interval	
household members	Survey	10	3.80	0.29	0.92	0.84	4.00	3.14	4.46
	Agent	20	3.85	0.20	0.88	0.77	4.00		
household cash	Survey	10	9,344.31	1,901.42	6,012.82	36,154,021.79	7,879.86	5,043.00	13,645.62
	Agent	20	9,603.34	1,304.56	5,834.17	34,037,529.66	8,708.23		
household debt	Survey	10	20,100.00	4,607.84	14,571.28	212,322,222.22	25,000.00	9,676.33	30,523.67
	Agent	20	20,750.00	3,235.39	14,469.11	209,355,263.16	26,000.00		
rice store	Survey	10	908.92	70.48	222.86	49,668.47	966.34	749.49	1,068.35
	Agent	20	918.27	41.78	186.84	34,907.94	972.49		
feed stuff store	Survey	10	372.91	6.14	19.42	377.20	376.27	359.02	386.80
	Agent	20	374.17	4.26	19.07	363.75	380.46		
number of plots	Survey	10	25.30	2.20	6.95	48.23	26.50	20.33	30.27
	Agent	20	25.75	1.53	6.82	46.51	28.00		
number of pigs	Survey	10	3.30	0.47	1.49	2.23	3.00	2.23	4.37
	Agent	20	3.35	0.33	1.46	2.13	3.00		
number of piglets	Survey	10	4.50	0.73	2.32	5.39	4.50	2.84	6.16
	Agent	20	4.65	0.51	2.30	5.29	5.00		
number of chicken	Survey	10	19.50	4.86	15.36	235.83	15.00	8.51	30.49
	Agent	20	20.50	3.34	14.95	223.42	20.00		
number of cows	Survey	10	3.90	1.68	5.32	28.32	3.00	0.09	7.71
	Agent	20	4.05	1.15	5.16	26.58	3.00		
number of buffalos	Survey	10	2.20	0.73	2.30	5.29	2.50	0.55	3.85
	Agent	20	2.35	0.49	2.18	4.77	3.00		
number of fruit plots	Survey	10	1.30	0.63	2.00	4.01	0.50	-0.13	2.73
	Agent	20	1.15	0.39	1.73	2.98	1.00		

Source: Calculation

3.5 Implementation of the model

The conceptual model of CatchScapeFS model which is based on the object-oriented modelling approach is implemented as the computer model for this study. The model is available under request to fecocrp@ku.ac.th. As the technique is rather a new approach of social science simulation (Gilbert and Troitzsch, 1999) and application to specific areas with unique features requires a particular model to address the research question, there is no commercial application software available. For this study, implementation of the model is performed through a platform called Common-Pool Resources and Multi-Agent Systems (CORMAS) developed by the Green research unit from the French Agricultural Research Centre for International Development (CIRAD) (Bousquet et al., 1998; Le Page and Bommel, 2005). The platform facilitates pre-existing entities and agents with their relation that are useful for incorporating biophysical and socioeconomic entities corresponding to real world system elements. In addition, the pre-existing entities are embedded by mechanisms such as location, perception, movement, communication, etc which can be re-used by relevant entities defined for the specific model. The compatible object-oriented programming language, SmallTalk, is used and programming is performed through CORMAS's interface (Figure 21).

The four main window interfaces of the platform guide the implementation of the model and control the simulation process. The first window interface is the main window which provides five menus to manage and manipulate the model. The File menu is designed to operate the file of the model in regard to opening, closing, saving, and exiting from the model. The second menu is the Program menu which leads to management and implementation of all entities of the model, controlling of the simulation process, and pointing out what is needed to be observed during the simulation. The next menu is the Visualization menu which contains options to visualize observed points on graphs, spatial entities, and passing messages during simulation. The forth menu, the Simulation menu, provides the simulation interface which is the main part used to control the simulation. The last menu, the Help menu, offers information on the model and the ability to switch to another CORMAS interface.

The second window interface is obtained through the selection of “the class for each entity” on the File menu at the first window interface. The window provides visualization of entity classes implemented in the model which are divided into 3 categories –Spatial, Agent, and Passive entity classes. The implemented entity classes are accessed through this window in order to manage and schedule the attributes and methods of the entity class.

The third window interface is activated through the Simulation menu of the first window. This window is used to control the simulation, for example, start and stop simulation, determination of number of simulation time steps, determination of setting parameters for sensitivity analysis, specification of simulation initial state, process, and outputs.

The forth window is the user interface window which is developed to provide information during simulation e.g. indication of season, decade, month, year, amount of rain of each time step. In addition, its special feature allows selecting attribute of spatial entity as point of view showing in the spatial user interface (next window) and accessing to the model instance which is useful for inspection the instances of model.

The last window is the spatial user interface used to display spatial grids representing the plots in reality. The visualization can be presented in many aspects of spatial entity corresponding to the state of its attribute such as land use presenting agricultural area, residential area, and forest area.

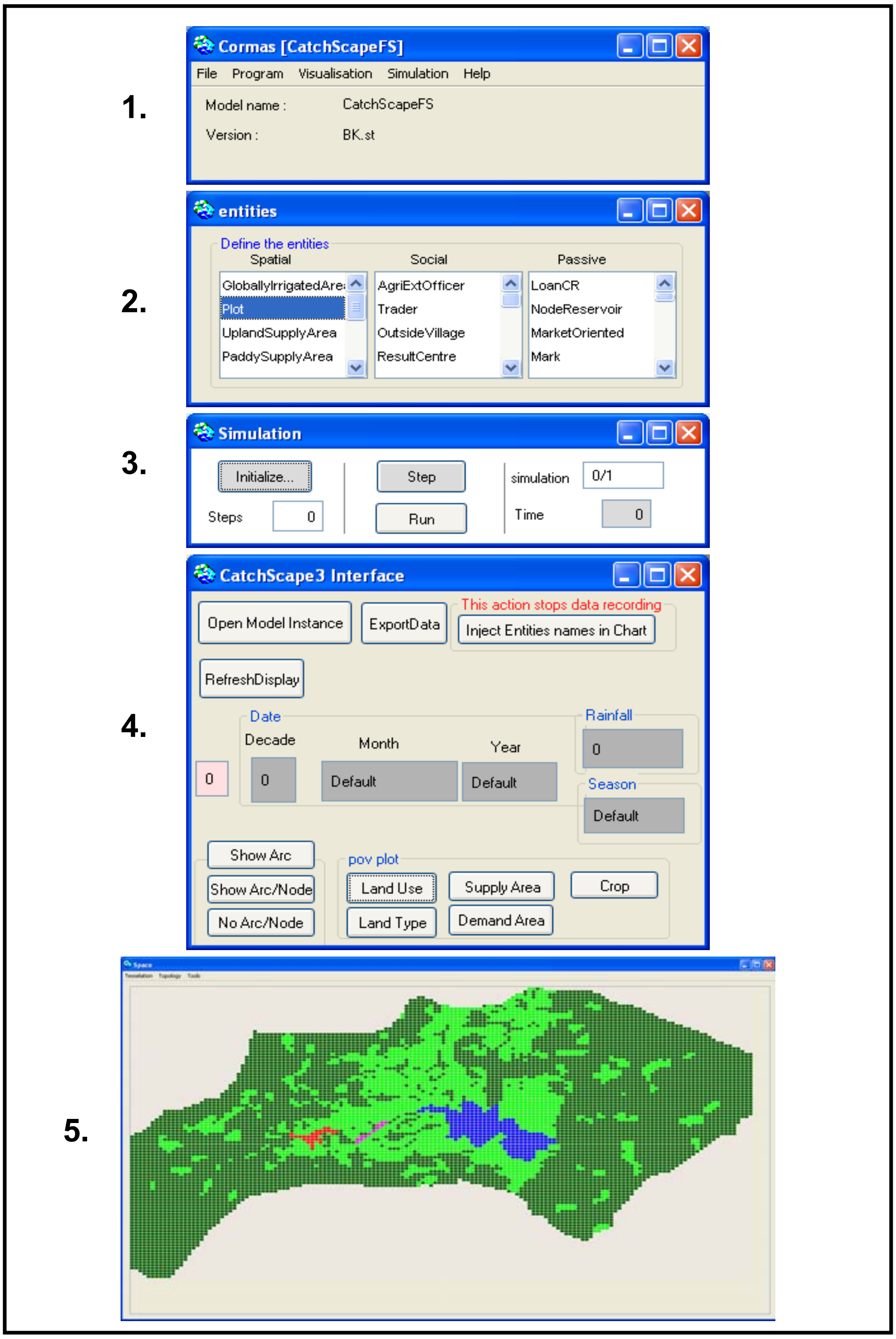


Figure 21: CORMAS user interface windows

3.6 Model validation and stability testing

The CatchScapeFS model in a computerized form is debugged and tested for validation. Validation is conducted in two ways which are social validation and statistic data comparison validation. At first, the social validation is carried out and its results are used to correct and improve the model. Based on the corrected and improved model, simulations are continued and the obtained results are used to compare with statistic data for the second validation. The validation description is described below.

3.6.1 Social validation

1) Social validation (Castella et al., 2005) is performed relying on the diagram participatory elicitation approach. The process focuses on the most important stakeholder, the farm household, whose roles are considered as the center of the farming systems in regard to decision making of resource allocation. The technique contributes corroboration regarding the farm household's decision making process based on survey and observation in area under assumptions. Additionally, the modelling process of this study is challenging because it needs to capture the complexity of the system in reality. Participation of significant stakeholders leads to acquisition of additional data which is useful for comprehension in the cause and effect relationships that drive stakeholders' behaviours under complex situation. Further, this process allows participation of stakeholders in model development together with a bottom-up modelling approach.

The process of social validation was held in March 2006. At first, four households of each behaviour group –market oriented, subsistence oriented, and partnership oriented group– are randomly selected and involved in an active participatory session. The session starts with introduction of the research project –objective, methods, outputs, and expected advantage of the research to the farm households and village– which is a recollection about the research that have been introduced before during the survey in 2005. Additionally, the research work that has been conducted after the last survey is presented to depict and bring more understanding between the research project and participants which aids collaboration in process. Explanation is carried out together with a complementary chart prepared as a simple mediation for collective representation and comprehension (Figure 22). The participants are allowed to ask questions and raise their opinions and suggestions at all processes during the session. The flow charts of the decision making processes regarding decision on using plots, choosing crops, selling crop products, and raising livestock are presented and discussed with participants (Appendix Figure 2 – 5). Additional data, opinions, and suggestions obtained during discussions are recorded and concluded to improve and validate the model afterwards.

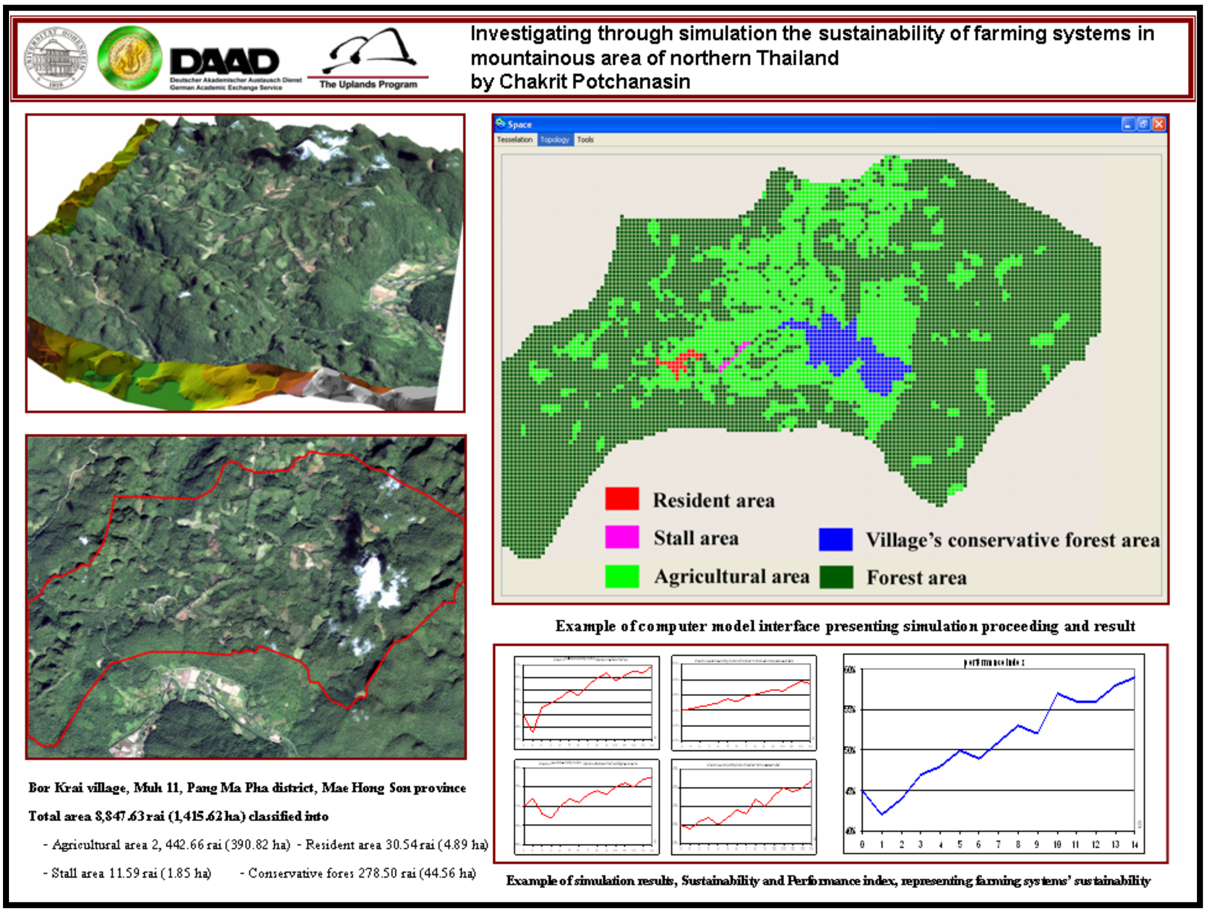


Figure 22: Chart presented in social validation process

Relying on flow charts of the decision process, validation results can be concluded as follows.

1) Concerning the flow chart of using plot decision, farm households confirmed that the process is similar to their decision making. They decide to use their plots to produce for consumption as the first priority. Considering the fallow period of the plot is also a significant factor where normally plots with more than two years fallow are considered for cultivation. However, exceptions can occur if land is still needed to reach the consumption level, therefore, in this case using plots that are less than two years fallow is accepted. Additionally, in situations of reaching the required consumption level the remaining plots with more than

two years will probably be used for cash crop production. Choosing a cash crop to grow follows the flow chart of decisions presented in next section.

2) As following the using plot decision process, the flow chart of choosing crop decision making is presented and discussed. In overall structure, the concept of choosing crop of farm households is based on the demand for consumption. After that, cash crops varying by farm household group information are chosen depending on factors which are: fallow period of plot, labour, and cash. Further, the farm households are requested to rank the crops which may be chosen when considering available resource conditions (quantity and quality) –land, labour, and cash–, market condition –price, market access, and market demand–, support condition –input support, and marketing support–. Also, the participants are asked for the trade-off between these conditions with the results showing that the market oriented group chooses cash crops by paying most attention to the market conditions and then available resources and support conditions respectively. This result can support analysis of farm household classification whereby this group tends to generate as much cash as possible in order to fulfill their income for consumption where there is a deficit because of farm production due to limitation of resources. The resource condition is the second interest factor because they have to consider resource availability and land quality which has to be suitable with the chosen crop.

The subsistence oriented group prefers to consider resource conditions as a priority which is consistent with the farm household classification analysis. This group has relatively more resource availability either land, labour, or cash and can produce enough for consumption. They tend to produce for themselves and so have to pay more consideration in resource conditions. Also, they consider support and market conditions as the second and third important conditions because with support they can obtain more products for consumption e.g. seed which is greatest concern of this group influencing their behaviour. Also, this group feels free to generate income to fulfill their consumption; therefore, they are not very interested in market conditions. For the last group, the partnership oriented group, they are interested in support conditions which can make them more confident in facing risk and this corresponds to the farm household classification analysis. In addition, they think about market conditions as the second important condition. Choosing crop that can generate more cash is preferable while the resource condition is the last important condition because they are not in a deficit situation in regard to resources for household production.

3) Flow chart of selling product decision process is slightly different from household performance in regard to how they choose market for selling their products. The farm households decide to sell their surplus products after having stored enough for consumption. However, this decision depends on whether there is demand and the price proposed is reasonable at that time. They prefer to sell their products in other markets instead of selling at local market close to the village or to traders who come to buy in the village directly. That is because if they sell at the local market they have to compete with similar products produced by other farm households in village. The products may be lost if they can not be sold within a particular time.

4) Process of raising livestock decision of the farm household follows only the first condition of consumption in flow chart diagram. The second condition which has been taken into account is household labour which initially is not included in the chart. After adding the second factor in the decision process, then they follow the chart which they consider cash condition to make decision.

These conclusions are used to validate and improve the model and the improved model is used for simulation. The results obtained from simulations are compared to the statistic data as the second validation of the model.

3.6.2 Statistic data comparison validation

Statistic data comparing validation (Bousquet and Le Page, 2004; Castella et al., 2005; Daniell et al., 2006) is undertaken by comparing the simulation and empirical data regarding land use (biophysical aspect) and income (socioeconomic aspect) performed by farm households and farm household agents. The results obtained from 35 simulations corresponding to year 2003 are compared to available statistic data of the same year. For land use comparison, total cultivated area and cultivated area of upland rice and maize are used while income comparison is accomplished by comparing 33 income items which are –cash crop income, non-cash crop income, total crop income, cash input cost, non cash input cost, total input cost, non-cash labour cost, cash fixed cost, non-cash fixed cost, total fixed cost, net cash crop income, net non-cash crop income, net crop income, cash livestock income, non-cash livestock income, total livestock income, net cash livestock income, net non-cash livestock income, net livestock income, net cash farm income, net non-cash farm income, net farm income, net cash off-farm income, net non-cash off-farm income, net off-farm income, household private expenditure, net cash household income, net non-cash household income, net household income, net cash household income without private expenditure, net non-cash household income without private expenditure, net household income without expenditure.

For land use comparison, the simulation results show that total cultivated area and cultivated area of upland rice and maize are close to land use statistic data in 2003 (Figure 23).

From the figure, the total cultivated area from simulation is less than the statistic data 4.12% or around 5.77 ha. The cultivated area of upland rice from simulation is more than statistic data 0.59% (0.32 ha) while maize cultivated area is less than 5.19% (3.05 ha). These results indicate that decision making of farm household agents in the model on land use corresponds to farm household in reality.

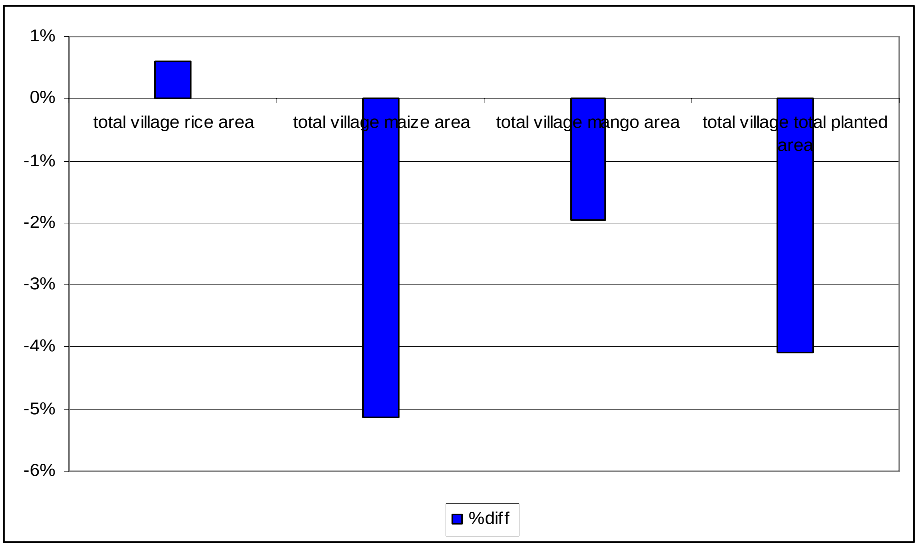


Figure 23: Percent of difference of land use between simulation results and statistic data in 2003
Source: Own simulation

In addition, the simulation results regarding income is close to statistic data of farm household income in 2003 (Figure 24). The results show a difference of less than 20% in most items except net cash household income and net household income (the sixth and forth column from last in Figure 24) which are less than the statistic data by approximately 30%

and 37% respectively. That is because farm household agents pay back loans at this year more than reality observed through private expenditure of farm household agent (the seventh column from last). Consequently, the net cash household income and net household income are less than statistic data. However, when considering net cash household income, net non-cash household income, net household income without private expenditure, these items are more than statistic data by only 1%, 8%, and 3% respectively. With these results, we can conclude that the model can reflect behaviour of the target system and represent farm household decisions and farming systems and the model can be used as the tool for capturing and monitoring farming systems and its sustainability situation in this study.

3.6.3 Test of model stability

The CatchScapeFS model is a stochastic model which in some cases have random variables that cannot be measured or determined (Gilbert and Troitzsch, 1999). For example, chances of getting a job as proposed by the labour market or appearance of forest products on plots cannot be measured and empirical data in specific areas that can explain this phenomenon is also missing. Therefore, simulations of the model usually obtain difference in outputs influenced by random effects in some processes. However, distribution of outputs should be in extent. Repetition results should not absolutely be different. Therefore, the test of consistency of the model is required. The test is performed by 35 simulations and afterwards selected items from the biophysical and socioeconomic components and sustainability assessment indicators are analyzed to indicate consistency of the model. The results of testing of the selected item categories are described below.

1) Socioeconomic component

For this component, the selected items consist of net crop income, net livestock income, net farm income, and net household income. Simulation outputs in regard to these items are presented in Figure 25 – 28. Each figure indicates consistency of the model by identical trend and small variation of results over the time of the simulations. Additionally, descriptive statistic values representing status and variation of the results at each point (year) (Table 22 – Table 25) can support consistency of the model by small values of standard deviation, standard error of mean, and range.

2) Biophysical component

By considering the selected items which are average yield per area of upland rice and maize, the simulation results can be concluded in the same way as the previous component (Figure 29 – Figure 30). Each graph indicates results of each item varying to a narrow extent and moving in the same direction. Also, descriptive statistic values which are standard deviation, standard error of mean, and range are small indicating consistency of the model (Table 26 – Table 27).

3) Sustainability assessment component

Performance index, Sustainability index of the net household income indicator (economic indicator), of food security indicator (social indicator), and of top-soil erosion indicator (environment indicator) are selected to test and represent consistency of the model. Similarly, the results of these items from simulations illustrate small variation and the same movement of result over time (Figure 31 – Figure 34). Further, small amount of descriptive statistic values –standard deviation, standard error of mean, and range– of each output item at each point of time indicates consistency of model when considering outputs of model from this component (Table 28 – Table 31).

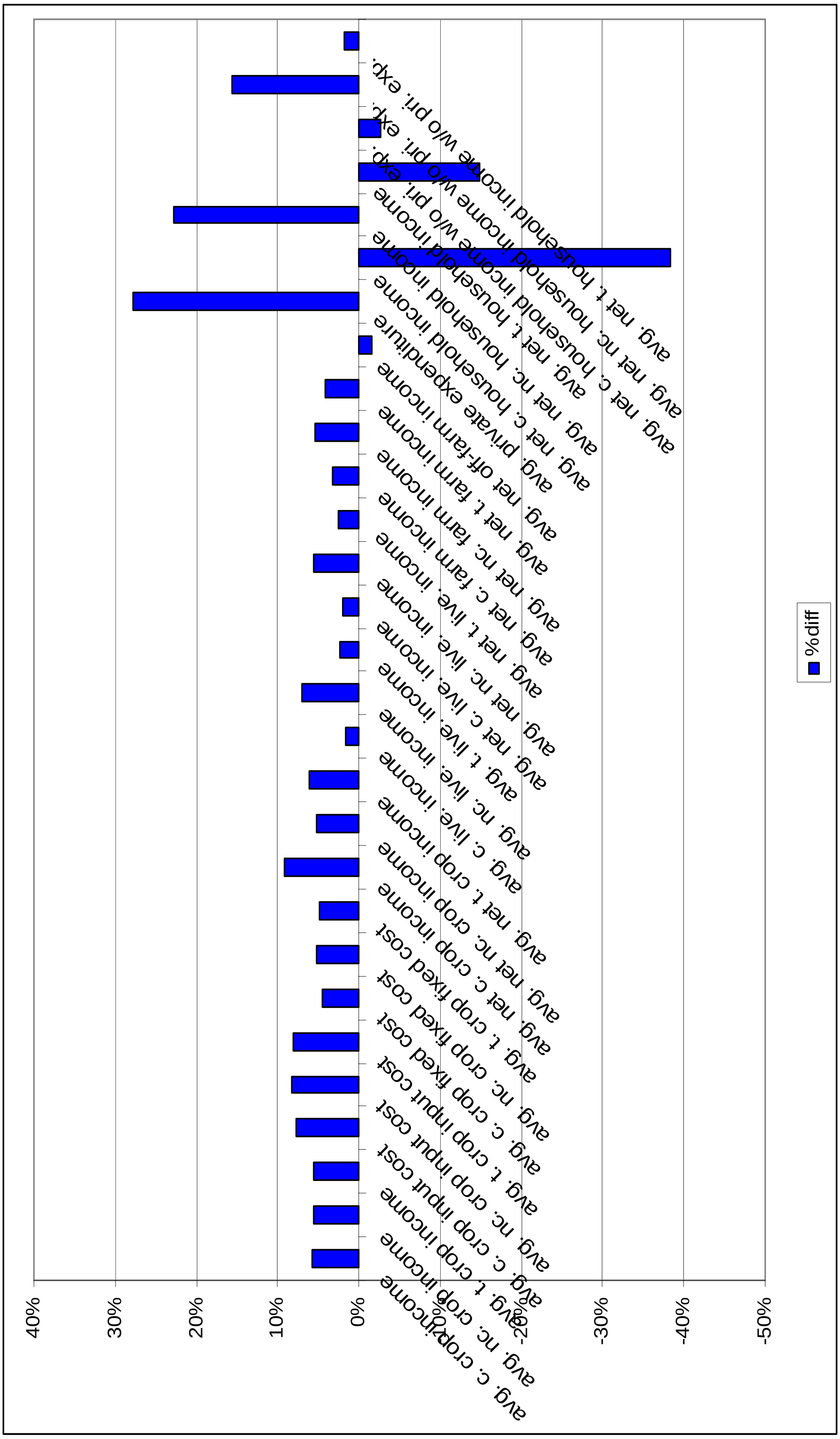


Figure 24: Percent of difference of income items comparing between statistic data and simulation result
Source: Own simulation

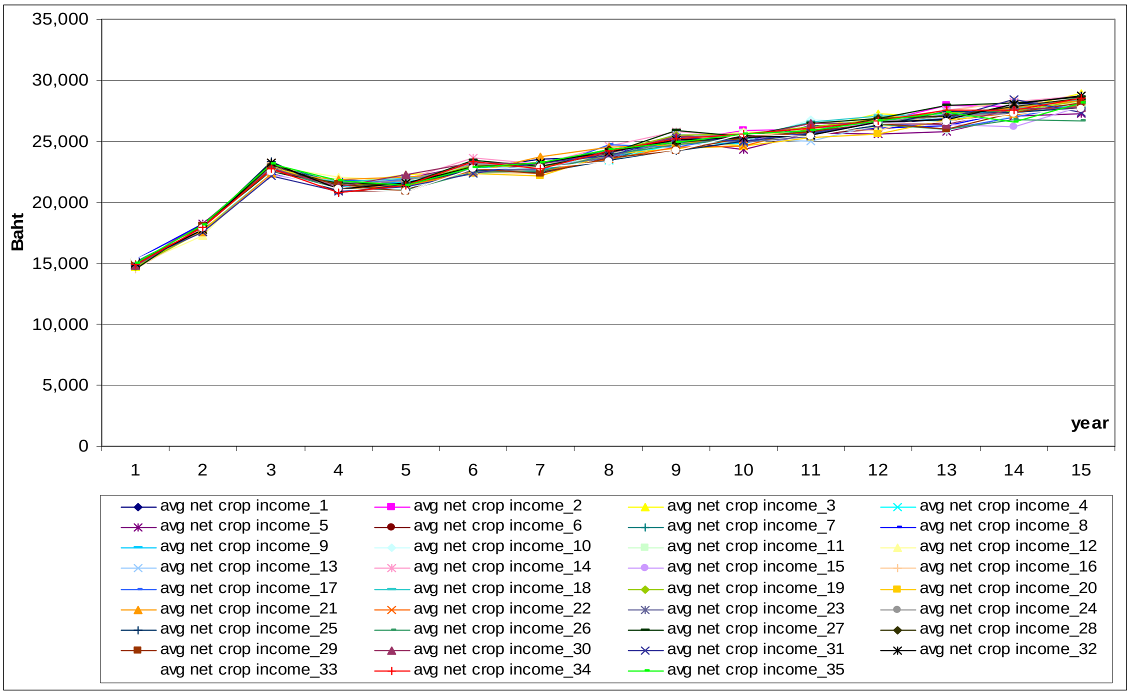


Figure 25: Average net crop income results of household generated by model simulations
Source: Own simulation

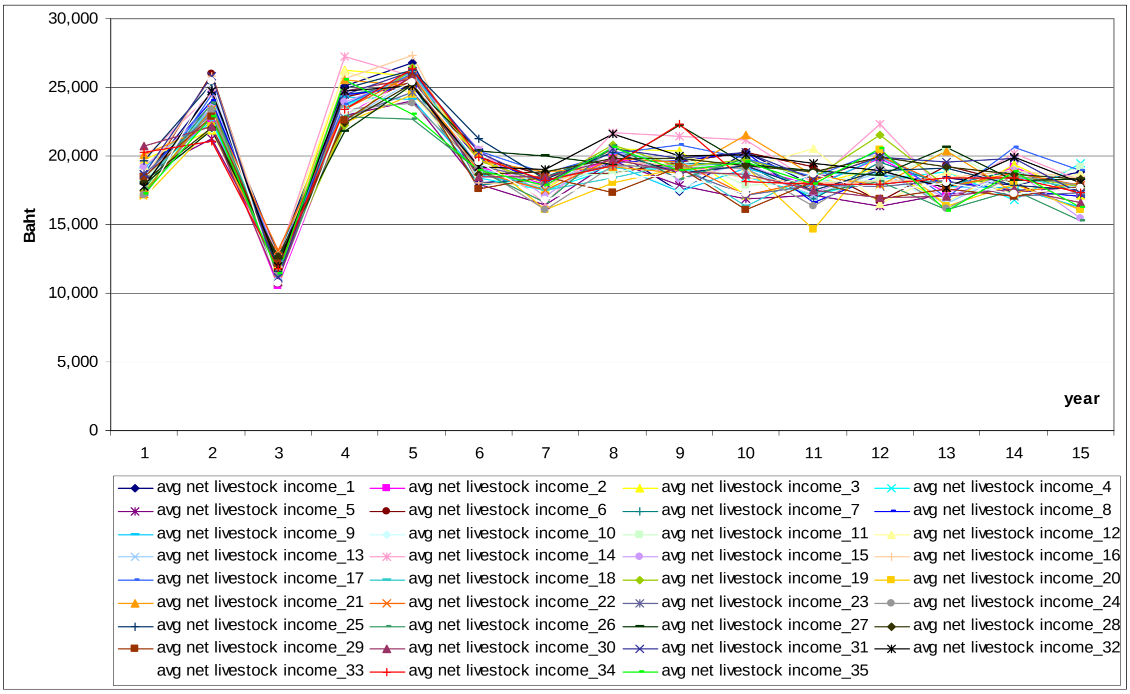


Figure 26: Average net livestock income of household results generated by model simulations
Source: Own simulation

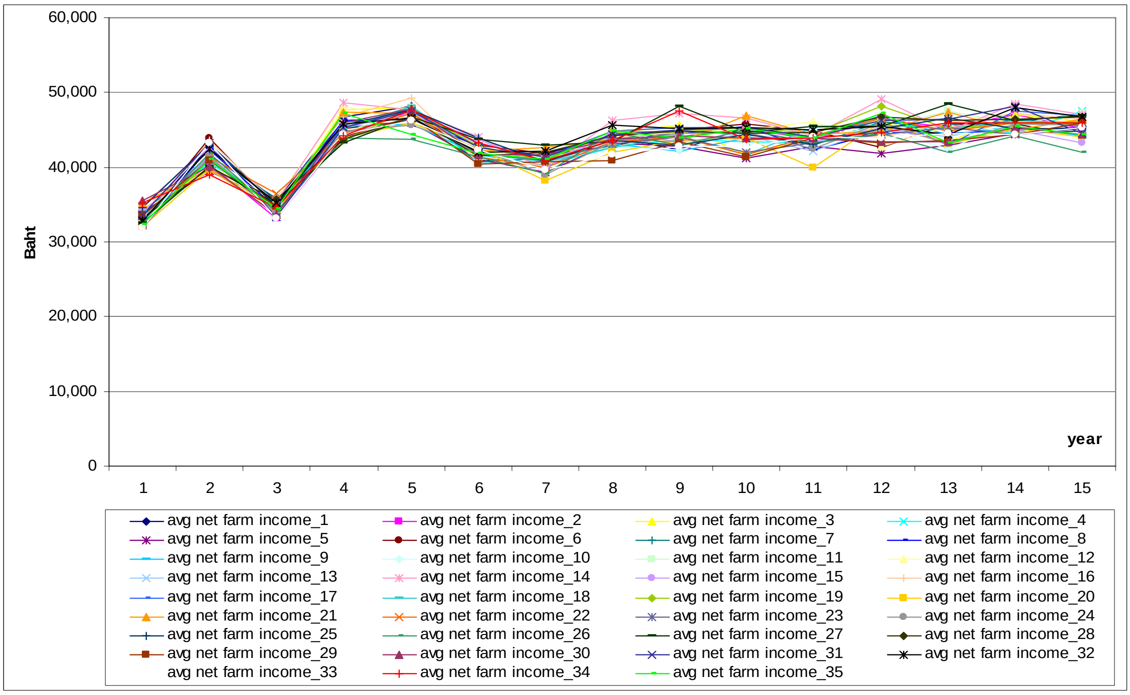


Figure 27: Average net farm income of household results generated by model simulations
Source: Own simulation

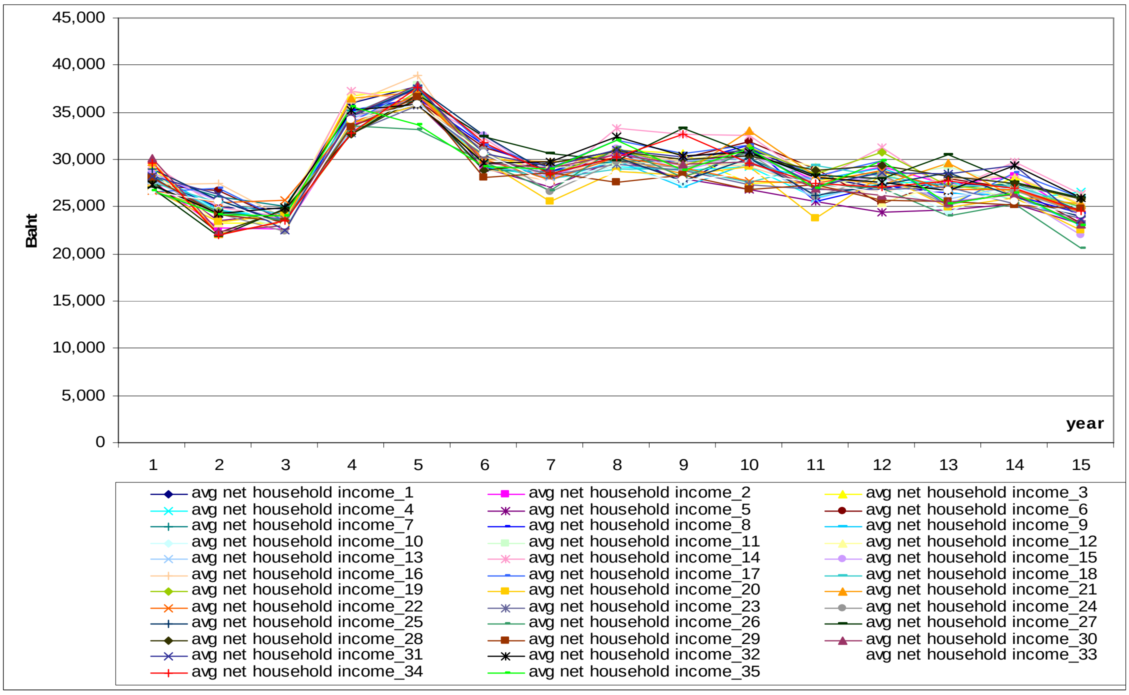


Figure 28: Average net household income of household results generated by model simulations
Source: Own simulation

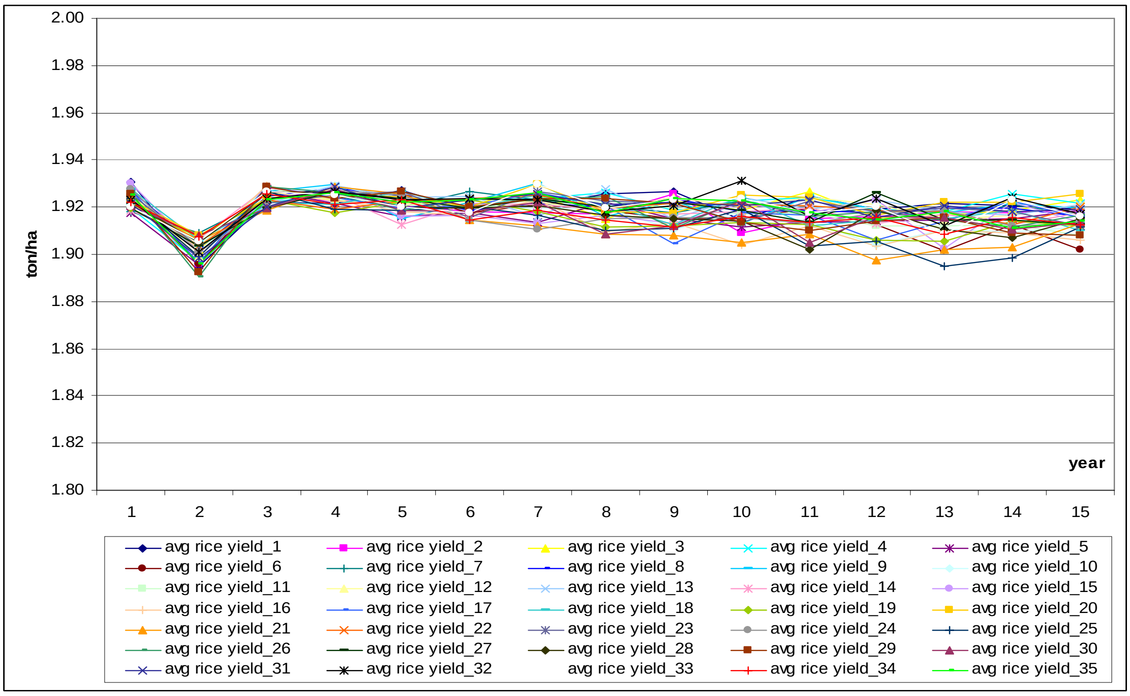


Figure 29: Average upland rice yield generated by model simulations
Source: Own simulation

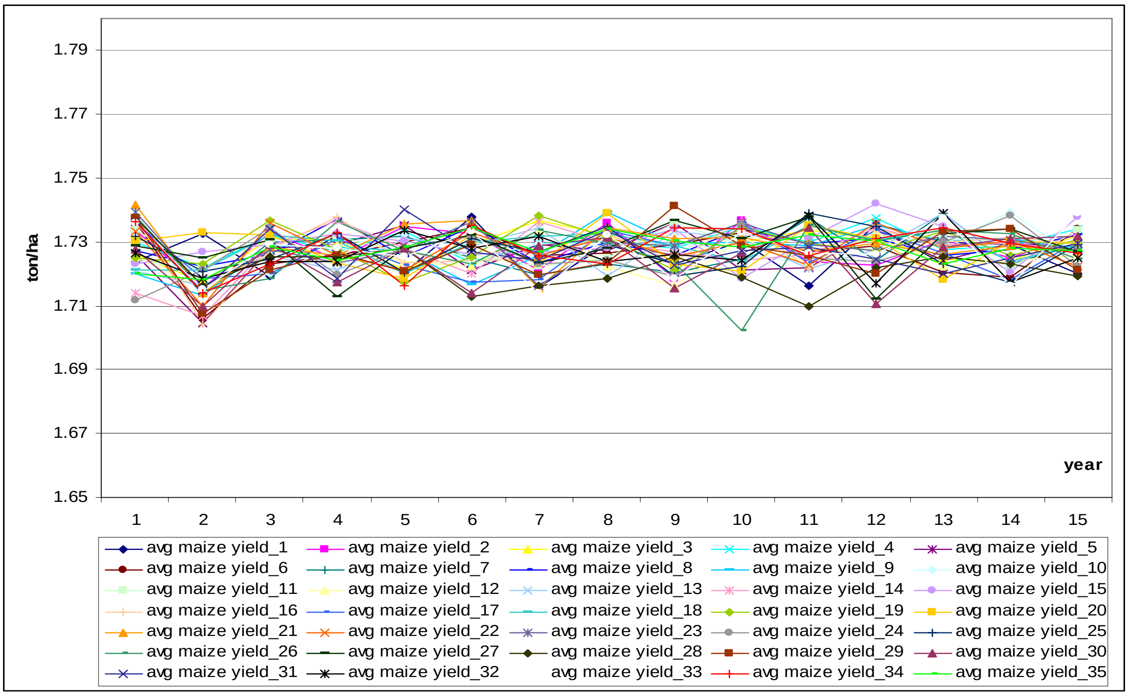


Figure 30: Average maize yield generated by model simulations
Source: Own simulation

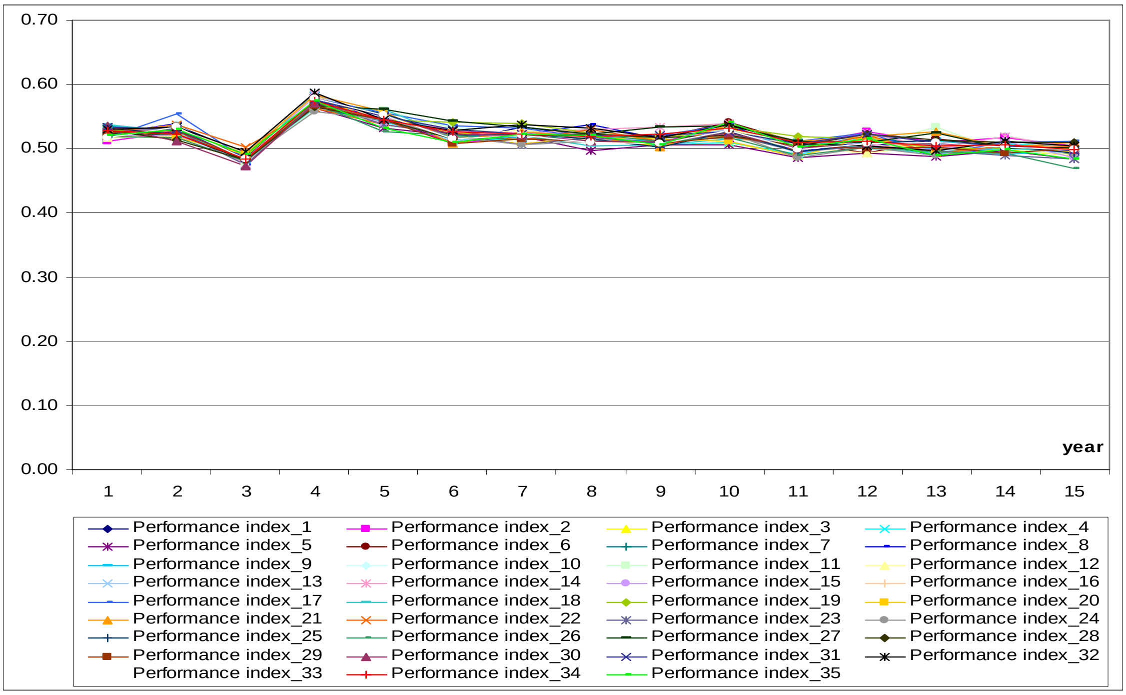


Figure 31: Performance index generated by model simulations
Source: Own simulation

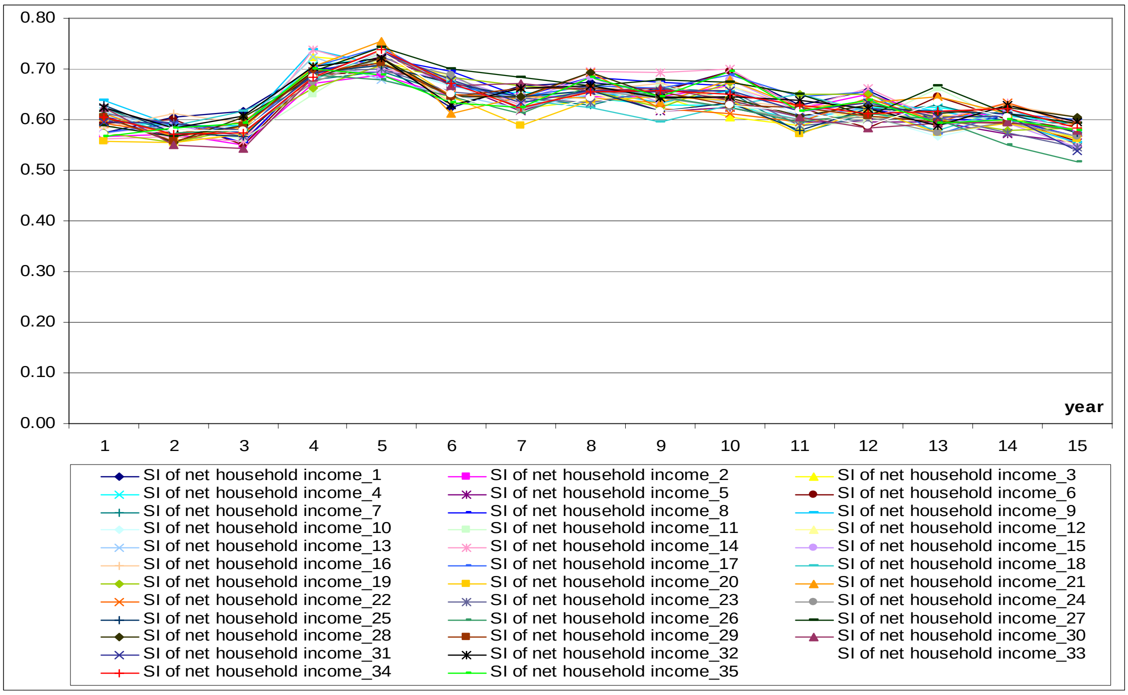


Figure 32: Sustainability index of net household income indicator generated by model simulations
Source: Own simulation

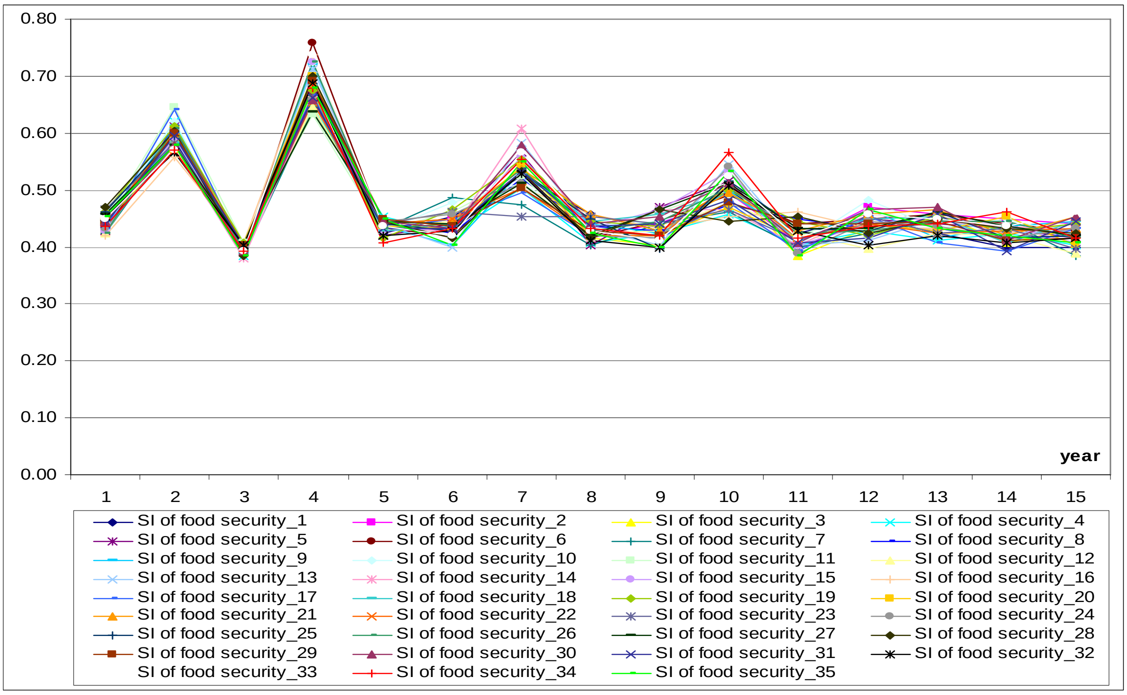


Figure 33: Sustainability index of food security indicator generated by model simulations
Source: Own simulation

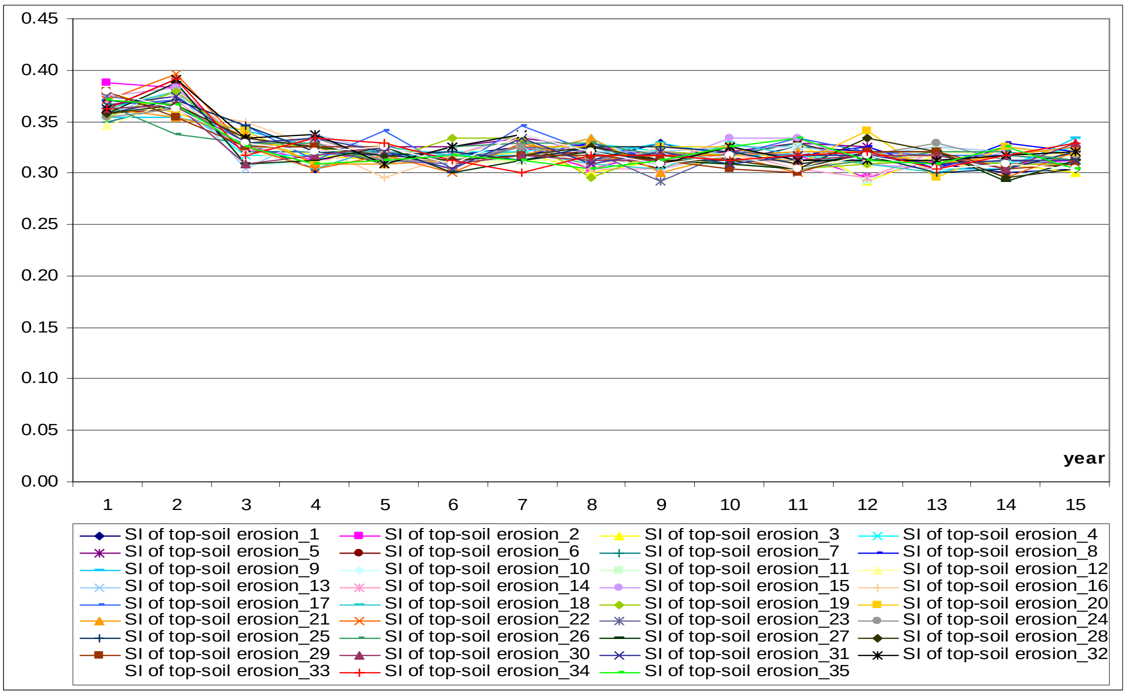


Figure 34: Sustainability index of top-soil erosion indicator generated by model simulations
Source: Own simulation

Table 22: Net crop income generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	14,940.31	17,900.24	22,748.51	21,342.98	21,552.74	22,816.80	22,902.50	23,945.17	24,972.89	25,211.45	25,900.16	26,498.62	26,884.50	27,509.06	28,093.43
Maximum	15,280.70	18,261.20	23,306.80	22,036.70	22,254.60	23,631.70	23,717.20	24,657.20	25,835.70	25,891.70	26,755.70	27,207.10	27,930.60	28,405.10	28,962.30
Minimum	14,508.80	17,220.40	22,160.60	20,744.20	20,862.00	22,337.00	22,162.70	23,313.30	24,182.40	24,300.20	24,979.20	25,567.60	25,741.10	26,175.30	26,675.00
Std Dev	179.68	228.19	295.82	315.76	352.04	321.47	337.92	345.95	408.27	368.51	379.63	362.40	564.31	490.50	453.97
Std Error	30.37	38.57	50.00	53.37	59.51	54.34	57.12	58.48	69.01	62.29	64.17	61.26	95.39	82.91	76.74
Median	14,953.30	17,924.00	22,748.80	21,409.60	21,508.60	22,773.50	22,872.40	24,003.60	24,964.10	25,247.50	25,933.40	26,538.20	26,919.20	27,522.20	28,104.20
Range	771.90	1,040.80	1,146.20	1,292.50	1,392.60	1,294.70	1,554.50	1,343.90	1,653.30	1,591.50	1,776.50	1,639.50	2,189.50	2,229.80	2,287.30

Source: Own simulation

Table 23: Net livestock income generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	20,756.00	26,018.60	13,144.40	27,207.70	27,321.80	21,234.40	20,024.80	21,672.30	22,316.50	21,477.10	20,552.10	22,282.50	20,589.60	20,621.80	19,468.50
Maximum	16,634.00	21,084.30	10,569.70	21,754.60	22,705.40	17,604.70	16,036.80	17,332.30	17,374.90	16,068.10	14,656.30	16,304.30	15,976.60	16,761.40	15,256.80
Minimum	997.54	1,304.76	647.27	1,308.60	1,003.15	877.78	880.41	938.64	1,142.48	1,312.39	1,008.64	1,376.20	1,231.27	953.30	990.09
Std Dev	168.62	220.55	109.41	221.19	169.56	148.37	148.82	158.66	193.11	221.83	170.49	232.62	208.12	161.14	167.36
Std Error	18,427.30	23,362.60	11,803.30	23,677.20	25,463.50	19,215.10	18,044.00	19,677.70	19,225.70	19,219.50	17,971.60	18,645.40	17,793.60	18,352.70	17,635.70
Median	4,122.00	4,934.30	2,574.70	5,453.10	4,616.40	3,629.70	3,988.00	4,340.00	4,941.60	5,409.00	5,895.80	5,978.20	4,613.00	3,860.40	4,211.70
Range	20,756.00	26,018.60	13,144.40	27,207.70	27,321.80	21,234.40	20,024.80	21,672.30	22,316.50	21,477.10	20,552.10	22,282.50	20,589.60	20,621.80	19,468.50

Source: Own simulation

Table 24: Net farm income generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	35,577.20	43,891.80	36,398.70	48,617.30	49,235.80	44,102.80	42,954.80	46,289.30	48,081.60	46,967.10	46,125.90	49,065.50	48,484.10	48,395.60	47,572.70
Maximum	31,880.90	38,979.10	33,088.50	43,275.50	43,723.30	40,363.60	38,199.40	40,968.40	42,197.50	41,168.50	39,994.40	41,918.10	42,022.70	44,256.30	41,931.80
Minimum	995.76	1,307.70	793.03	1,397.12	1,106.94	982.77	1,031.29	1,077.02	1,364.28	1,456.15	1,101.09	1,523.98	1,506.77	1,121.67	1,234.23
Std Dev	168.31	221.04	134.05	236.16	187.11	166.12	174.32	182.05	230.60	246.13	186.12	257.60	254.69	189.60	208.62
Std Error	33,433.90	41,119.10	34,543.80	45,188.80	46,792.50	42,011.50	40,827.20	43,651.70	44,274.60	44,466.00	43,956.20	45,260.90	44,833.20	45,831.00	45,800.30
Median	3,696.30	4,912.70	3,310.20	5,341.80	5,512.50	3,739.20	4,755.40	5,320.90	5,884.10	5,798.60	6,131.50	7,147.40	6,461.40	4,139.30	5,640.90
Range	35,577.20	43,891.80	36,398.70	48,617.30	49,235.80	44,102.80	42,954.80	46,289.30	48,081.60	46,967.10	46,125.90	49,065.50	48,484.10	48,395.60	47,572.70

Source: Own simulation

Table 25: Net household income generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	27,907.12	24,464.66	23,697.79	34,451.43	36,587.05	30,274.18	28,427.38	30,324.67	29,406.89	30,000.26	27,378.66	27,801.18	26,792.02	26,902.73	24,486.45
Maximum	30,129.90	27,495.90	25,683.80	37,202.30	38,926.40	32,585.40	30,583.70	33,304.80	33,322.60	33,090.60	29,385.90	31,248.60	30,551.10	29,710.70	26,592.80
Minimum	26,535.50	21,924.10	22,412.40	32,620.10	33,236.70	28,046.70	25,604.90	27,534.00	27,033.30	26,838.80	23,819.00	24,374.00	24,069.40	25,176.80	20,530.70
Std Dev	975.94	1,418.83	776.34	1,258.18	1,136.80	1,173.48	1,007.39	1,129.24	1,428.45	1,562.15	1,169.22	1,516.88	1,537.34	1,199.39	1,361.42
Std Error	164.96	239.83	131.23	212.67	192.16	198.35	170.28	190.88	241.45	264.05	197.64	256.40	259.86	202.73	230.12
Median	27,849.50	24,489.80	23,519.20	34,276.70	36,571.90	29,987.30	28,504.60	30,243.20	29,340.50	30,423.30	27,519.80	27,680.60	26,867.60	26,860.10	24,471.40
Range	3,594.40	5,571.80	3,271.40	4,582.20	5,689.70	4,538.70	4,978.80	5,770.80	6,289.30	6,251.80	5,566.90	6,874.60	6,481.70	4,533.90	6,062.10

Source: Own simulation

Table 26: Average upland rice yield generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	307.78	304.24	307.90	307.97	307.45	307.21	307.46	306.95	306.78	306.88	306.63	306.46	306.17	306.47	306.43
Maximum	308.87	305.48	308.64	308.75	308.31	308.25	308.81	308.39	308.26	308.95	308.28	308.22	307.52	308.10	308.07
Minimum	306.85	302.51	306.99	306.83	306.00	306.30	305.72	305.37	304.69	304.61	304.31	303.63	303.21	303.80	304.34
Std Dev	0.51	0.77	0.47	0.50	0.57	0.50	0.77	0.77	0.89	0.91	0.97	1.01	1.01	0.97	0.81
Std Error	0.09	0.13	0.08	0.08	0.10	0.08	0.13	0.13	0.15	0.15	0.16	0.17	0.17	0.16	0.14
Median	307.81	304.31	307.94	308.01	307.51	307.18	307.57	307.07	306.78	306.93	306.71	306.56	306.37	306.52	306.52
Range	2.02	2.97	1.65	1.92	2.31	1.95	3.09	3.02	3.57	4.33	3.97	4.59	4.32	4.31	3.73

Source: Own simulation

Table 27: Average maize yield generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	276.73	274.71	276.47	276.43	276.31	276.44	276.11	276.70	276.28	276.55	276.49	276.63	276.70	276.31	276.58
Maximum	278.68	277.29	277.91	278.05	278.42	278.06	278.12	278.32	278.58	277.87	278.23	278.70	278.26	278.33	278.26
Minimum	273.89	272.67	274.94	274.08	274.61	274.09	274.25	274.95	274.49	272.36	273.60	273.72	274.91	274.62	275.11
Std Dev	1.20	1.12	0.76	0.91	0.92	1.05	1.04	0.81	1.00	1.10	1.03	1.08	0.88	0.92	0.73
Std Error	0.20	0.19	0.13	0.15	0.16	0.18	0.18	0.14	0.17	0.19	0.17	0.18	0.15	0.16	0.12
Median	276.78	274.59	276.55	276.49	276.39	276.60	276.12	276.79	276.16	276.77	276.34	276.93	276.77	276.46	276.67
Range	4.79	4.62	2.97	3.96	3.82	3.97	3.87	3.37	4.09	5.51	4.63	4.97	3.35	3.71	3.15

Source: Own simulation

Table 28: Performance index generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	0.53	0.53	0.48	0.57	0.55	0.52	0.52	0.52	0.51	0.53	0.50	0.51	0.50	0.50	0.50
Maximum	0.54	0.55	0.50	0.59	0.56	0.54	0.54	0.54	0.53	0.54	0.52	0.53	0.53	0.52	0.51
Minimum	0.51	0.51	0.47	0.56	0.53	0.51	0.51	0.50	0.50	0.51	0.49	0.49	0.49	0.49	0.47
Std Dev	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Std Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.53	0.53	0.48	0.57	0.54	0.52	0.52	0.52	0.51	0.53	0.50	0.51	0.50	0.50	0.50

Source: Own simulation

Table 29: Sustainability index of net household income indicator generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	0.60	0.58	0.58	0.69	0.72	0.66	0.64	0.66	0.65	0.65	0.61	0.62	0.61	0.60	0.57
Maximum	0.64	0.61	0.62	0.74	0.75	0.70	0.68	0.70	0.69	0.70	0.65	0.66	0.67	0.63	0.60
Minimum	0.56	0.55	0.54	0.65	0.68	0.61	0.59	0.63	0.60	0.60	0.57	0.58	0.57	0.55	0.52
Std Dev	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Std Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.60	0.58	0.58	0.69	0.72	0.67	0.64	0.66	0.65	0.65	0.62	0.62	0.60	0.60	0.58
Mean	0.08	0.06	0.08	0.09	0.08	0.09	0.10	0.07	0.10	0.10	0.08	0.08	0.10	0.08	0.09

Source: Own simulation

Table 30: Sustainability index of food security indicator generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	0.44	0.59	0.40	0.68	0.44	0.44	0.53	0.43	0.43	0.50	0.42	0.44	0.44	0.43	0.42
Maximum	0.47	0.65	0.41	0.76	0.45	0.49	0.61	0.46	0.47	0.57	0.46	0.48	0.47	0.46	0.46
Minimum	0.42	0.56	0.38	0.63	0.41	0.40	0.45	0.40	0.40	0.45	0.38	0.40	0.41	0.39	0.38
Std Dev	0.01	0.02	0.01	0.03	0.01	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Std Error	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.44	0.59	0.40	0.68	0.43	0.44	0.53	0.43	0.43	0.50	0.42	0.44	0.45	0.43	0.42
Mean	0.05	0.09	0.03	0.13	0.05	0.09	0.15	0.05	0.08	0.12	0.08	0.09	0.06	0.07	0.08

Source: Own simulation

Table 31: Sustainability index of top-soil erosion indicator generated by model simulations

items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Mean	0.36	0.37	0.33	0.32	0.32	0.31	0.32	0.32	0.31	0.32	0.32	0.31	0.31	0.31	0.31
Maximum	0.39	0.40	0.35	0.34	0.34	0.33	0.35	0.33	0.33	0.33	0.33	0.34	0.33	0.33	0.33
Minimum	0.35	0.34	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.30	0.30	0.29	0.30	0.29	0.30
Std Dev	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Std Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.36	0.37	0.33	0.32	0.32	0.31	0.32	0.32	0.31	0.32	0.32	0.32	0.31	0.31	0.31
Mean	0.04	0.06	0.05	0.03	0.05	0.03	0.05	0.04	0.04	0.03	0.03	0.05	0.03	0.04	0.03

Source: Own simulation

4. Sustainability analysis of Bor Krai village's farming systems

After having been tested and validated, the CatchScapeFS model is used for simulation in order to assess and observe sustainability of the study area, Bor Krai village. The model run under current condition is set as the baseline scenario. Its results are analyzed and used to compare with other potential scenarios in the scenario analysis which is presented in detail in the next chapter. The simulation results under the baseline scenario are presented in this chapter.

4.1 Sustainability of the study area at the household level

For the baseline scenario which corresponds to the simulation under current conditions, the results at household level show that at present nearly all farm households, 97% approximately, are classified in the Conditional sustained class (C) and there is only a small number of households classified in the Sustained (S) and Non-sustained (N) class in some years (Figure 35). Compared to the first year, the trend shows a slight decrease in the number of S class households.

However, the number of households in each sustainability class is different for each indicator. For the household income indicator, the number of households in the Conditional sustained class (C) tends to increase while the number of households in Sustained (S) class is declining (Figure 36). This corresponds to the decreasing number of households in Sustained (S) class for net farm income indicator (Figure 37). Due to the lower growth rate of income (farm and off-farm income) compared to the growth rate of private expenditures (Figure 38), the sustainability situation of the households regarding the household income indicator as well as the net farm income indicator is getting worse over time. Increasing household private expenditure occurs because of increasing household members and inflation over time. Additionally, this development induces an increasing number of households in the Non-sustained (N) class for the household saving indicator (Figure 39), as household cash savings are decreasing (Figure 40).

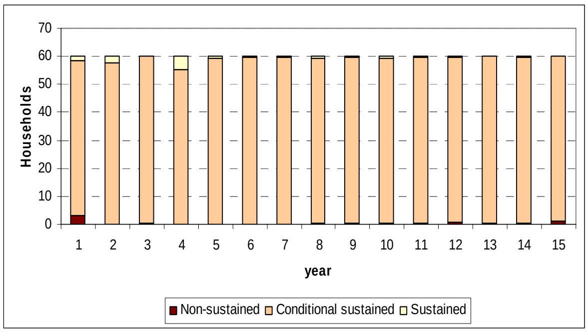


Figure 35: Number of households in each sustainable class classified by total sustainable score from all indicators

Source: Simulation

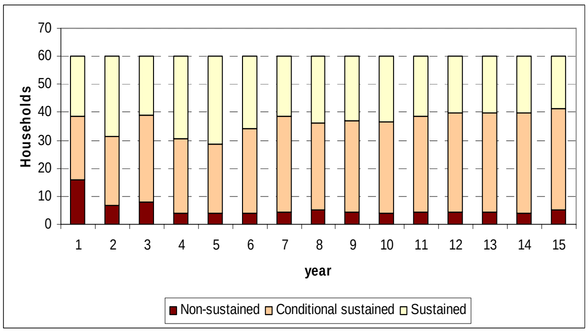


Figure 36: Number of households in each sustainable class classified by sustainable score of household income indicator

Source: Simulation

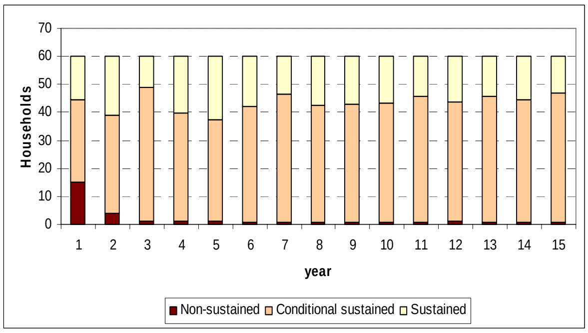


Figure 37: Number of households in each sustainable class classified by sustainable score of net farm income indicator

Source: Simulation

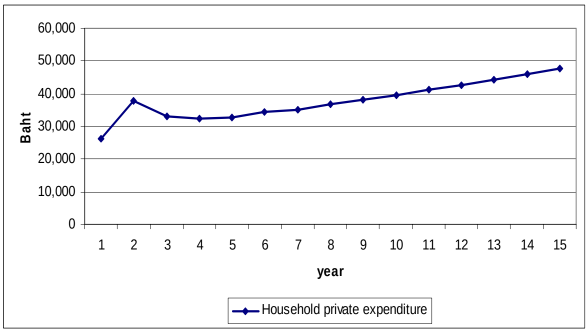


Figure 38: Average farm household private expenditure of farm households

Source: Simulation

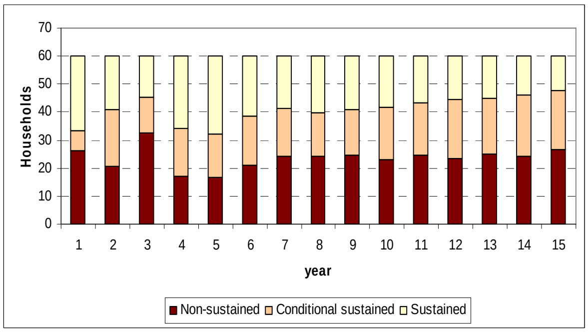


Figure 39: Number of households in each sustainable class classified by sustainable score of household saving indicator

Source: Simulation

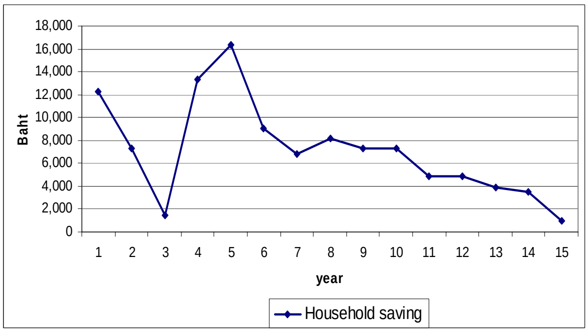


Figure 40: Average of household saving

Source: Simulation

For the household capital indicator, most households are classified into the Conditional sustained (C) class and over time the number of households in Sustained (S) class decreases (Figure 41). This results from decreasing farm products as the capital goods. Reduction in these products induces a reduction in the household capacity to generate income. In reality the farm products are stored. This increases the options for households in the following year and makes them more secure. In addition, this helps the household to recover when facing a stressful situation. For example, the products set aside for consumption will be occasionally sold during a cash deficit in the year.

For the food security indicator, the number of households in the Sustainable class (S) changes with relatively high variation in the first four years. Afterwards the variation is small with an increasing trend of households in the Non-sustained class (N) (Figure 42). High fluctuation at the beginning occurs from a contribution of biophysical and socioeconomic factors. The distribution of rain and the suitability of land as biophysical factors during the growing period of upland rice influence the rice yields as well as the sustainable situation of households in each year. For the year with unsuitable rain distribution and land, the yield is low and induces an increasing rice deficit and a growing number of households in Non-sustained (N) class. Then, the production decision for the following year is influenced by the rice deficit and the low yield expectation from this experience. This shows how socioeconomic factor are influencing the fluctuations. The households will extend their production in the following year which is a way of adaptation that can be correct decision making with limitation of current information. If expectation and decision making is made in the right way, the annual variation will become smooth and narrow but on the other hand if errors occur a high fluctuation like lag of adjustment can be also observed.

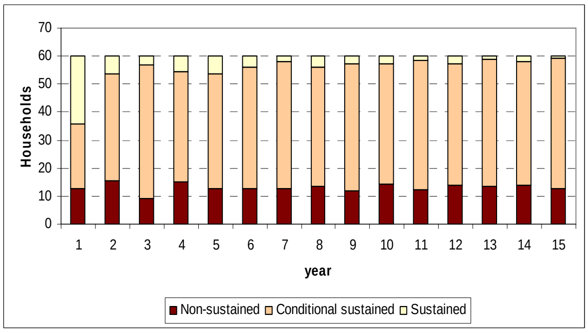


Figure 41: Number of households in each sustainable class classified by sustainable score of household capital indicator
Source: Simulation

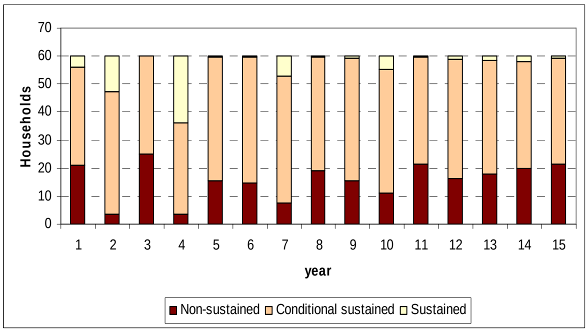


Figure 42: Number of households in each sustainable class classified by sustainable score of food security indicator
Source: Simulation

In addition, the point in time at which the rice production decision takes place has also a significant influence to the variation in rice deficits. For example, in the case where the current year has an early start to the rainy season (e.g. beginning of May), the household decision making will be made by considering the current resource availability (land, cash, labour) and the amount of rice needed which is of course enough until the beginning of May of next year. The calculation is roughly carried out based on the net household amount of rice needed. Decision making of using land is made plot by plot until consumption and cash generation purposes under the restrictions are met. The plot use is decided by a rough calculation of household needs, which can be expressed by net household rice needed = rice consumption needed – expected rice obtained – current household rice remaining + rice borrowing – rice being borrowed. The plot will be used for rice production in the case that the household still needs rice to consume which will be indicated by a positive value of net household rice needed. From the expression, expected rice obtained is calculated based on the area which is assigned to be used to produce rice multiplied by the average rice yield obtained in last year from their knowledge base. In the case where the rainy season in following year is late, the households risk of rice deficit increases (increasing of rice borrowing term) in the coming year. This induces households to increase rice production to cover a shortage in next year. On the other hand, if the rainy season started early in the following year, the household will not suffer from rice deficit (low value of rice borrowing term), but in that year the decision of rice production will be made earlier, when the remaining rice amount of the household is still high. Then, the area of rice production will be reduced and the household will probably suffer from rice deficit in that year again if the rainy season again starts with delay in the coming year. Due to this behaviour, fluctuation of rice deficit happens according to the variation of biophysical and socioeconomic conditions in each year.

Regarding simulation results, after the first four years the number of households in the Non-sustained class (N) tends to increase. This is influenced by the increasing population which pushes up the demand for rice needed for consumption. A trend of growing rice deficit can be observed and rice acquisition by borrowing rice from the village's rice bank and neighbours is captured through simulation corresponding to the behaviour found in the area (Figure 43 and 44). In addition, the average amount of rice borrowed by households tends to increase and leads to a higher number of households in the Non-sustained class (N) in the long run.

In the case of the top-soil erosion indicator, the results show that around 70% of the households are classified in the Non-sustained (N) class (Figure 45). The number of households in this class increases rapidly between the second and third year. In the following year, the sustainability of households only changes by a small variation. The trend of households in the Non-sustained (N) class slightly increases in the long run. These results correspond to the amount of soil erosion produced by farm households per area unit, which shows high variation at the beginning because of high amounts of rain in this period (Figure 46). In addition, erosion caused by rain will be much more significant if the heavy rain occurs during clearing and preparing the land for cropping, as there is no covering of land by vegetation. This means, that the distribution and the time of rainfall is more important for land erosion than the total amount of rainfall during the year. Variation of erosion in each year is also caused by the properties of each plot but in the result this effect is smaller than the impact of rain and the land properties do not vary a lot between years. Thus, variation of erosion after the third year is low because there is only a small variation in rainfall. However, the situation of soil erosion in this area is rather severe, because most of the households are classified as Non-sustained (N) and their number tends to be increasing in the long run.

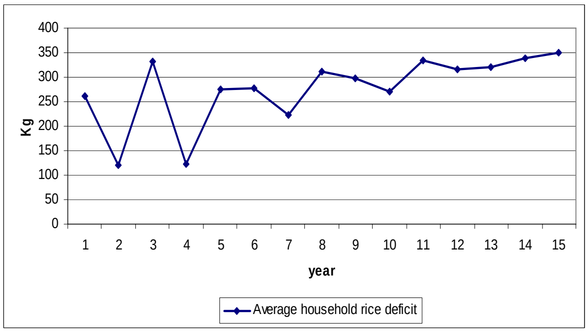


Figure 43: Average of household rice deficit
Source: Simulation

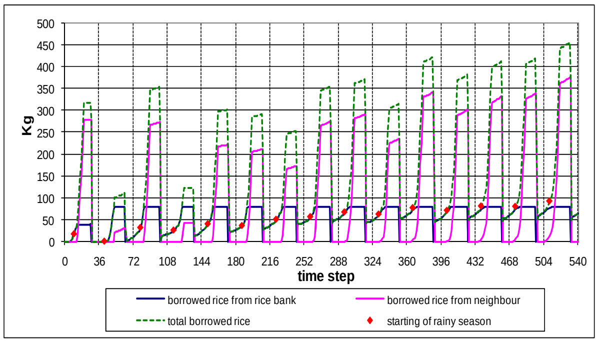


Figure 44: Average borrowing rice of household in each time step of simulation
Source: Simulation

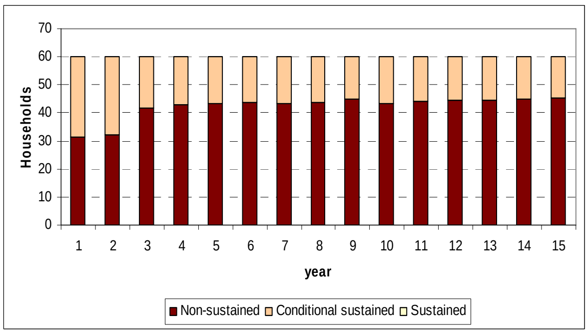


Figure 45: Number of households in each sustainable class classified by sustainable score of top-soil erosion indicator
Source: Simulation

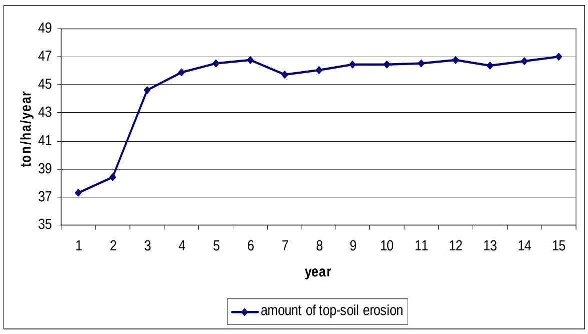


Figure 46: Average amount of top-soil erosion generated by household
Source: Simulation

Regarding the fallow period indicator, in the long run the number of households in the Non-sustained (N) class is increasing (Figure 47). This results from production growth to reach consumption needs. More land is needed to produce rice to satisfy the increasing demand of a growing population. Because encroachment to the forest for new plots is not allowed, the existing agricultural land is used more intensively by shortening the fallow period. This can be observed by the development of the average fallow period of households in Figure 48. This is harmful to fertility and the recovery of land which potentially induces land degradation in the long run (Place and Dewees, 1999; Szott et al., 1999; van Noordwijk, 1999; Wangpakapattanawong, 2002).

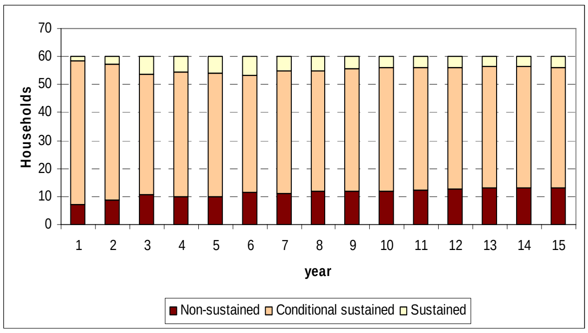


Figure 47: Number of households in each sustainable class classified by sustainable score of fallow period indicator
Source: Simulation

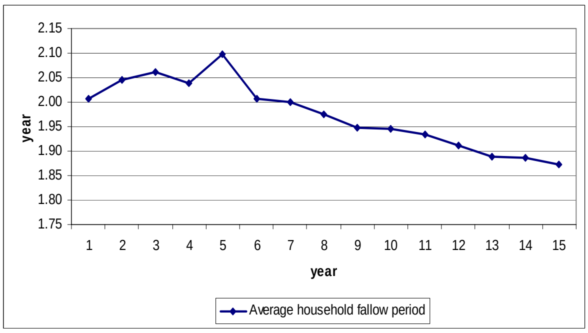


Figure 48: Average household fallow period
Source: Simulation

4.2 Sustainability of the study area at the village level

The sustainability situation of the study area at the village level is represented by the Sustainability index (hereafter SI), when single indicators are concerned and the Performance index (hereafter PI), when a group of indicators is regarded. The SI indicates the sustainability of a single indicator, whereas the PI describes the sustainability situation of the whole area in general or for a specific condition such as economic, social, or environmental conditions. The details of the sustainability situation at the village level are explained in the following sections.

Sustainability index of economic condition

The sustainability situation concerning the economic condition is represented through the SIs of four indicators, which are the household income indicator, the net farm income indicator, the household capital indicator, and the household saving indicator. Each of these SIs is used to present the sustainability situation of the relevant indicator issue. In addition, the PI of these economic indicators represents the economic situation of the area in general. Based on simulation results, the SI figures show the development of the sustainability situation during the simulation period (Figure 49). When the simulation results are ranked at the initial stage of the simulation period, the household capital is the most sustained issue (observed by highest SI value of household capital indicator), followed by household savings, the household income, and the net farm income issue, respectively. The household capital is presented as the most sustainable issue, because generally households store farm products as capital stock which can be used for production activities and occasionally to sell for cash. So, storing large amounts of products increases sustainability of households and contributes to essentially the relative high sustainability at the village level. At the beginning of the simulation period, the SI of this issue amounts to 0.65 whereas the SI for the household saving indicator, the household income indicator, and the net farm income indicator are 0.613, 0.611, and 0.61 respectively. The PI of the economic indicators amounts to 0.61 at the initial stage.

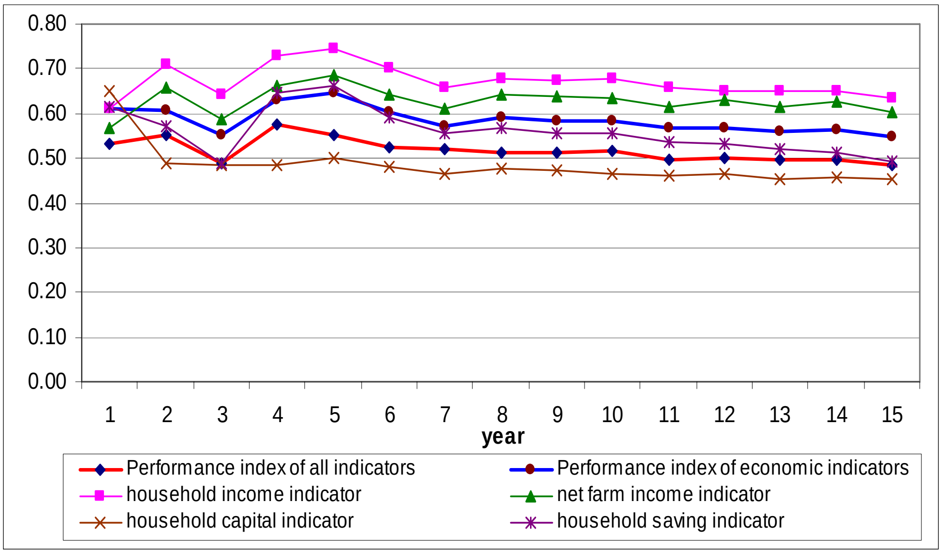


Figure 49: Performance indexes and sustainability index of each economic indicator

Source: Simulation

In the long run, the development of these indexes is presented by the simulation process covering 15 years. The results show that the area is not sustainable, indicated by the projection of the PI of the economic indicators (Figure 49). Furthermore, when consider in each indicator, unsustainability aspects presented through each indicator are observed. This is indicated by a negative progression of the SI for each indicator. Particularly, the results show a relatively high decline of the SI of the household saving and household capital indicator over time, compared to the development of the household income and net farm income indicator.

The decline of the household saving indicator is caused by increasing household private expenditures which lead to a decrease in savings. Therefore, in the long run an increasing number of households in the unsustained class concerning household savings, generates a decrease in the SI of the household saving indicator. For the household capital indicator, the decline in household capital is caused by a decreasing value of products, which the household produces and stores for consumption. Whereas the production amount shows only little variation over time, the production value decreases through monetary devaluation. This indicates a decreasing ability of the households to generate cash from stored products and consequently they are at risk of becoming unsustainable concerning their capital.

Regarding the household income indicator, declining SI is caused by a reduction in the number of households in the Sustained class (S). They become in Conditional sustained (C) class because of the decline in household income. In the case of the Non-sustained class (N), the number of households is high variable in the first three years but after that there is only small variation. This aspect can be also perceived in the case of the net farm income indicators. Due to a decreasing farm income, the number of households in the Sustained class (S) declines, while the share of households in the Conditional sustained (C) class increases.

Considering the dynamic of all economic SIs in the long run, a ranking of the different economic sustainability issues can be made by regarding the trend of the single SIs. The result shows that the most critical issue is the household saving issue, followed by the household capital issue, the household income and the net farm income issue respectively. All indicators which have a negative development of their SI over time, show decreasing sustainability of the issue. The increasing unsustainability of the most critical issue, the household saving issue, is caused by increasing private household expenditures for living costs and consumption. For the household capital, the devaluation of money over time is the factor which affects the value of the stored products and the ability to generate cash in case it is suddenly needed. Also, the performance of generating income for some households is declining which can be observed by changing into a lower sustainable situation class and a declining SI of household income and net farm income indicator over time. However, in general the farm households in this area have a rather good performance in farming. The projection of the SI of the net farm income indicator shows only a very small decrease and this item is the most sustainable aspect regarding the economic condition, compared to the other economic issues.

Sustainability index of social condition

As the social condition is only described by one indicator, which is the food security indicator, the value of SI and PI are equal. Consequently, the graph of the SI of the food security indicator and the PI of the social condition are identical in Figure 50. The sustainability situation under this condition has rather high variation at the beginning. This variation occurs due to the variation of different factors, which determine the household rice production decision, either biophysical or socioeconomic factors, as it is explained in the previous section on the sustainability of the study area at the household level. Here is an example for this interrelation: in the third year the SI of the food security indicator is lower than in the second year. In the 2nd year the rainy season starts early so the decision making of households takes place at a relative early period, while the households have high amounts of rice remaining and therefore, the planted rice area in that year is relatively low. This leads to a relatively high rice deficit in the third year, when the start of the rainy season comes relative late (Figure 51). In addition, households are borrowing higher amounts of rice in the third year compared to the second year (Figure 52). In the third year, adjustment to recover from suffering of rice deficit is perceived as the planted rice area is increasing. Then, the SI of the food security indicator increases again and the amount of rice borrowing declines in the fourth year.

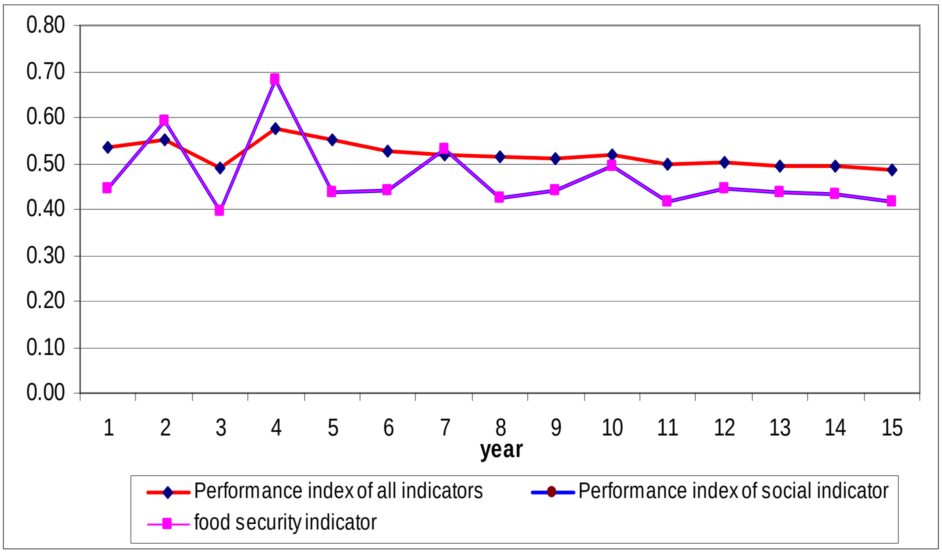


Figure 50: Performance indexes and sustainability index of each social indicator
Source: Simulation

According to this, the fluctuation of the food security SI can occur. The fluctuation will be high if the variation of influencing factors, biophysical and socioeconomic factors, which affects household decision and adjustment afterwards is high. As at the beginning the variation of biophysical factors is high, a fluctuation of the food security SI is perceived. In general, the issue of social condition in this area is not sustainable, presented by the declining PI of the social indicator over time.

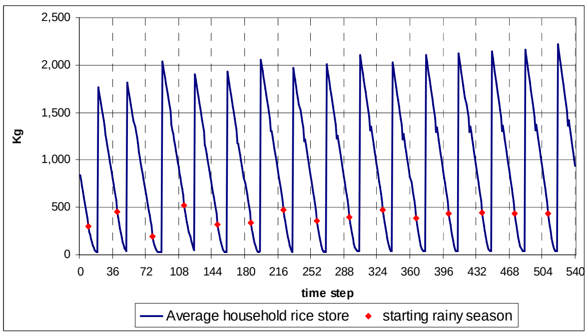


Figure 51: Performance indexes and sustainability index of each social indicator
Source: Simulation

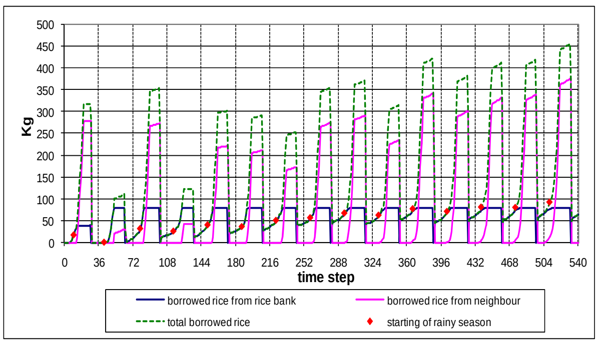


Figure 52: Average of amount of household rice borrowed from each source
Source: Simulation

Sustainability index of environment condition

The SIs representing the area's environmental sustainability consist of the SI of the top-soil erosion indicator and the SI of the fallow period indicator. These indicators represent factors which are important and affect the circumstances and recovering fertility of soil and potentially influence sustainability concerning the environmental condition (Gypmantasiri and Amaruekachoke, 1995; Ratanawaraha, 1995). The results show that at the beginning stage the SIs of the top-soil erosion and fallow period indicator are 0.37 and 0.48 respectively (Figure 53). Also, the PI of the environmental indicators is 0.42 at the beginning and tends to decline over time. The decline of this PI is influenced by the SIs of both indicators in the long term. However, the SI of the top-soil erosion indicator declines more than the SI of the fallow period indicator. Also, the top-soil erosion's SI is much lower than the SI of the fallow period indicator during the whole simulation period. Although, the value is higher and rate of decline is lower, the SI of the fallow period indicator contributes to the decline of the PI of the environmental condition. The decrease of the SI of the fallow period indicator is caused by using more land with shorter fallow period to increase production for consumption, due to the population growth.

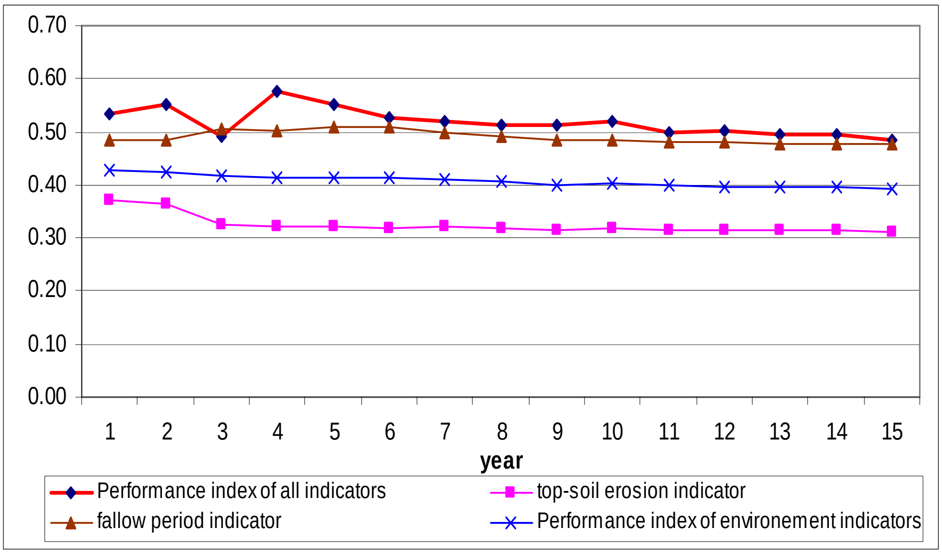


Figure 53: Performance indexes and sustainability index of each social indicator

Source: Simulation

Sustainability situation concerning overall condition

Concerning the PI and SI of all indicators, the sustainability situation of the study area is not sustainable. Unsustainability is observed by the decline of the PI of all indicators in the long term (Figure 54). In addition, the decrease of the SIs of all indicators contributes to the unsustainability. The sustainability situation regarding the economic condition is rather higher than the sustainability situation concerning the social and environmental condition, as the trend and value of the PI for each condition show (Figure 55). Concerning the trend, the PI of the economic indicators shows small decrease over time. Also, in almost over all periods the PI values of the economic indicators are higher than the PI values of the social and environmental indicators and also higher than the PI values of all indicators. The higher sustainability is indicated by the SI values of the household income, net farm income, and household capital and also the value of the PIs of the economic indicators is higher than that of the other two conditions.

For the social condition, the PI and SIs of the food security indicator change with relative high fluctuation. Also, the trend of negative progression indicates the highest decline in the long term. This implies that this issue is the most significant unsustainable aspect and needs to be improved with the highest priority.

When the environmental condition is considered, the PI of the environmental indicators –top-soil and fallow period indicator– show a moderate decrease in the long run, but most of the values over the simulation period are lower than the PI values of the economic and social indicators. The top-soil erosion indicator shows much lower SI values than the fallow period indicator and additionally has a much higher trend of reduction.

Considering all SIs and their development over the simulation period, the sustainability issues can be ranked and used to determine prior sustainability issues which need to be improved. The food security issue is considered as the most unsustainable issue which highly contributes to the area's unsustainability. The household saving issue is the second of the unsustainable issues, followed by the issues of household capital, top-soil erosion, household income, fallow period, and net farm income respectively.

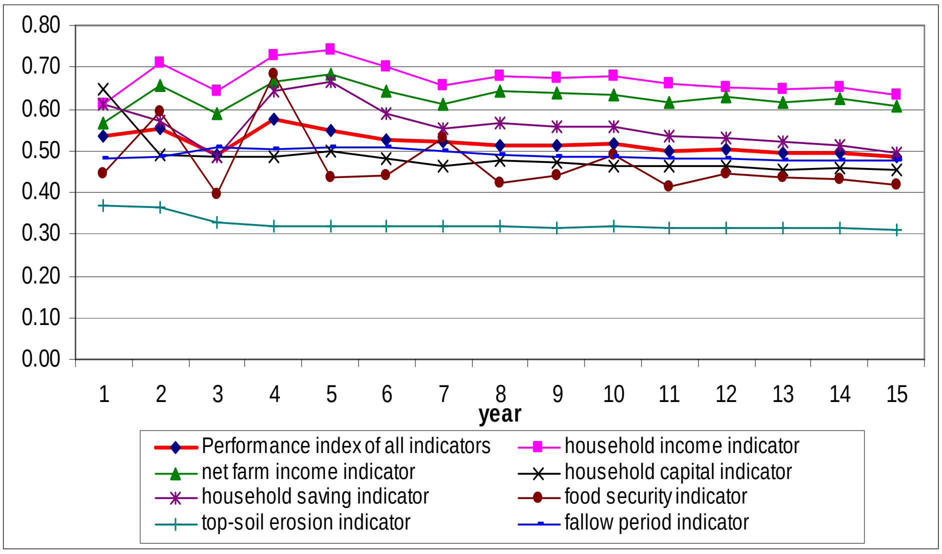


Figure 54: Performance indexes and sustainability index of all indicators

Source: Simulation

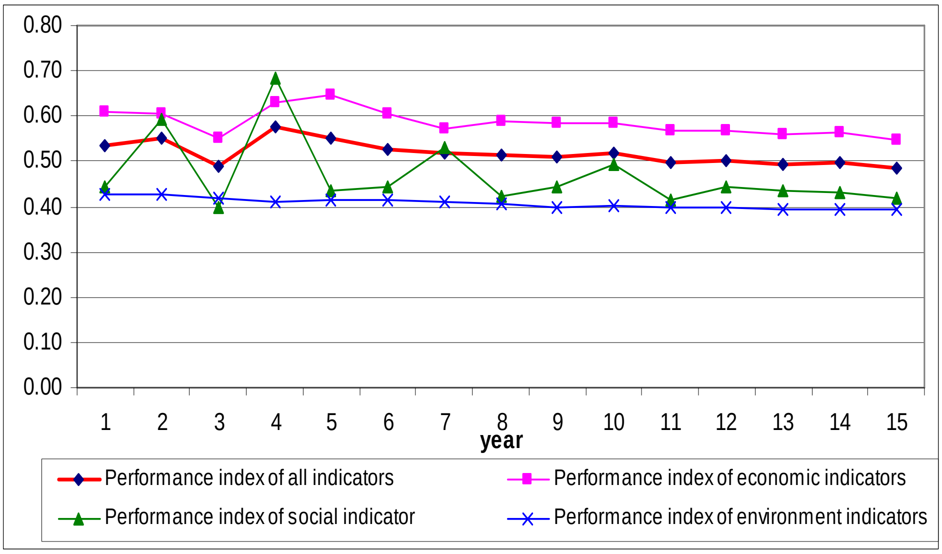


Figure 55: Performance index of all indicators and each indicator condition

Source: Simulation

5. Scenario analysis

In the previous chapter, the sustainability situation of the Bor Krai village study area, under current conditions, was presented and described. These results are the reference or baseline scenario used to compare with other scenarios in the scenario analysis. Within this chapter, the scenario analysis is carried out. Scenarios are identified as potential events which may cause significant changes from the baseline scenario. Results of long run simulations under each defined scenario are analyzed and compared with the baseline scenario to indicate and capture the dynamics of the sustainability situation which might potentially occur. First, the detail of the scenario determination is described and then the analysis for each scenario is presented and explained.

5.1 Scenario determination

In this study, the framework to determine scenarios is dependent on 2 approaches:

1) scenario of implementation of policy to improve sustainability from the baseline situation

2) scenarios of occurring unexpected events which consist of changes in biophysical and economic factors

For the first approach, the results of the baseline scenario indicate that the study area's farming systems are not sustainable, as indicated by a decline over time of the Performance index (PI) of all indicators. Additionally, sustainability issues can be ranked. Food security is considered the most unsustainable issue followed by household saving, household capital, top-soil erosion, household income, fallow period, and net farm income issue respectively.

Overall unsustainability is particularly affected by declining food security caused by insufficient rice consumption due to land resource limitations and uncertainty of biophysical condition. In addition, the household saving issue also induces the household in this area to be unsustainable. They risk living with a cash deficit if they have a reduction of cash savings over time. This happens because of increasing private expenditure due to the rising number of household members.

Additionally, there are environmental concerns over agricultural practices on slope land, as it produces a large amount of erosion. This can potentially induce land degradation and environmental consequences especially to low land and downstream areas in the long term. Moreover, land use intensification in the area also should be considered. From the simulation results, the area's fallow period of agricultural land tends to decrease, because of increasing household consumption with limited agricultural land. As such, the land resource is intensively used by shortening the fallow period which restricts the time available to recover soil structure and fertility. With these two environment issues, the area faces environmental and land resource degradation problems which need to be improved.

However, the simulation results also show that the households in this area have a good performance in farming with subsistence mixed crops and livestock which enhances household income. As such, the farm and household income appear to be sustainable as indicated by relative high SI value with only a slow decline in the long run. Thus, sustainability improvement policy inventions need to consider this fact.

Relying on the analysis of the baseline summary results explained above, the policy intervention to improve the sustainability situation of this study should pursue methods of maintaining and improving the activities which farm households have performed well in, to improve household cash and income, as well as to reach consumption requirements. At the same time, the policy should be environmentally-friendly and induce maintenance and improvement of environmental and resource conditions, as the agricultural lands are limited and encroachment to forest area is not allowed. In addition, special characteristics regarding the area's limitations and experience should be considered. Land suitability for cropping of this area is quite constrained (in the past many cash crops have been introduced to the area by government agencies and NGOs but they were not successful), thus introduction of new crops will face a risk of failure because of suitability of land to such introduced crops. Research to find out about the area's potential cash crops is required and probably possible but this may takes a long time and be very expensive due to the scientific experiments required. As such, new crop options are limited and existing crops which have been cultivated and performed well in the area should be considered.

Therefore, the policy for the sustainability improvement scenario is set as the introduction of a high yield variety of upland rice and maize, which potentially increases not only the output for consumption but also reduces the intensive use of the cultivated area. In addition, these two kinds of crops have already been cultivated and have performed well in the area, thus, introduction of these crops is suitable. At the same time, fruit trees such as mango which have been cultivated in the area, are introduced to the households which perform only annual cropping. This can be a source of additional household income and cash. Fruit trees are also environmentally-friendly, as they can potentially improve soil erosion. In this scenario, the simulation condition is set as the introduction of upland rice and maize (high yield variety) to farm households, launched at the 5th year (2007). Also, suggestion and seed input support of 0.16 ha for mango production to 25 farm households which have only annual crops is performed through the government agency, the agricultural extension officer, starting at the same year of introduction as the high yield variety crop.

For the second approach, scenarios about changing biophysical and socioeconomic factors are set, based on the empirical data of each corresponding factor. Drought and rain increasing scenarios are set as unexpected events of the biophysical factor change. The drought is determined in the year after the current year of analyzing (2006) which is separated into two periods which each covers three years. It can be considered as an extreme case of a long drought in order to capture the adjustment and tolerance testing of systems to drought. In the opposite way, rain increasing is also implemented as the same aspect of two periods occurring to investigate the effect of an opposite extreme event. For these two scenarios, the first period is determined in the year 2007 to 2009 and the second period is in between 2013 to 2015. Change of rain decreasing and increasing is set to 25% from the baseline scenario based on precipitation data dated back 12 years from 1994 to 2005.

For another unexpected event, a price decreasing scenario is determined to consider the impact of a change in an economic factor. A decrease in price are assigned to the years after the analyzing year (2006) which occurs in 2 periods which are from 2007 to 2009 and 2013 to 2015. The duration of the price change is determined based on main crop price (upland rice and maize) statistical variation data with the specific purpose to analyze and investigate change and system behaviour under extreme cases of declining prices. In each period, the price of each crop is reduced by a certain percentage, based on statistical data of each crop. Upland rice and maize price are decreased by 23.77% and 25.04% while mango and vegetables (bean, melon, and pumpkin) price are decreased by 29.39% and 34.67% from the baseline scenario respectively.

5.2 Analysis of results

5.2.1 Implementation of proposed sustainability improvement policy

After long run simulation, the results show that in the year of launching the sustainability improvement policy (2007), the upland rice and maize high yield variety are introduced to the farm households, especially to the Market oriented and Partnership oriented group which are consisted of 38 households. These groups are the first which have extension information before the Subsistence oriented group, because of their behaviour in which they are active to find the way and information to generate more cash than the other traditional group. They attempt to obtain information as much as possible to achieve their decision. Therefore, at first introduction of the crops, these groups can immediately include them in their trial options. After the decision making process, these groups have adopted high yield variety crop as they can get higher yield and income from these new crops even though they have to face the risk of failure from inexperience with these crop options.

After the first year of having introduced the high yield variety crop, information of achievement i.e. the kind of new crop option and its average yield, as well as price of the high yield variety, is exchanged among households in the village, which leads to the diffusion of new crop to the Subsistence oriented farm group. As such, a year later (2008) high yield variety crops become an option of all households in the process of crop decision, which will then be made by considering total income, resource use, and supporting information. Thus, in this year the high yield crops, since they generating more income because of higher yields (Figure 56 – 57) are chosen by all farm households. In addition, in the year 2007, the introduction of mango is launched and adopted by the households who produce only annual crops. Thus, the fruit tree production of the village increases by approximately four ha because of adoption of mango production by 25 farm households.

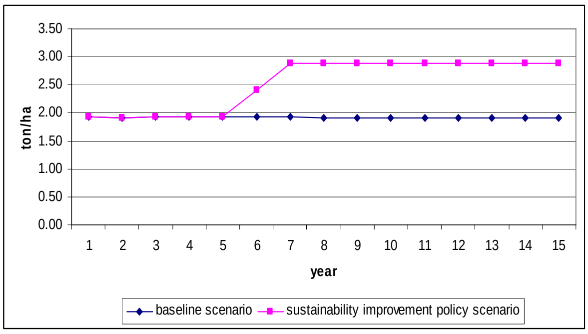


Figure 56: Average upland rice yield of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

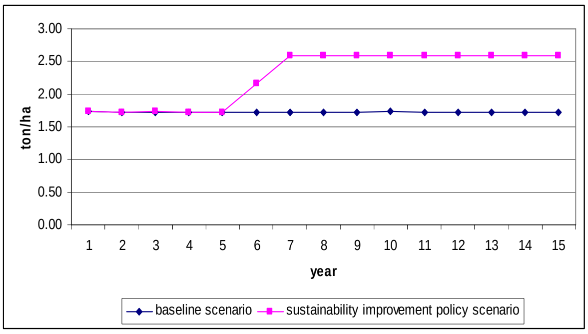


Figure 57: Average maize yield of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

In addition, the results show that the sustainability situation of study area is obviously improved, highlighted by increased value and the positive progression of trend of PI over time (Figure 58). After the year of implementing policy (2007), the number of households in the sustained class increases. The farm household sustainability situation changes into the higher level of sustainable class when considering the sustainable score of all indicators (Figure 59 – 60). Further, SIs of many indicators are increasing except SI of household saving which is rather constant (Figure 61 – 67). Particularly, PI of economic indicators is improved by contribution of getting better and being classified into the higher sustained class of households when consider the household income, net farm income, and household capital indicator (Figure 68 – 74). Increasing household crop income shown in Figure 75 induces increasing to net farm income, net household income, and household capital which then contributes to increasing of SIs of the corresponding indicators. However, the household saving is only one of economic indicators that SI and number of households in sustained class decrease (Figure 76 – 77) because high yield variety crop especially helps household consumption and non-cash household income but not cash holdings. Even so, the cash household income is not highly affected although the effect can occur through the reduction of cash from vegetable cash crops –bean, melon, pumpkin– which are the mixed cash crop mixing produced with main crops –upland rice and maize– for consumption (Figure 78 – 79). The reduction in the main crop area probably induces lower household cash and saving but the results from this scenario show that the extent of household saving reduction is acceptable and not changed significantly. That is because the reduction of household cash from mixed crop is partly recovered by an increase of cash from mango production, with all households growing at least 0.16 ha. As such, only a small reduction of SI and households in the sustained class of indicator can be seen.

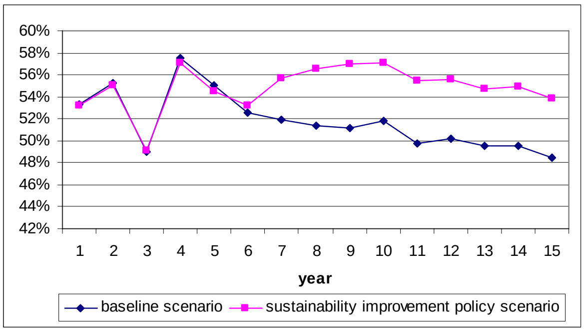


Figure 58: Performance index of all indicators of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

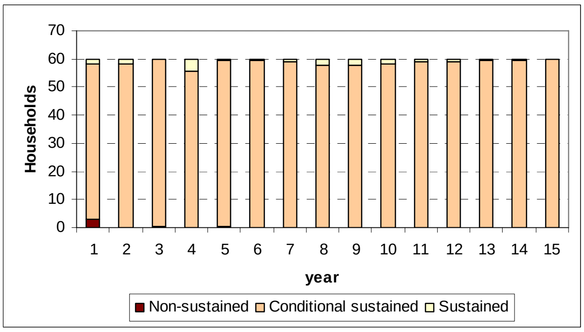


Figure 59: Number of households in each sustainable class classified by sustainable score of all indicators of sustainability improvement policy implementation scenario

Source: Simulation

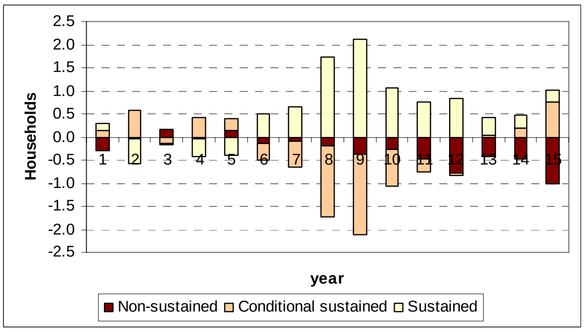


Figure 60: Change of number of households in each sustainable class classified by sustainable score of all indicators of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

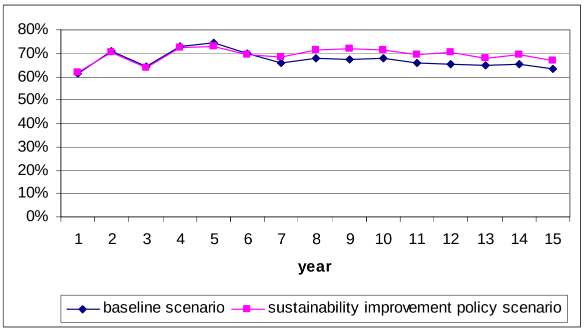


Figure 61: Sustainability index of household income indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

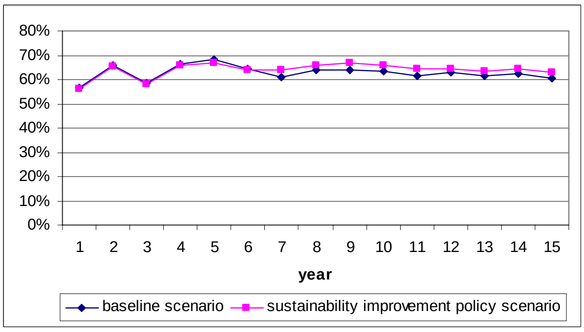


Figure 62: Sustainability index of net farm income indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

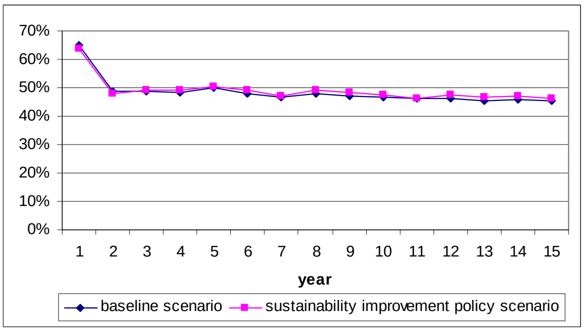


Figure 63: Sustainability index of household capital indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

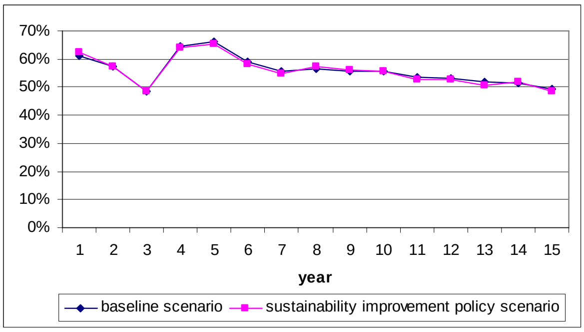


Figure 64: Sustainability index of household saving indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

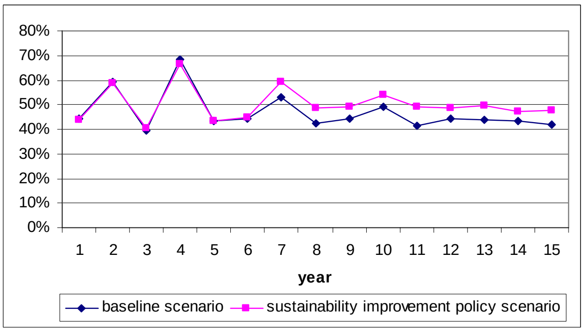


Figure 65: Sustainability index of food security indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

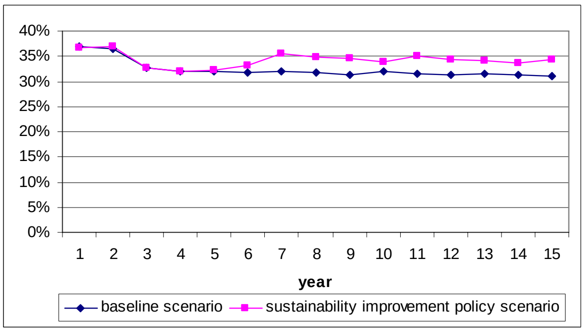


Figure 66: Sustainability index of top-soil erosion indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

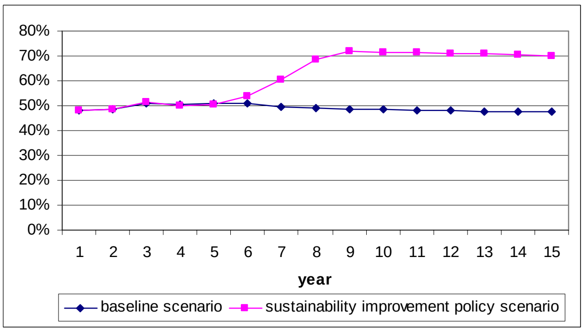


Figure 67: Sustainability index of fallow period indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

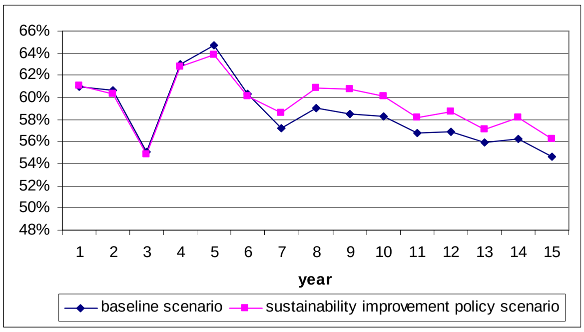


Figure 68: Performance index of economic indicators of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

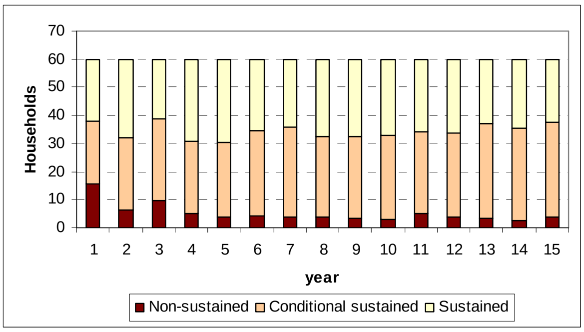


Figure 69: Number of households in each sustainable class classified by sustainable score of household income indicator of sustainability improvement policy implementation scenario

Source: Simulation

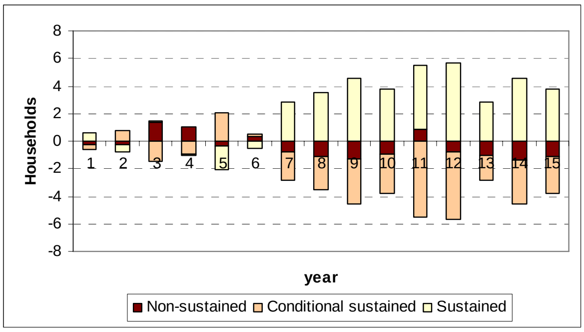


Figure 70: Change of number of households in each sustainable class classified by sustainable score of household income indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

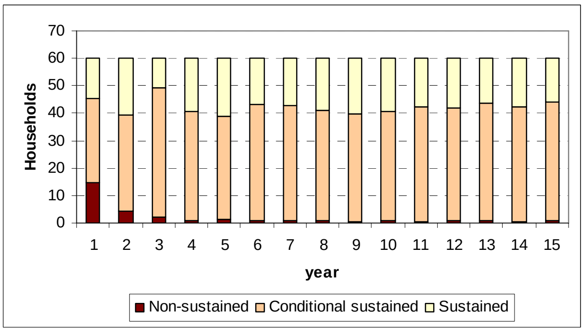


Figure 71: Number of households in each sustainable class classified by sustainable score of net farm income indicator of sustainability improvement policy implementation scenario

Source: Simulation

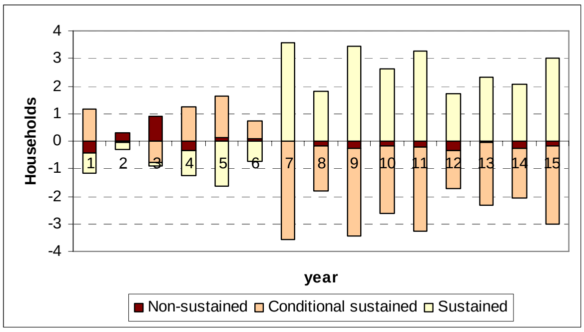


Figure 72: Change of number of households in each sustainable class classified by sustainable score of net farm income indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

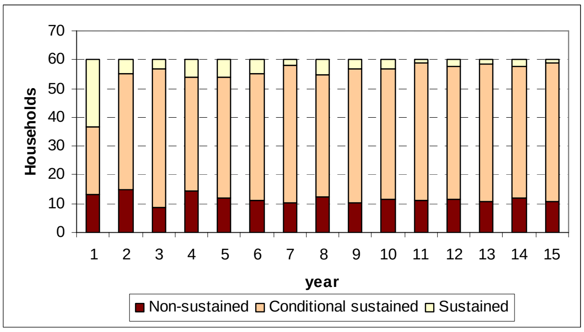


Figure 73: Number of households in each sustainable class classified by sustainable score of household capital indicator of sustainability improvement policy implementation scenario

Source: Simulation

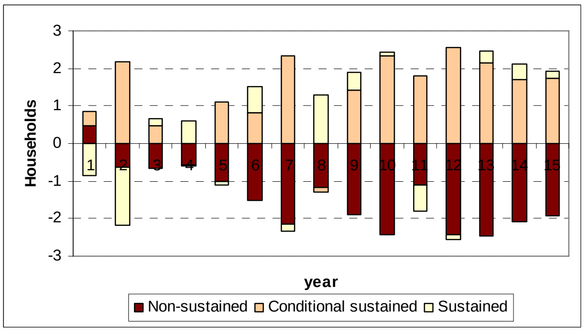


Figure 74: Change of number of households in each sustainable class classified by sustainable score of household capital indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

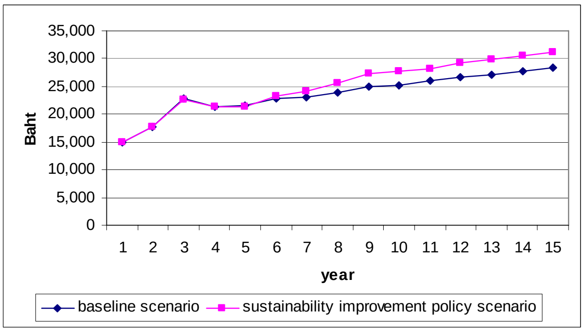


Figure 75: Net crop income of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

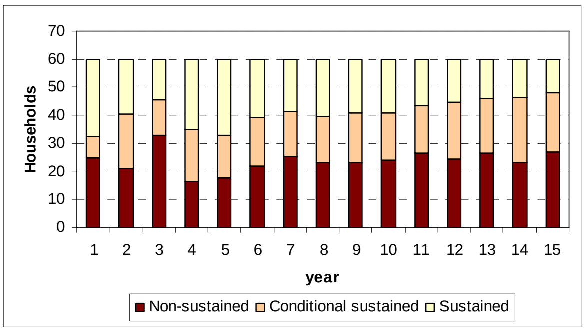


Figure 76: Number of households in each sustainable class classified by sustainable score of household saving indicator of sustainability improvement policy implementation scenario

Source: Simulation

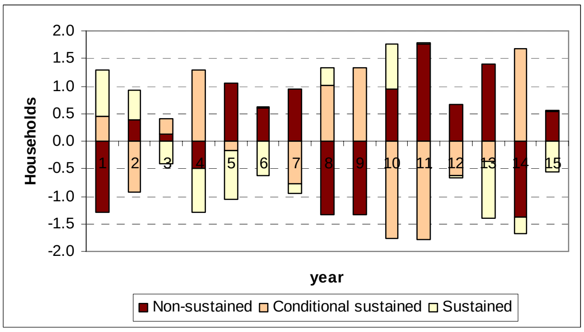


Figure 77: Change of number of households in each sustainable class classified by sustainable score of household saving indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

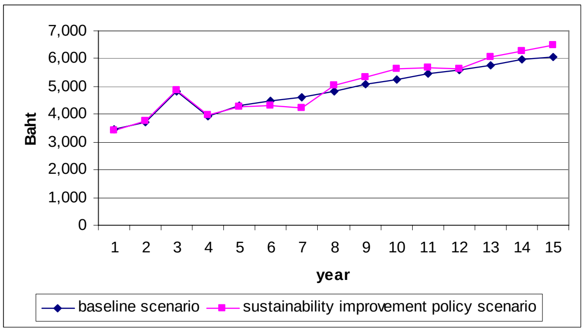


Figure 78: Net cash crop income of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

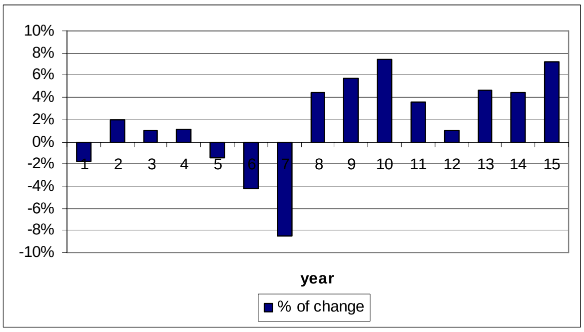


Figure 79: Percentage of change of net cash crop income of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

For the social condition, after the year of launching the policy the result shows an increase of households in higher sustainable classes (Figure 80 – 81). The number of households in the higher sustained classes is increased by the improvement of some households from the lower sustained class, and in particular, households' rice deficit in the village area (Figure 82). Consequently, the SI of food security is increased when compared to the baseline scenario (Figure 65).

Concerning the condition of the environment, the situation after the policy implementation year (2007) is much improved. The PI of environment indicators is increased which contributes to an improved household sustainability situation of top-soil erosion and fallow period indicator (Figure 83 – 87). Top-soil erosion is reduced especially corresponding to areas of increasing fruit tree production. Fruit tree production generates relatively low erosion in comparison to annual crop production which potentially decreases top-soil erosion (Figure 88). In addition, the application of the high yield variety encourages a reduction in land required for consumptive purposes. In each year, the proportion of cultivated land to fallow land of each household is lower. Then, the household can take longer fallow (Figure 89) which is advantageous for the environment and land resource condition. The longer period of fallow potentially leads to a recovery soil fertility and structure, as well as ecological system of land (Gypmantasiri and Amaruekachoke, 1995; Ratanawaraha, 1995). This situation is observed by the changing number of households in each sustainable class of fallow period indicator. Some households can take longer fallow period of land and so they are considered within a higher level of sustainable class. The improved household environment sustainability situation represented by these two indicators explained above contributes to an increase over time of SIs of both indicators shown in previous figures (Figure 66 and Figure 67).

Based on the changes of the sustainability situation which are explained above, the conclusion can be made that the proposed policy under this scenario provides a policy option which potentially leads to an improvement of the sustainability situation of the study area.

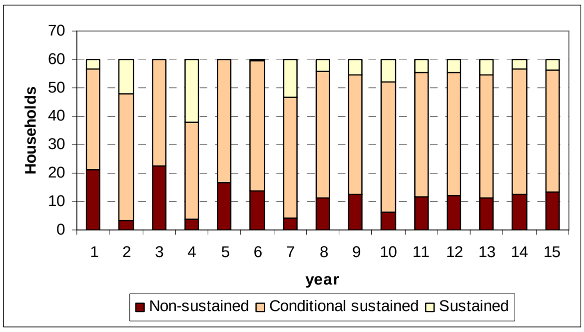


Figure 80: Number of households in each sustainable class classified by sustainable score of food security indicator of sustainability improvement policy implementation scenario

Source: Simulation

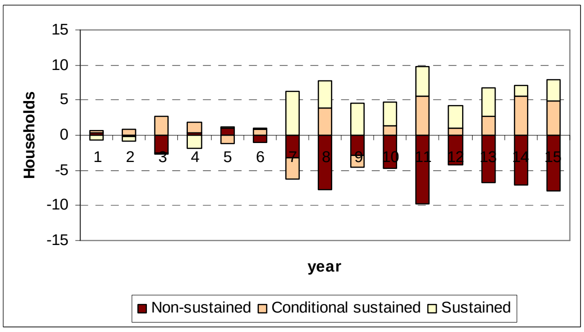


Figure 81: Change of number of households in each sustainable class classified by sustainable score of food security indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

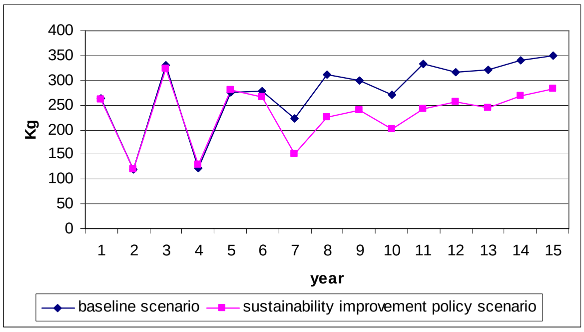


Figure 82: Average of amount of rice deficit per year of households of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

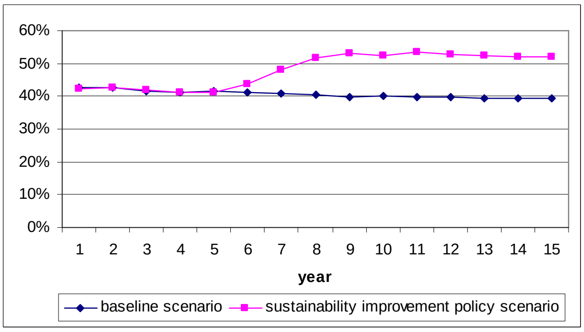


Figure 83: Performance index of environment indicators of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

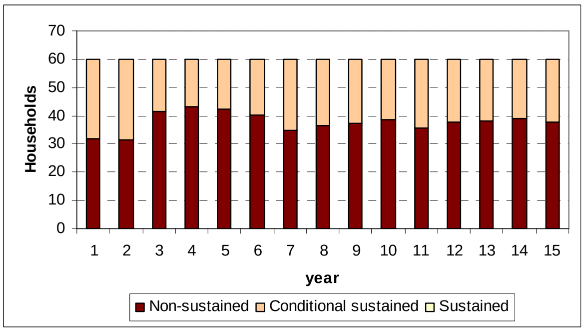


Figure 84: Number of households in each sustainable class classified by sustainable score of top-soil erosion indicator of sustainability improvement policy implementation scenario

Source: Simulation

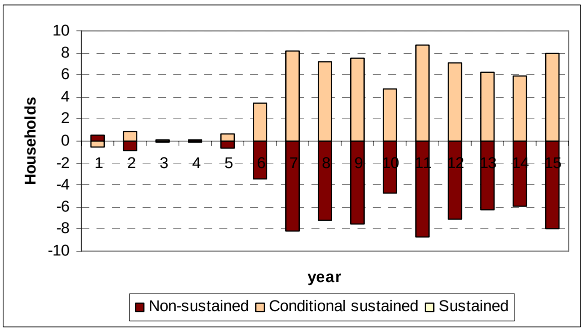


Figure 85: Change of number of households in each sustainable class classified by sustainable score of top-soil erosion indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

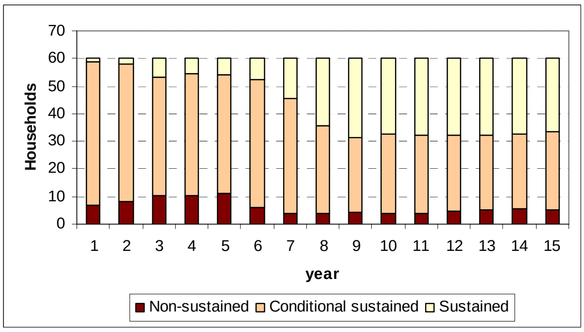


Figure 86: Number of households in each sustainable class classified by sustainable score of fallow period indicator of sustainability improvement policy implementation scenario

Source: Simulation

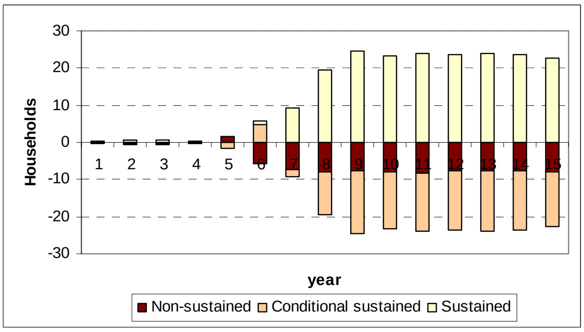


Figure 87: Change of number of households in each sustainable class classified by sustainable score of fallow period indicator of sustainability improvement policy implementation scenario comparing to baseline scenario

Source: Simulation

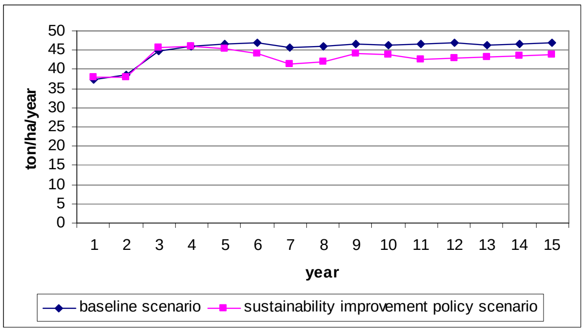


Figure 88: Average of amount of top-soil erosion produced by household of sustainability improvement policy implementation scenario comparing to baseline scenario
Source: Simulation

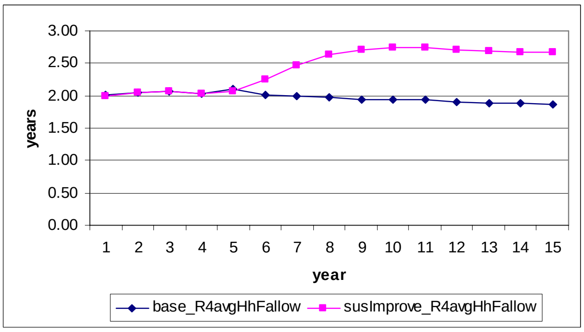


Figure 89: Average of fallow period of household of sustainability improvement policy implementation scenario comparing to baseline scenario
Source: Simulation

5.2.2 Change of biophysical factor scenario

Drought scenario

Under this scenario, drought occurring in 2 periods during 2007 to 2009 and 2013 to 2015, with a 25% of rain reduction, only has a small effect on the average yield of staple crops –upland rice and maize– compared to the baseline scenario (Figure 90 – 95). Nevertheless, this contributes to an approximate 4% reduction of fruit tree yield which is affected by the amount of accumulation of water shortage all year round (Figure 94 – 95). But, in the case of staple crops, the amount of water shortage is less than for fruit trees, and thus the smaller yield reduction for these crops.

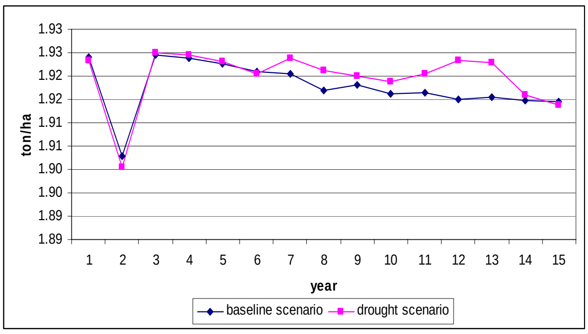


Figure 90: Average upland rice yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

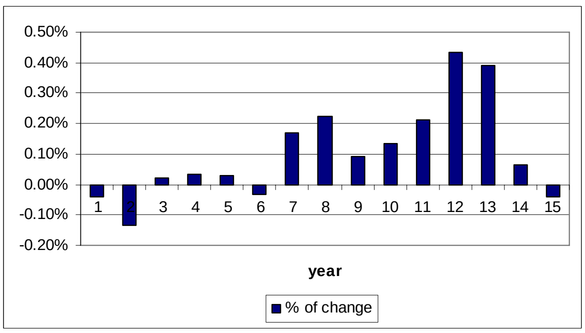


Figure 91: Percent change of average upland rice yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

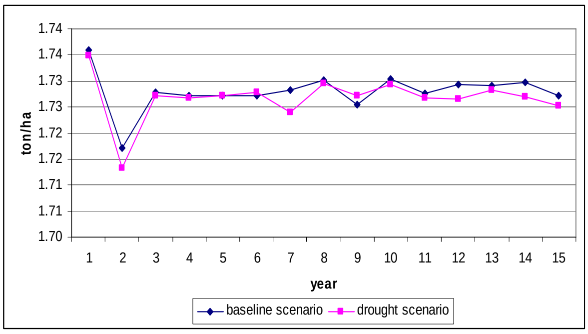


Figure 92: Average maize yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

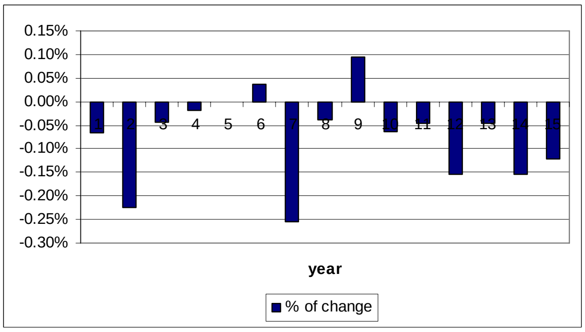


Figure 93: Percent change of average maize yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

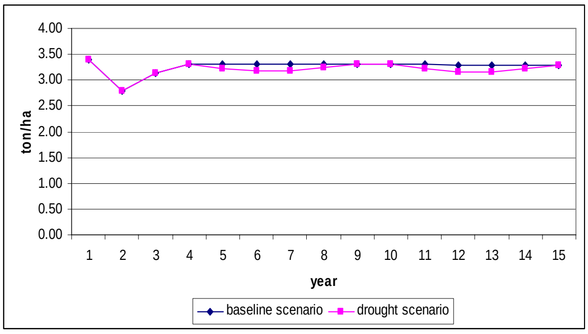


Figure 94: Average mango yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

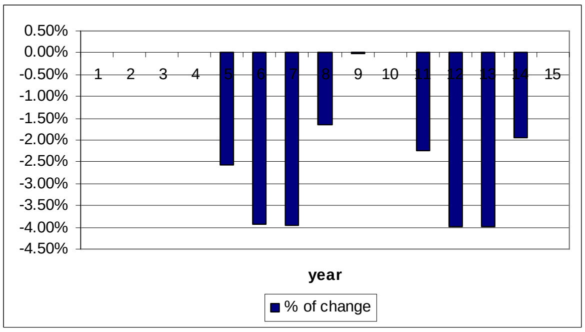


Figure 95: Percent change of average mango yield of drought occurring scenario comparing to baseline scenario
Source: Simulation

However, this situation including change of weather condition induces notable variation of planted area, which is a result of decision making process of households (Figure 96 – 98). Reduction in the amount of rainfall influences the timing of the rainy season which affects some factors determining the household's cropping decision making process. As having perception ability to environment of farm household agents, a decrease in rainfall is perceived and households adjust themselves by deferring planting until the actual rainy season starts, which is denoted through frequency and accumulation of amount of rain.

As such, the cultivation of farm household agents during the drought is delayed approximately 40 days from baseline. Postponement of cultivated time increases the accumulative amount of a household's deficit, and increases borrowing of rice and maize, which becomes a huge amount by the time the household reaches the appropriate time of making a decision to plant crops.

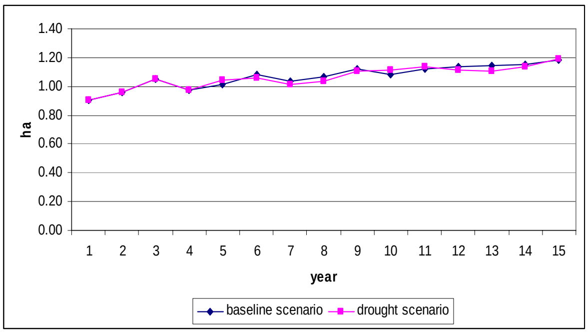


Figure 96: Average upland rice planted area of household of drought occurring scenario comparing to baseline scenario

Source: Simulation

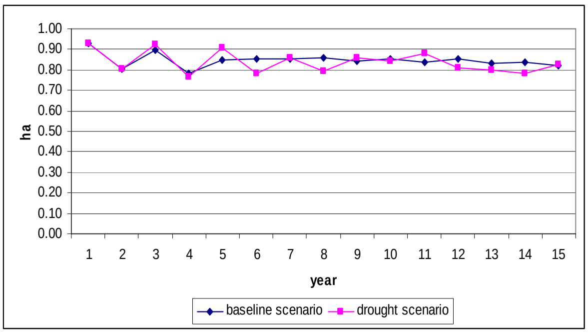


Figure 97: Average maize planted area of household of drought occurring scenario comparing to baseline scenario

Source: Simulation

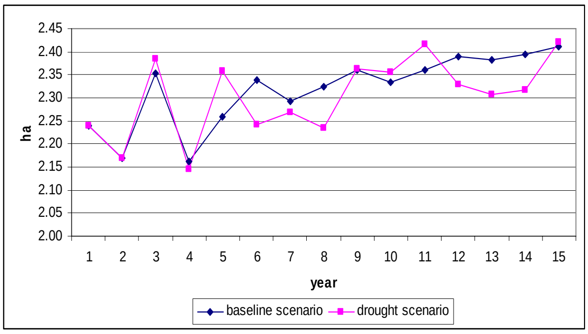


Figure 98: Average total planted area of household of drought occurring scenario comparing to baseline scenario

Source: Simulation

Since the decision making is executed, the expected planting area is estimated based on rice needed under the current situation and the knowledge base which is explained and expressed in the previous section (For upland rice: net household rice needed = rice needed – expected rice obtained – current household rice remaining + rice borrowing – rice being borrowed; and for maize: net household maize needed = maize needed – expected maize obtained – current household maize remaining + maize deficit). With a delay to the start of the rainy season, the large accumulated amount of rice borrowing and maize deficit is taken into account, causing an increase of cultivated area in the first year in each drought period 2007 and 2013 (Figure 99 – 102). Larger area cultivation with a low variation from average yield brings a huge amount of total yield which influences the decision making in the following year (the second year of drought). At that time household rice remaining is high so that planted area in that year is then reduced. For the third year of drought, adjustment of households to the situation of a late rainy season in the two previous years brings about a low variation in the cultivated area when compared with the change in the two previous years of drought.

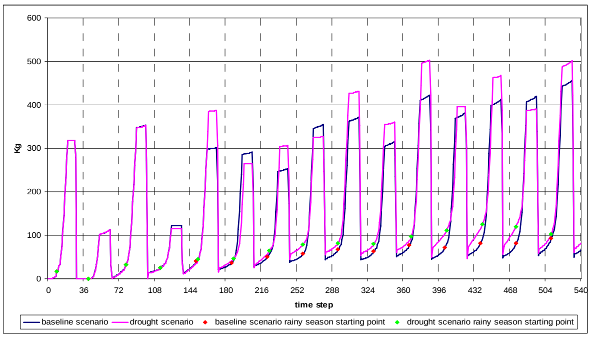


Figure 99: Average amount of borrowed rice of households over time of drought occurring scenario comparing to baseline scenario

Source: Simulation

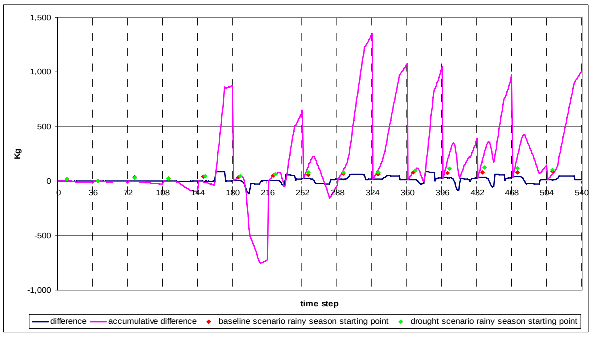


Figure 100: Difference and accumulative difference of average amount of borrowed rice of households over time of drought occurring scenario comparing to baseline scenario

Source: Simulation

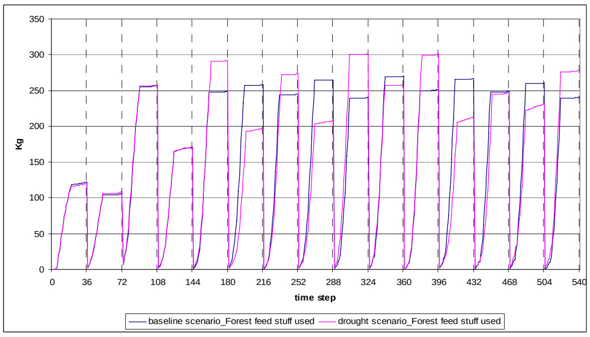


Figure 101: Average amount of forest feed stuff used of households over time of drought occurring scenario

Source: Simulation

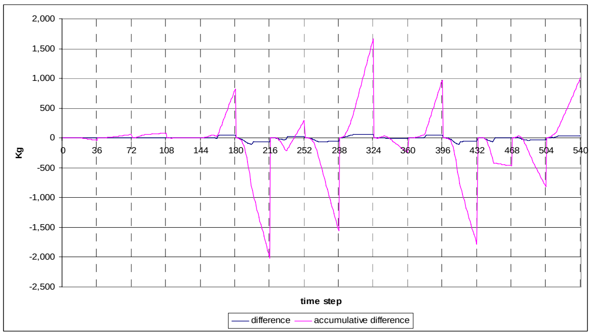


Figure 102: Difference and accumulative difference of average amount of forest feed stuff used of households over time of drought occurring scenario comparing to baseline scenario

Source: Simulation

Variation of cultivated area induces a variation of cash farm and household income which is affected by changes to cash obtained from vegetable mixed crops (Figure 103 – 104). However, by considering the overall sustainability situation, the results show slightly better PI during the drought period, which is increasing and has a relative slow decline compared to the baseline scenario (Figure 105 – 106). These are effects of trade-off between indicators. The top-soil erosion indicator becomes better and therefore the PI of the environmental condition is also better (Figure 107 – 108) while social and economic condition shows only a slightly change over time (Figure 109 – 112).

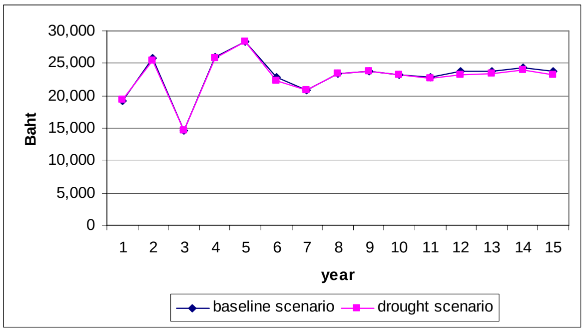


Figure 103: Average net cash farm income of drought occurring scenario comparing to baseline scenario
Source: Simulation

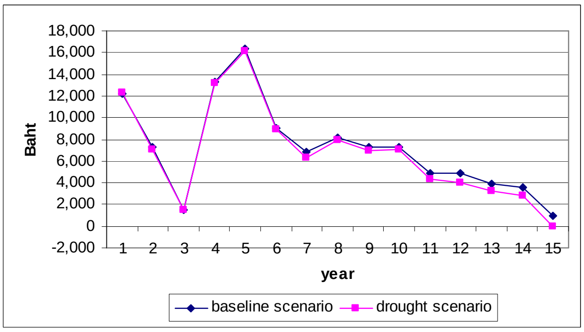


Figure 104: Average net cash household income of drought occurring scenario comparing to baseline scenario
Source: Simulation

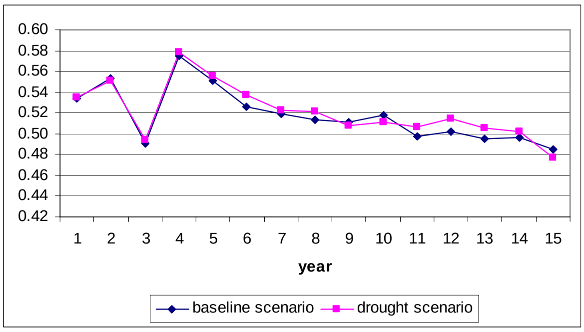


Figure 105: Performance index of all indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

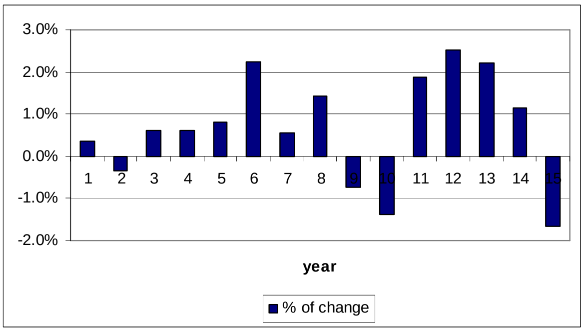


Figure 106: Percentage change of Performance index of all indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

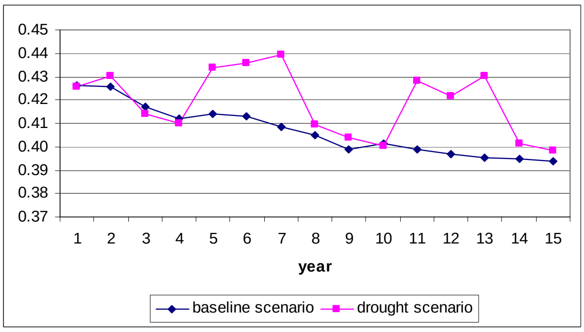


Figure 107: Performance index of environment indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

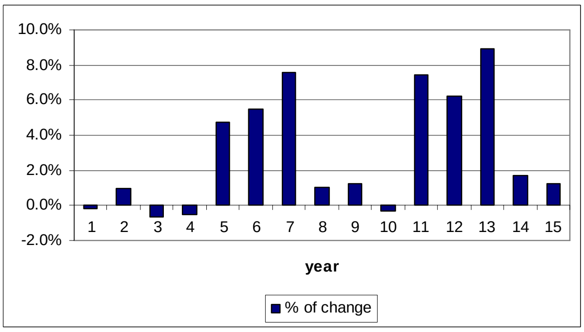


Figure 108: Percentage change of Performance index of environment indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

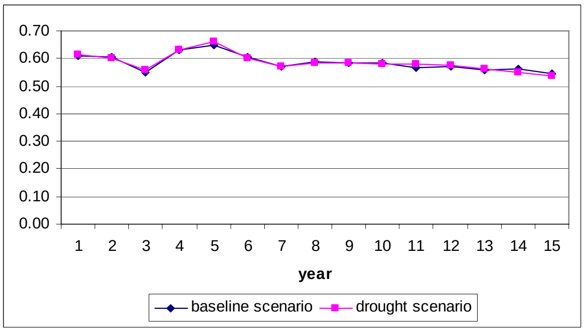


Figure 109: Performance index of economic indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

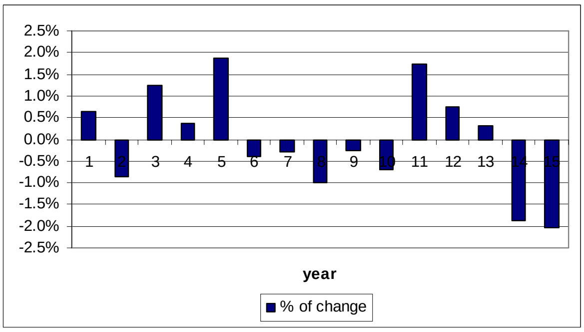


Figure 110: Percentage change of Performance index of economic indicators of drought occurring scenario comparing to baseline scenario
Source: Simulation

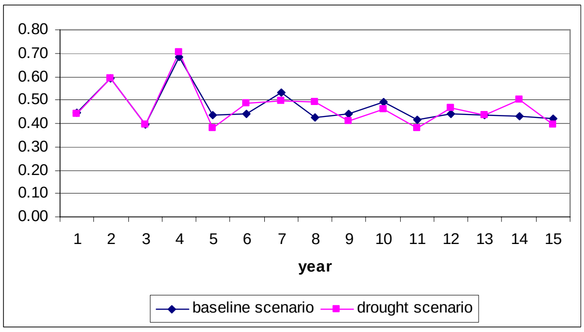


Figure 111: Performance index of social indicator of drought occurring scenario comparing to baseline scenario
Source: Simulation

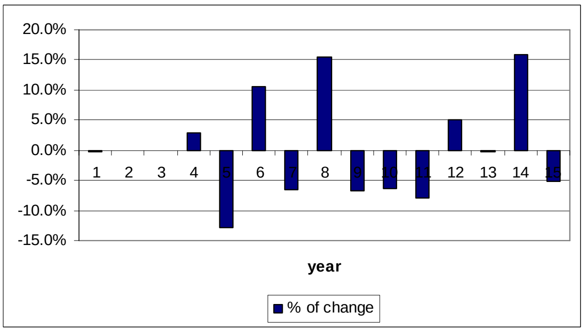


Figure 112: Percentage change of Performance index of social indicator of drought occurring scenario comparing to baseline scenario
Source: Simulation

The PI of the social indicator is decreased especially in the first year of both drought periods because of the increase in rice deficiency. The value of the PI of the social indicator is decreased by 12.93% and 8.01% from the baseline scenario. However, the PI of economic indicators is slightly increased because of increasing crop income, especially for the first year of drought periods, as the planted area is increased because of the effect of the drought, as explained above. The households obtain higher total crop income from obtaining higher total yield by expanding crop area, and by producing mixed crops which are grown together with staple crops. Thus, total crop income is raised when compared to baseline, which induces increases in the SI of net farm income, household capital, household saving, as well as the PI of economic indicators. In contrast to these two conditions, the change of PI of environmental indicators is relatively large. That is because the top-soil erosion situation has been improved by the reduction of rainfall during the drought periods. The value of this PI is increased in both drought periods by approximately 5.92% and 7.52% in comparison to the baseline scenario respectively (Figure 107 – 108).

Furthermore, simulation results present adaptation and reaction of farm household agents to drought events given their resource endowment. The perception of drought induces the decision to postpone growing crops to avoid damage of plant from drought. This is consistent with the behaviour of farm households in reality and captured through the model which the household agents make crop production decision based on knowledge and experience about planting in suitable condition. Consequently, the delay of cultivation in the previous year affects the decision making process of the coming year. The amount of borrowed and deficit of rice and maize influences the crop area decision. Rice and maize deficits will accumulate as long as this decision making is deferred.

This circumstance results in the simulation where farm households decide to expand the area of cropping after the first year of drought occurring (Figure 96 – 98). However, in the second and third year of the drought period the consequences become lower because of the adaptation of farm household decision making which is based on experience and what they have learned from the past. For the first year of the drought period, the households obtain relative high crop products compared to the baseline, as the planted area is expanded, which in turn affects the decision of cultivation in the following year. The high amount of crop product obtained causes a high amount of rice remaining at the time of decision making for the next year, resulting in a decision to reduce cultivated area (in the second year of drought periods).

During long run simulation, the behaviour of farm household agents when facing drought is also observed. Increase in rice deficiency occurs in both periods of drought. The farm household agents acquire rice by borrowing from the village rice bank and their neighbours that are the same of households' current performing found in area (Figure 113). Simulation results show an increasing average amount of borrowed rice starting at the first year of the first drought period (Figure 99 – 100). Adjustment of farm households to drought occurs because of the change in factors determining crop decision making, which leads to adjustments in planting area. Uncertainty and imperfect information regarding the biophysical and socioeconomic condition (e.g. rain, availability of household rice and maize for consumption and other purposes) lead to incomplete and lags in adaptation behaviour.

In addition, the results show farm household response to maize deficiency corresponding to actual behaviour as they try to collect wild vegetables to feed their livestock. An increasing amount of wild vegetables used for feeding during drought periods is captured and shown in Figure 101 – 102. Furthermore, during simulation farm household agents perform off-farm activities such as gathering forest products, selling mixed crops e.g. local bean, local melon, and pumpkin, as well as selling household capital products to generate cash when needed. These results also correlate with existing farm household behaviour found in the area.

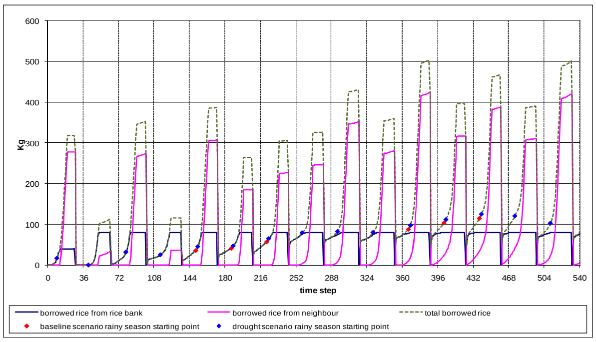


Figure 113: Average amount of borrowed rice of households over time of drought occurring scenario
Source: Simulation

When considering the area's general sustainability situation, the PI shows a decreasing trend which is unsustainable, similar to the baseline scenario (Figure 105 – 106). However, the rate of decline for this scenario is slightly lower than the baseline result. This is because of the trade-off between indicators, as the top-soil erosion situation becomes better while the drought occurs. In addition, there is only a small change in the number of households in sustainable class compared to the baseline.

However, when considering the number of households in each sustained class in the first year of drought, the number of households in Sustained (S) and Conditional sustained (C) class decreases while the number of households in Non-sustained (N) class increases (Figure 114 – 115). This is because the effect of drought contributes to a worsening of households regarding food security, fallow period, and household saving condition which induces change into unsustainable situation for many households. This result leads to changing the households into worse sustainable situation when considering all conditions together. This is caused by a worsening of food security, fallow period, and household saving aspect even though the households have better situation in top-soil erosion, net farm income, household income, and household capital. However, for the first year of the second drought period this result is slightly different. A higher number of households reach a higher sustained class in top-soil erosion, net farm income, household income, and household capital indicator induces an increase in the higher sustained class. As such, in the first year of the second drought period the result shows an increase in the number of households in the higher sustained class.

After the first year of both drought periods, the households are changed into more sustained class by getting a better sustainability situation in top-soil erosion and household capital situation even though they are suffering from worse food security and fallow period condition.

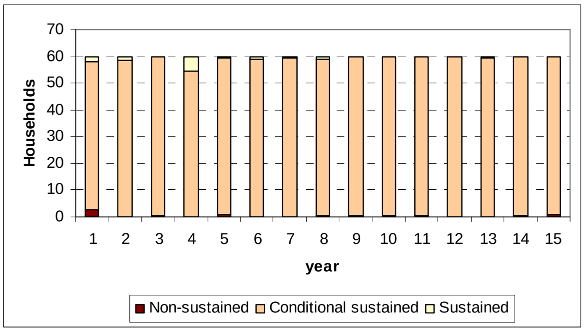


Figure 114: Number of households in each sustainable class classified by sustainable score of all indicators of drought scenario
Source: Simulation

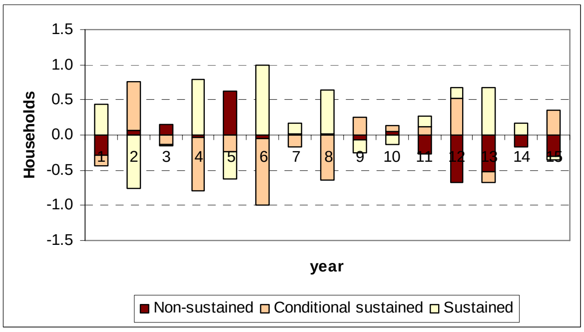


Figure 115: Change of number of households in each sustainable class classified by sustainable score of all indicators of drought scenario comparing to baseline scenario
Source: Simulation

For more detail, the change in number of households varies depending on each indicator. For the economic condition, in the first year of drought periods the number of households in the sustained class is increasing because planted area extension caused by household adjustment to drought leads to higher household income, net farm income, and household capital (Figure 116 – 121). So, the number of households in sustained class in these corresponding items is higher. Two years later in the drought periods, for the household income indicator, the number of households in the unsustained class increases. This is mainly because of the household adjustment process when facing drought. Also, this is caused by increasing of household expenditure and decreasing off-farm income which is affected by limitation on household labour availability or limitation on labour market need. For the net farm income and household capital indicator, the number of households in the sustained class is increasing because of cropping area expansion in the first year of drought periods as previously explained. However, for the last two years during drought periods, the decision to reduce the planted area leads to a reduction of the number of households in the sustained class. In the case of the household saving indicator, the number of households in the unsustained class increases during drought periods because of decreasing farm cash income which is mainly caused by a reduction in cash crop especially from mango affected by yield reduction (Figure 122 – 123). However, in the first year of the first drought period these effects are mitigated by increasing cash income from livestock selling, as the household tries to recover from the stress of a cash deficit in the previous year, in which the household had higher average debt and lower average cash income (Figure 124 – 125).

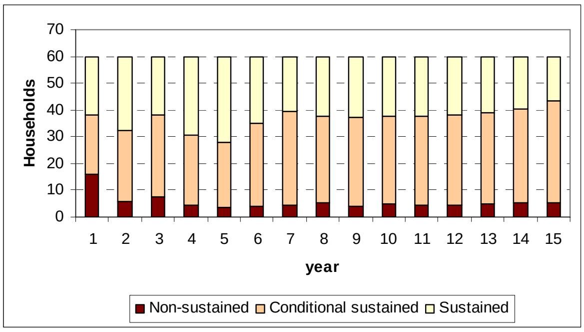


Figure 116: Number of households in each sustainable class classified by sustainable score of household income indicator of drought scenario
Source: Simulation

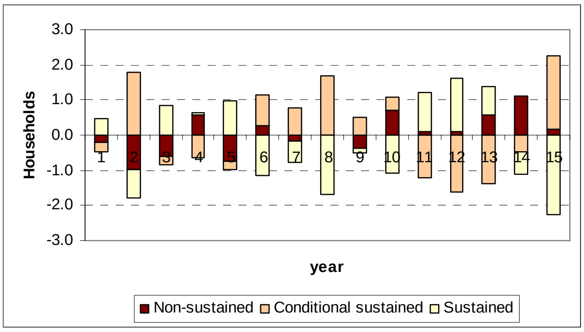


Figure 117: Change of number of households in each sustainable class classified by sustainable score of household income indicator of drought scenario comparing to baseline scenario
Source: Simulation

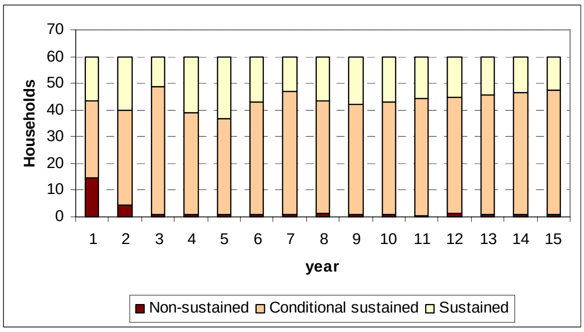


Figure 118: Number of households in each sustainable class classified by sustainable score of net farm income indicator of drought scenario
Source: Simulation

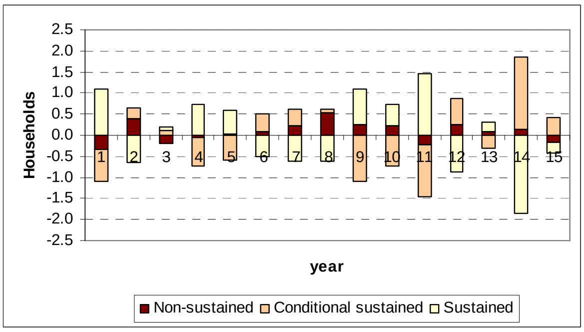


Figure 119: Change of number of households in each sustainable class classified by sustainable score of net farm income indicator of drought scenario comparing to baseline scenario
Source: Simulation

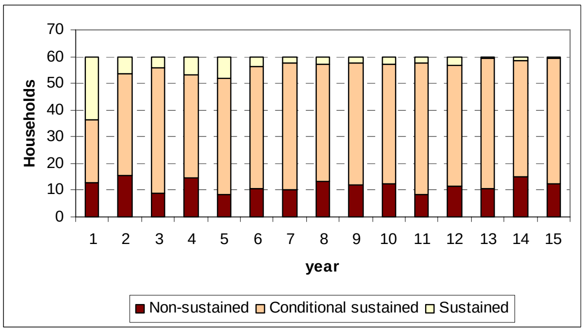


Figure 120: Number of households in each sustainable class classified by sustainable score of household capital indicator of drought scenario
Source: Simulation

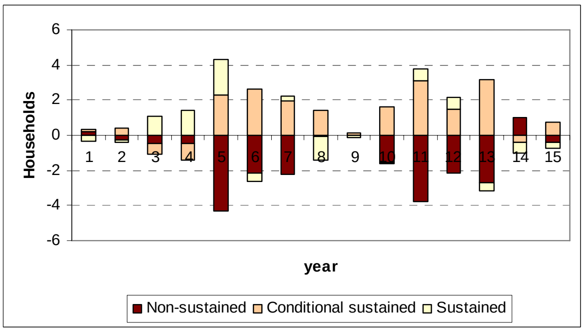


Figure 121: Change of number of households in each sustainable class classified by sustainable score of household capital indicator of drought scenario comparing to baseline scenario
Source: Simulation

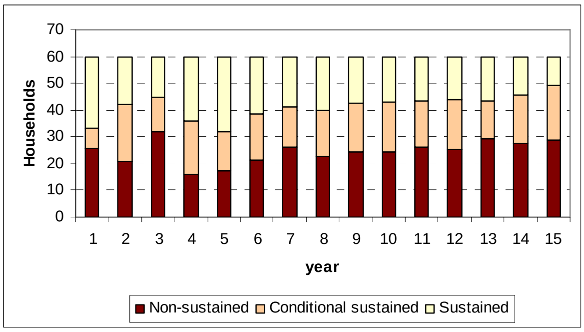


Figure 122: Number of households in each sustainable class classified by sustainable score of household saving indicator of drought scenario
Source: Simulation

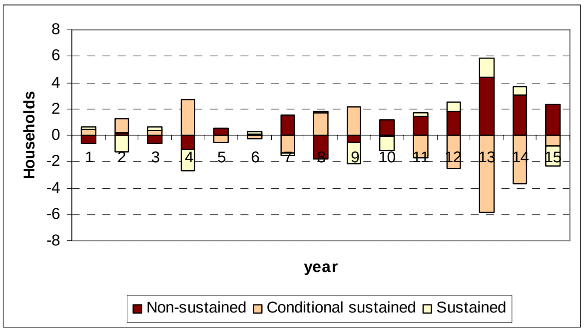


Figure 123: Change of number of households in each sustainable class classified by sustainable score of household saving indicator of drought scenario comparing to baseline scenario
Source: Simulation

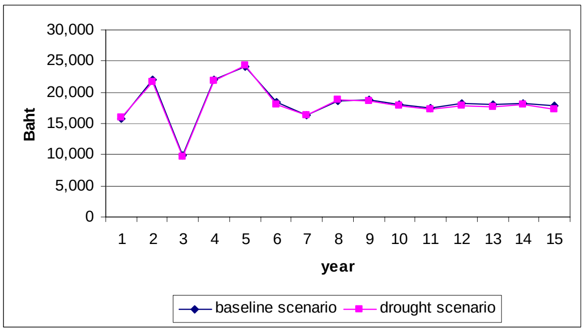


Figure 124: Average net cash livestock income of household of drought scenario comparing to baseline scenario
Source: Simulation

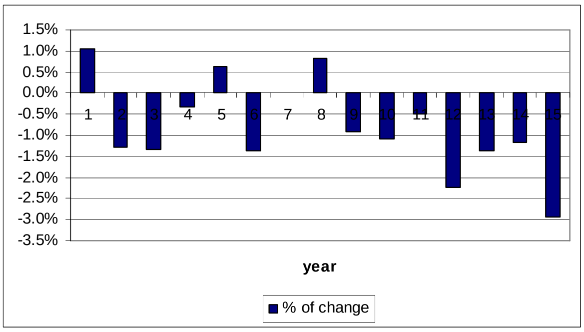


Figure 125: Percentage change of average net cash livestock income of household of drought scenario comparing to baseline scenario
Source: Simulation

For the social condition, particularly in the first year of drought periods there is a large increase of number of Non-sustained (N) households in the food security indicator (Figure 126 – 127). As the drought is an unexpected event, the households can make mistakes estimating the amount of rice needed. The decision on rice production in the previous normal year before the droughts is made based on the usual situation from the past which does not expect a drought to occur. As such, the total yield obtained cannot cover the amount of additional rice required during the delay of harvesting in the year of drought periods. Therefore, borrowing rice increases significantly during the first year of drought. This induces an adjustment to the drought of households' decision making about rice production in the next year as the households will increase their rice production (Figure 96). This leads to a high total rice yield obtained in the following year. In the second year of drought periods, the area planted to rice is reduced because of adjustment to the drought as the total yield obtained in the previous year is high. At the point of time of decision making the rice in the store is still high (see equation of planting rice decision in section 3.3.3). Therefore, rice area planted is reduced.

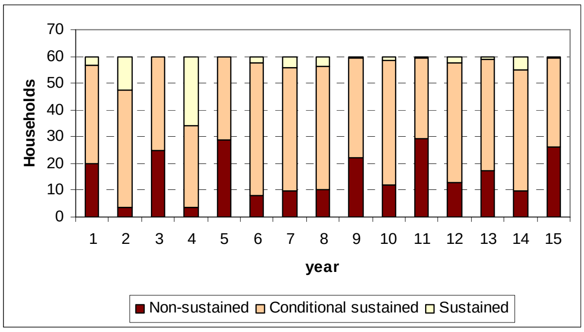


Figure 126: Number of households in each sustainable class classified by sustainable score of food security indicator of drought scenario

Source: Simulation

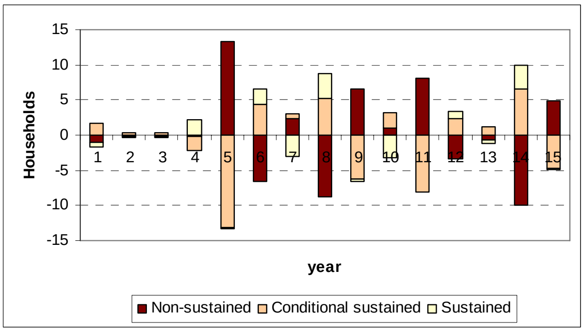


Figure 127: Change of number of households in each sustainable class classified by sustainable score of food security indicator of drought scenario comparing to baseline scenario

Source: Simulation

In the case of considering the environmental condition, during the drought the number of households in the higher sustained class increases, which is notably influenced by the top-soil erosion indicator (Figure 128 – 129). A reduction of erosion occurs due to decreasing rainfall which is a significant determinant of soil erosion. As a consequence, top-soil erosion made from household cultivation is relatively low compared to the baseline (Figure 130 – 131), thus, some households are considered in the higher sustainable class, which also induces an increase in the SI of the top-soil erosion indicator (Figure 132 – 133). For the fallow period indicator, the result shows a decreasing of number of households in sustained class, especially for the first two years of the drought periods (Figure 134 – 135). Increasing the planted area in the first year during drought periods brings about a decrease in the fallow period which the households have to use land by shorten fallow period. As such, the results show a reduction of average fallow period of households starting in the first year of drought periods (Figure 136 – 137). In the following years of drought periods the fallow is gradually longer due to the adaptation of households. However, in general the trend of the area's fallow still tends to be decreasing under the drought scenario. A large reduction in the fallow period occurs in the first year of the first drought period. Subsequently, the fallow period increases until the first year of the second drought period, in which the length of the fallow immediately decreases again, before becoming longer again in the coming years.

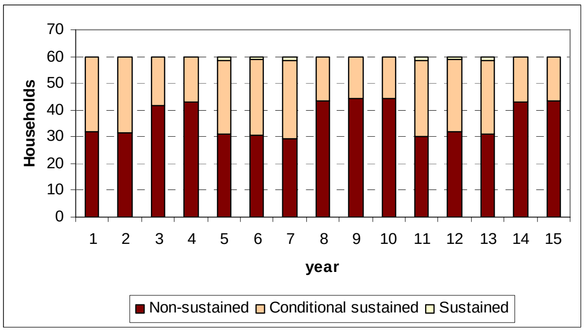


Figure 128: Number of households in each sustainable class classified by sustainable score of top-soil erosion indicator of drought scenario
Source: Simulation

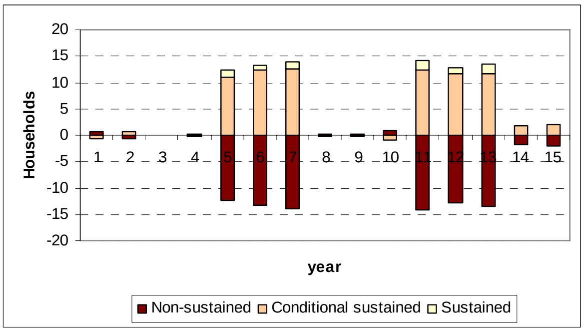


Figure 129: Change of number of households in each sustainable class classified by sustainable score of top-soil indicator of drought scenario comparing to baseline scenario
Source: Simulation

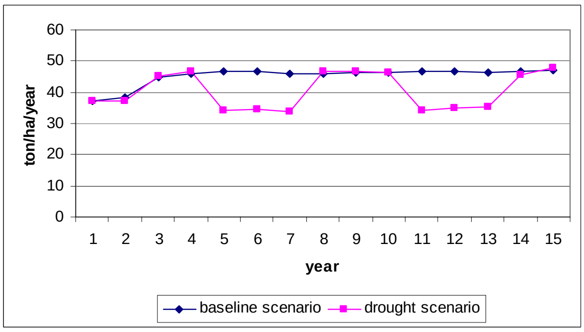


Figure 130: Average amount of top-soil erosion of household of drought scenario comparing to baseline scenario
Source: Simulation

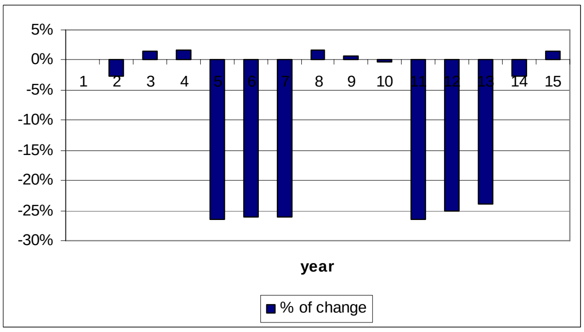


Figure 131: Percentage of change of average amount of top-soil erosion of household of drought scenario comparing to baseline scenario
Source: Simulation

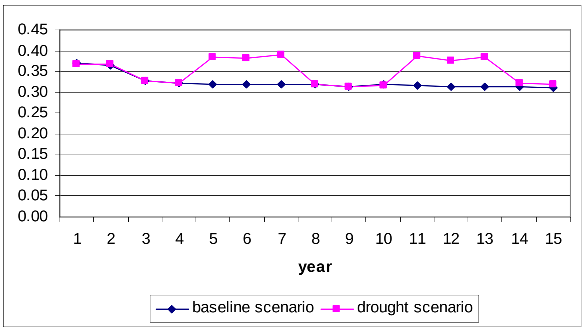


Figure 132: Sustainability index of top-soil erosion indicator of drought scenario comparing to baseline scenario
Source: Simulation

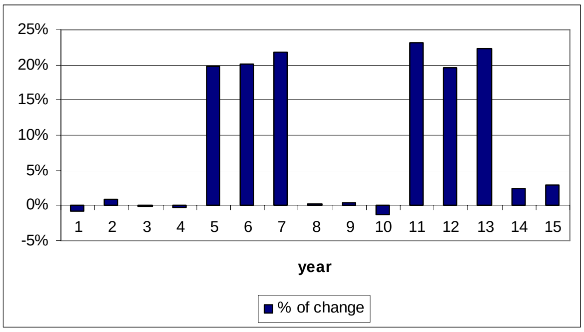


Figure 133: Percentage of change of Sustainability index of top-soil erosion indicator of drought scenario comparing to baseline scenario
Source: Simulation

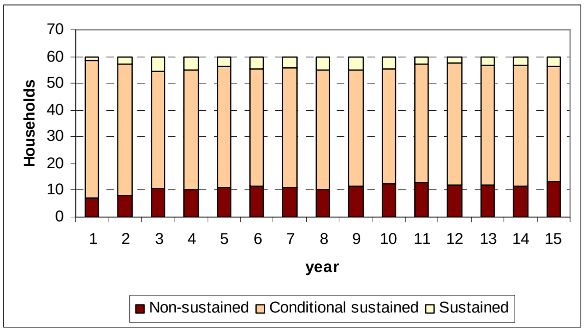


Figure 134: Number of households in each sustainable class classified by sustainable score of fallow period indicator of drought scenario
Source: Simulation

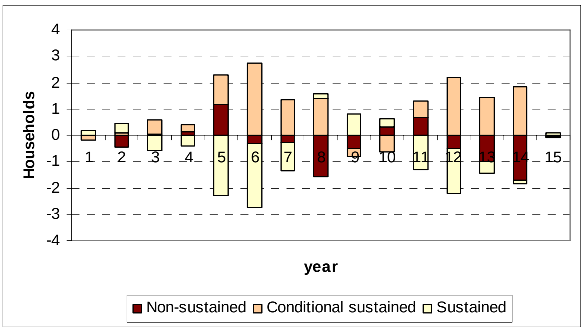


Figure 135: Change of number of households in each sustainable class classified by sustainable score of fallow indicator of drought scenario comparing to baseline scenario
Source: Simulation

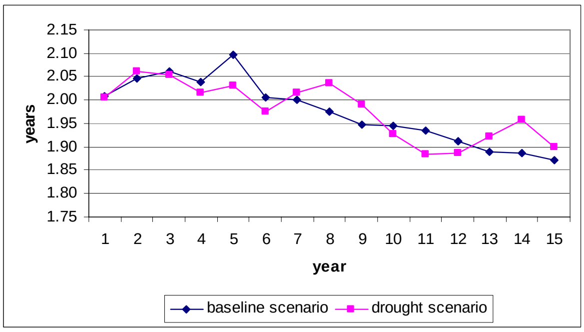


Figure 136: Average fallow period of household of drought scenario comparing to baseline scenario
Source: Simulation

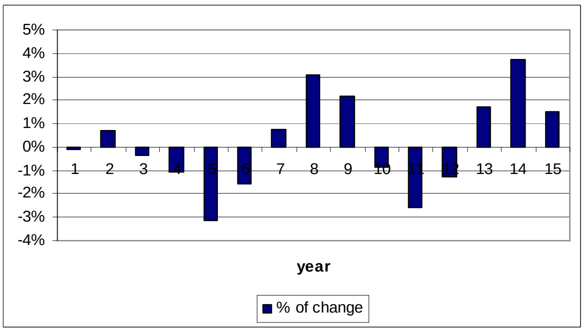


Figure 137: Percentage of change of average fallow period of household of drought scenario comparing to baseline scenario
Source: Simulation

However, by considering the general sustainability situation under the drought scenario, the study area is still unsustainable with the same trend as the baseline scenario. Unsustainability is observed by the decline over time of the PI. However, in the drought scenario, the decrease is at a slightly lower rate because of trade-offs between indicators. A reduction in rainfall induces a better of environmental indicator especially top-soil erosion. This positive effect can compensate for negative effects occurring in the economic, social and environmental conditions such as a decrease in household saving, food security, and fallow period. Furthermore, the results of this scenario present the ability of farm households to cope with and recover themselves from drought to some extent.

Rain increasing scenario

For this scenario, the event is set in contrast to the drought scenario. In the periods during 2007 to 2009 and 2013 to 2015, the amount of rain is increased by 25% relative to the baseline scenario. The results of the simulation show that crop yield is not significantly affected by an increase in rainfall (Figure 138 – 143). There is only a small effect on the fruit trees, as the increase in rainfall contributes to a relatively high increase in yield. However, the increase observed is less than 1% greater than that in the baseline scenario. For staple crops, small variations are observed but this is not due to an increase in rainfall but because of random effects in the initial stage. Initial random distribution of fallow of plots directly influences the household decision to use the plot. Therefore, at the initial stage of each simulation there is a difference in the set of plots which have a suitable fallow period to be used in agricultural activities. Then, the plots used in each simulation are different and of course have different properties. In this case, the soil layer depth property influences the crop model which directly affects the actual yield obtained in each simulation. So, the crop yield results obtained from each simulation are different but the variation is small and does not significantly influence yield. In addition, random effects at the initial stage regarding the dynamic of household livestock such as the initial stage of livestock age, new birth, selling out of products influences the household decision. The consequences can be observed through changing of income, capital, saving, and planted area but the variation is generally small.

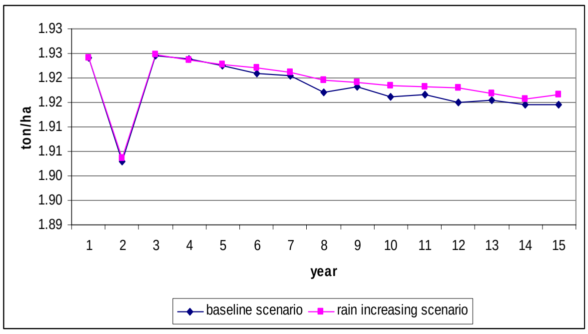


Figure 138: Average upland rice yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

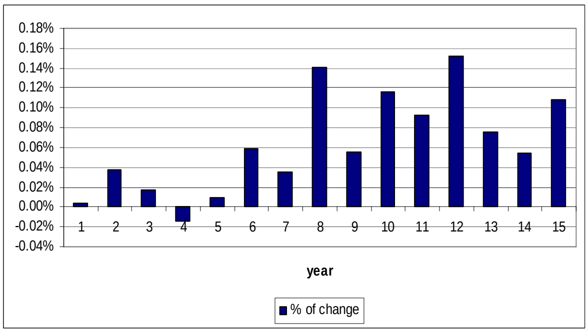


Figure 139: Percentage of change of average upland rice yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

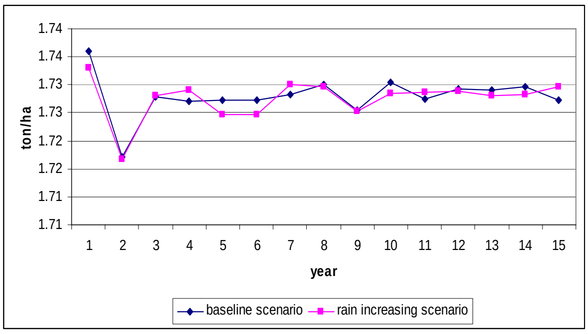


Figure 140: Average maize yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

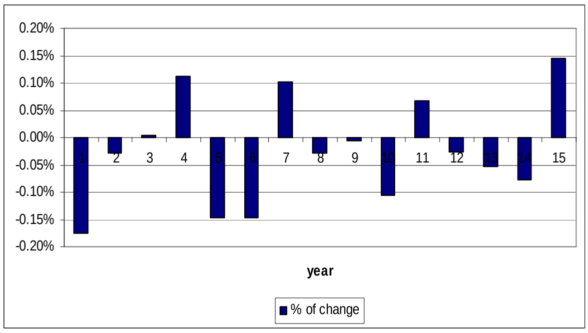


Figure 141: Percentage of change of average maize yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

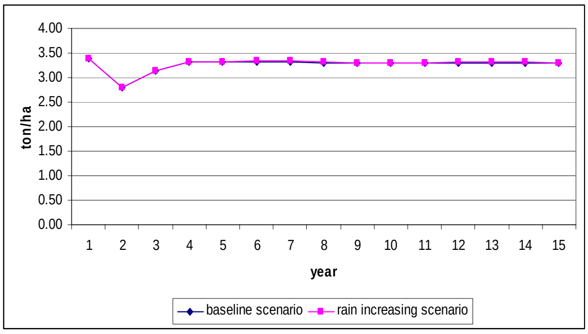


Figure 142: Average mango yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

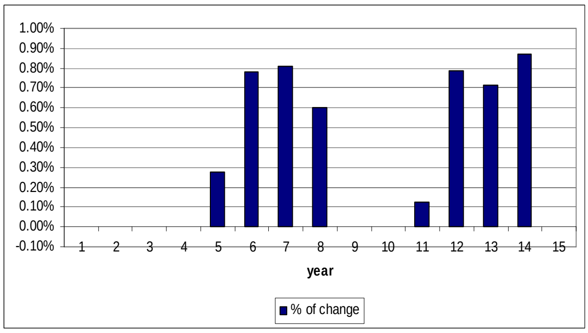


Figure 143: Percentage of change of average mango yield of household of rain increasing scenario comparing to baseline scenario
Source: Simulation

Under this scenario, the sustainability situation in general is trending in the same way as baseline. However, for this scenario the top-soil erosion situation is worse, as it is directly affected by the increase in rainfall. The PI is still presenting unsustainability and slightly worse than baseline (Figure 144 – 145). Decreases in the PI can be observed during both drought periods (the year 5th – 7th and 11th – 13th). Nevertheless, some negative effects of top-soil erosion are alleviated by the increasing of cash livestock income due to the influence of random effects of livestock age at initial stage of simulation. The households have more available livestock at the right age that can be sold. This increases livestock cash income, especially in the first year when rainfall increases, and results in an increase in net farm and household income (Figure 146 – 149).

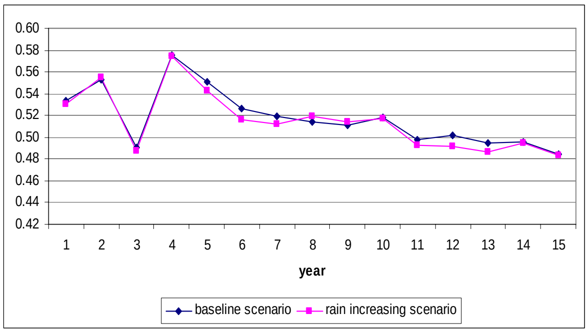


Figure 144: Performance index of all indicators of rain increasing scenario comparing to baseline scenario

Source: Simulation

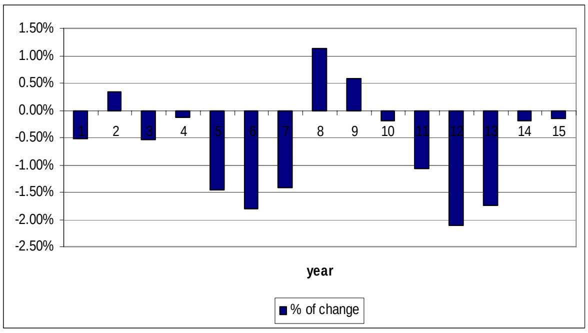


Figure 145: Percentage change of Performance index of all indicators of rain increasing scenario comparing to baseline scenario

Source: Simulation

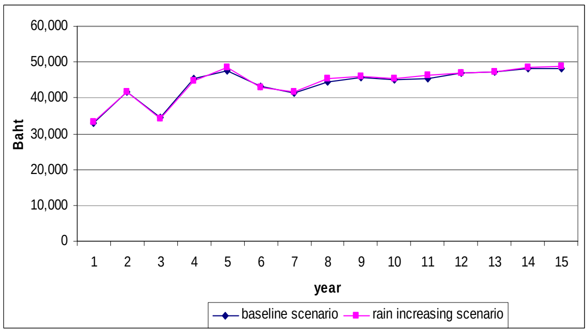


Figure 146: Average net farm income of household of rain increasing scenario comparing to baseline scenario

Source: Simulation

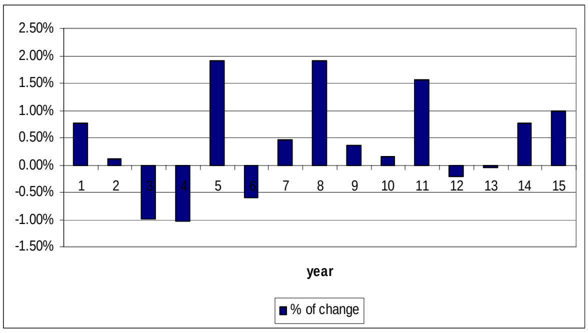


Figure 147: Percentage change of average net farm income of household of rain increasing scenario comparing to baseline scenario

Source: Simulation

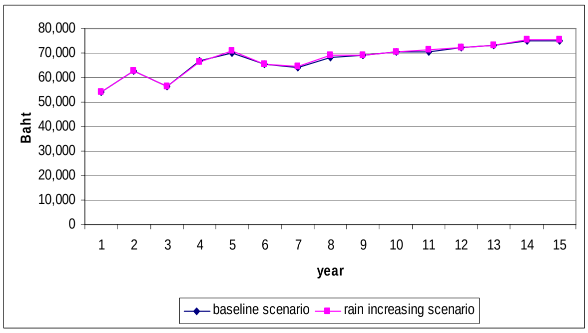


Figure 148: Average household income of rain increasing scenario comparing to baseline scenario

Source: Simulation

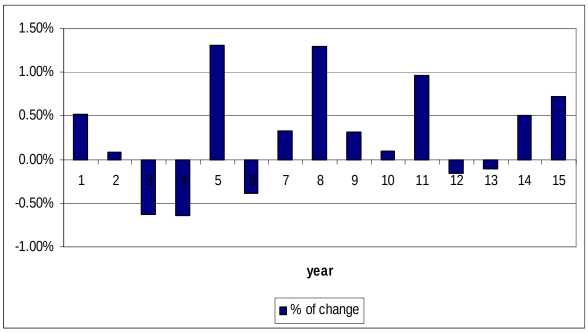


Figure 149: Percentage change of average household income of rain increasing scenario comparing to baseline scenario

Source: Simulation

Because of increasing income from livestock production, the PI of economic indictors is slightly increasing, especially for the first year of the increased rainfall periods. This occurs by contributions of all SIs of economic indicators (Figure 150 – 157). In the first year of rain increased rainfall, the households earn higher farm income as net livestock income increases over time because of the influence of random effects at initial stage of livestock age (Figure 146 – 147 and 158 – 159). Therefore, the households are slightly improved as having higher farm income while net crop income and off-farm income of household are constant (Figure 160 – 163).

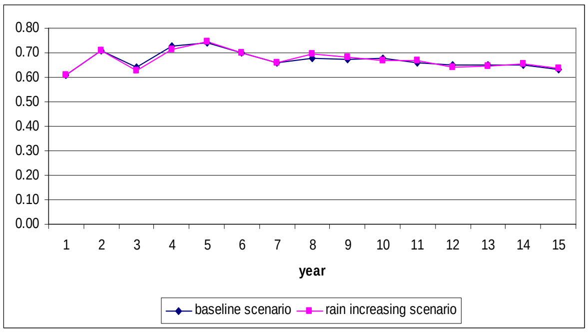


Figure 150: Sustainability index of household income indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

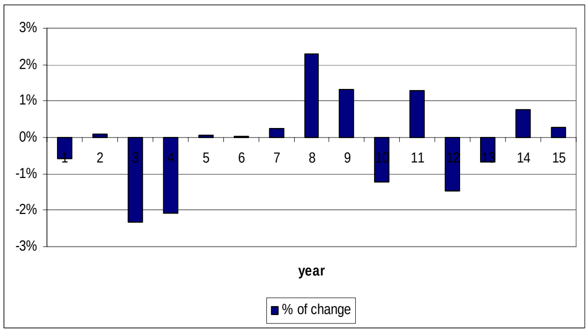


Figure 151: Percentage change of Sustainability index of household income indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

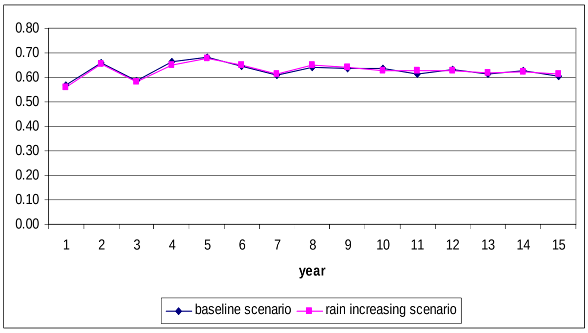


Figure 152: Sustainability index of net farm income indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

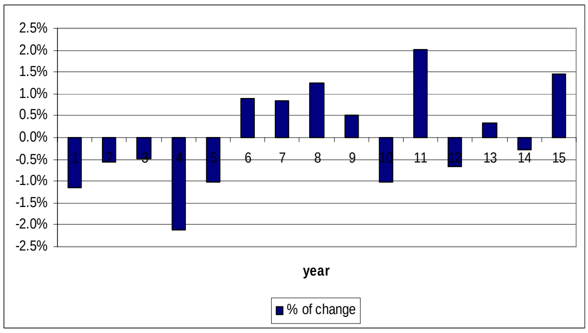


Figure 153: Percentage change of Sustainability index of net farm income indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

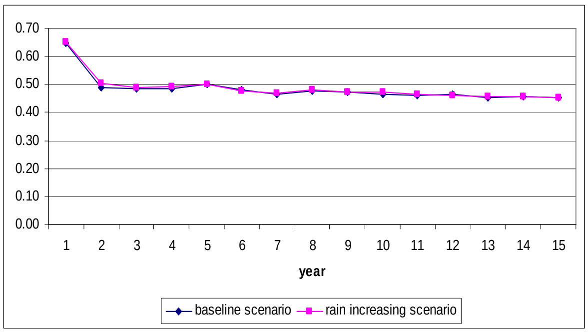


Figure 154: Sustainability index of household capital indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

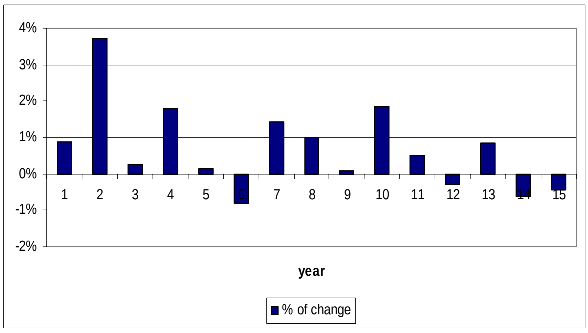


Figure 155: Percentage change of Sustainability index of household capital indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

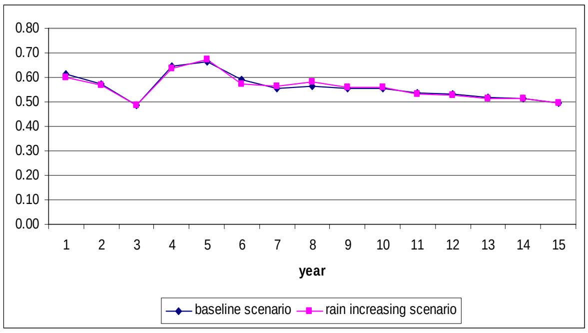


Figure 156: Sustainability index of household saving indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

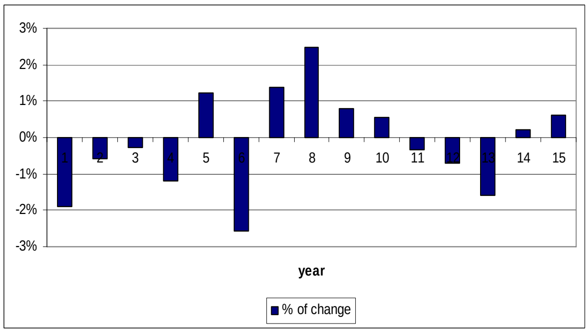


Figure 157: Percentage change of Sustainability index of household saving indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

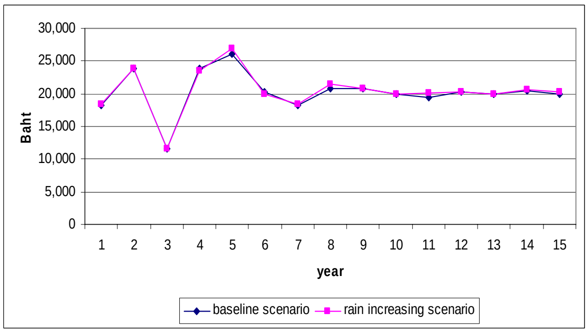


Figure 158: Average net livestock income of rain increasing scenario comparing to baseline scenario

Source: Simulation

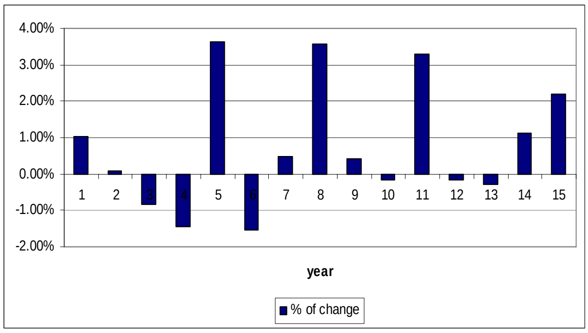


Figure 159: Percentage change of average net livestock income of rain increasing scenario comparing to baseline scenario

Source: Simulation

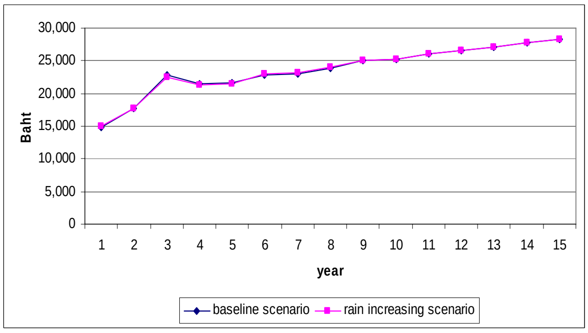


Figure 160: Average net crop income of rain increasing scenario comparing to baseline scenario

Source: Simulation

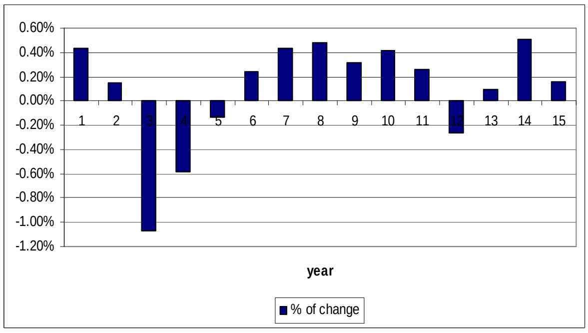


Figure 161: Percentage change of average net crop income of rain increasing scenario comparing to baseline scenario

Source: Simulation

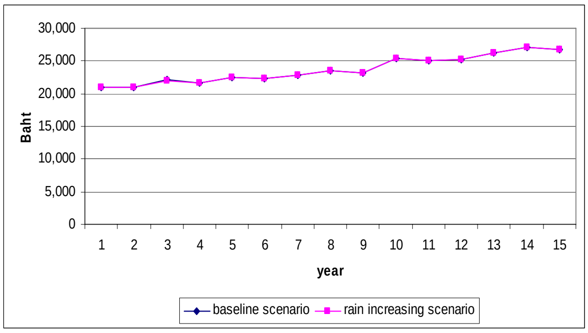


Figure 162: Average net off-farm income of rain increasing scenario comparing to baseline scenario

Source: Simulation

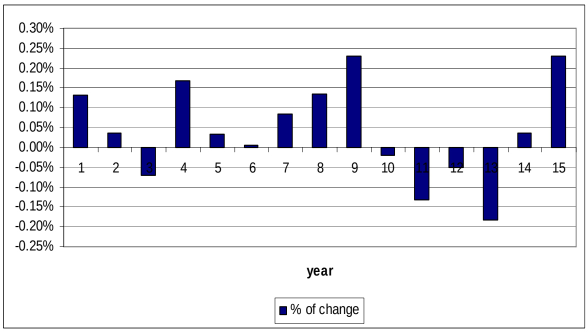


Figure 163: Percentage change of average net off-farm income of rain increasing scenario comparing to baseline scenario

Source: Simulation

In the case of the social sustainability situation, the PI and SI are the same because there is only one indicator for this condition. A small distinction of PI and SI is found when compared to the baseline because of a small variation in the household rice deficit. This can happen in some years if household consumption increases (increase of household members) and rice production cannot cover the additional rice need (Figure 164 – 165). Thus, some households face a rice deficit in some periods before adjustment of rice production. The trend of PI and SI is the same as baseline showing unsustainability concerning this condition.

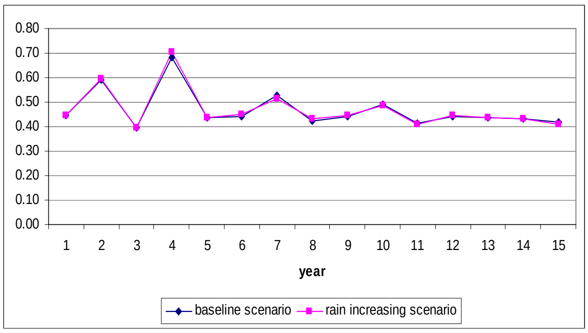


Figure 164: Performance and Sustainability index of social indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

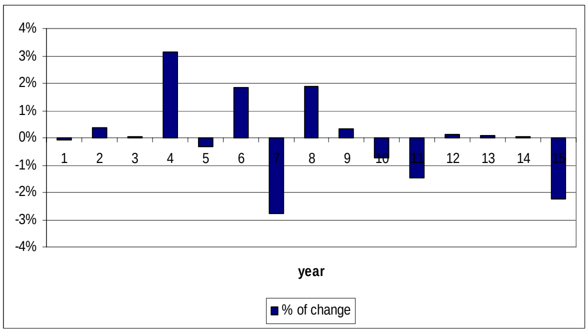


Figure 165: Percentage change of Performance and Sustainability index of social indicator of rain increasing scenario comparing to baseline scenario

Source: Simulation

For sustainability of the environmental condition, the general situation presented by the PI of environment indicators becomes poorly unsustained (Figure 166 – 167). A decreasing trend that is declining faster than the baseline case is apparent. For more detail, consider each indicator: top-soil erosion which is affected by increased rainfall becomes worse (Figure 168 – 169). Decreasing of SI of this issue especially during the periods of greater rainfall is evident and the index reduction is approximately 17% of the baseline scenario. In addition, the point of time in which heavy rain occurs is also important to determine the hazard of top-soil erosion. If heavy rain takes place at the same time as land preparation when there is no vegetation covering the soil, the erosion hazard will be higher than in other periods. It can be concluded that the erosion hazard will increase if the amount of rain is increased or rainfall occurs during clearing and preparation of land.

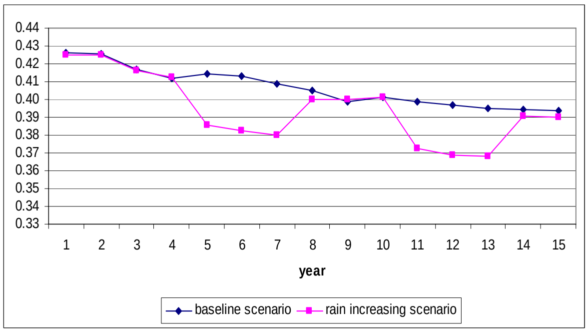


Figure 166: Performance index of environment indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

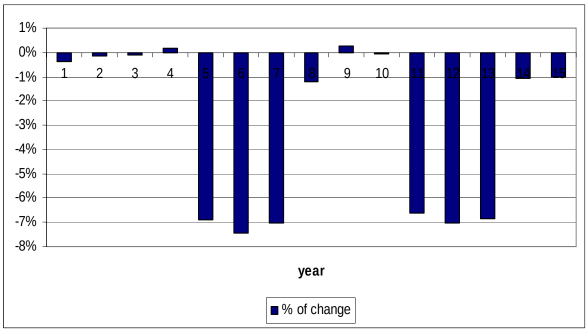


Figure 167: Percentage of change of Performance index of environment indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

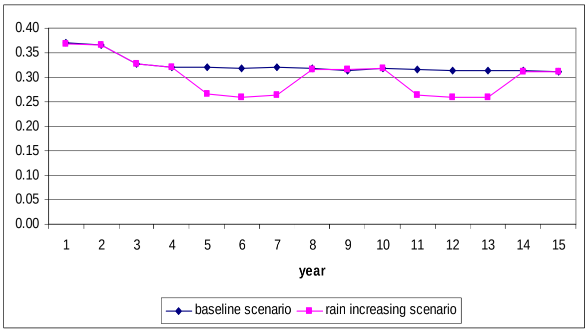


Figure 168: Sustainability index of top-soil erosion indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

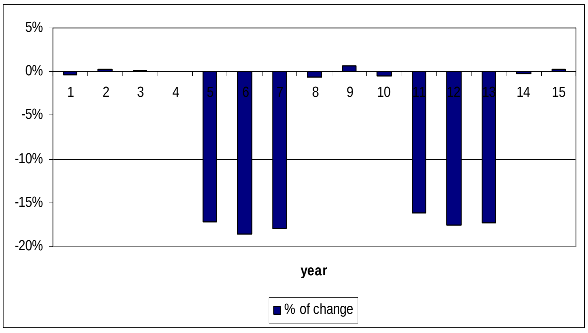


Figure 169: Percentage change of Sustainability index of top-soil erosion indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

In case of the fallow period indicator, the SI of fallow period indicator is similar to the baseline scenario. There are only some differences which are because of random effects influencing the use of plots in each simulation (Figure 170 – 171). Also, the SI's trend for this scenario is going in the same way as the baseline scenario which shows an unsustainability aspect about the fallow period of the study area.

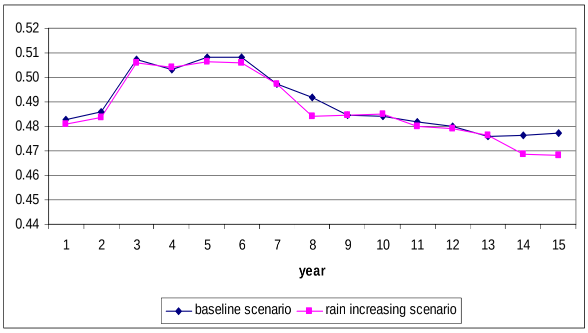


Figure 170: Sustainability index of fallow period indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

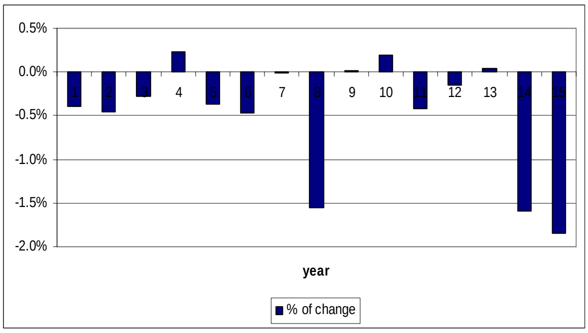


Figure 171: Percentage change of Sustainability index of fallow period indicator of rain increasing scenario comparing to baseline scenario
Source: Simulation

5.2.3 Change of socioeconomic factor

For the scenario of price decreasing, all crop prices are decreased in two periods during 2007 to 2009 and 2013 to 2015. A reduction in price is determined for upland rice, maize, mango, and vegetables (bean, melon, and pumpkin). Their prices are deducted by 23.77%, 25.04%, 29.39%, and 34.67% of baseline respectively. Theoretically, decreasing crop prices will influence the decision making process which probably leads to a change of cropping pattern and resource use. The resource will be reallocated into activities in which the higher returns will be obtained. However, relying on the actual situation of the study area crop options are limited by having poor soil fertility and unsuitability of arable land location. In the past, farm households tried to produce various cash crops by imitation from neighbouring villages and introduction through government agencies, NGO, and traders. However, with poor fertility and unsuitable land, productions of those crops were not successful. Therefore, in reality there are no households which mainly perform cash crop production but they mainly rely on production for consumption. Staple crops –upland rice and maize– are the main crops produced in this area with vegetable mixed crops in the plot such as local bean, local melon, pumpkin etc which are captured and included in the results of baseline scenario. In addition, there are approximately 50% of households who used a small proportion of area to grow fruit trees e.g. mango and other temperate fruits which are the sources of cash for households. Production of fruit trees is proceeding on farm households relying on extension policy introduced by government agencies to the area. Sometimes production is pursued to indicate their right of usage over lands which are located around the tension of acquisition to be the National Reserved Forest area. Thus, the decision of crops and fruit trees production is not mainly executed by motivation of price but by reason of subsistence and other reason as previously explained. Therefore, a decline in crop price in this scenario produces only a small impact on the crop decision making process but it influences directly the cash household income which the households have to accommodate and resolve when facing a cash deficit event.

After long run simulation under this scenario, the results show a worsening sustainability situation for the area. The PI of this scenario declines at a slightly higher rate compared to the baseline scenario (Figure 172). This decline is affected by a decrease of SIs of all economic indicators which are notably decreasing in the year during the periods the crop price decreases occurred (Figure 173 – 176). In addition, the number of households in the sustainable class changes direction as the households move into lower sustainable class compared to baseline (Figure 177 – 184). The worsening of households' sustainability situation in this case is caused by a decline in crop prices which eventually decreases of farm and household income (Figure 185 – 190). As such, the households have to face a deficiency of cash for farm and household expenses. During simulation, higher household acquisition of cash is captured and cash obtained by selling livestock is used to recover the shortage. The result shows an increase in cash livestock income especially in the year 2007 which is the first year when prices fall (Figure 191 – 192).

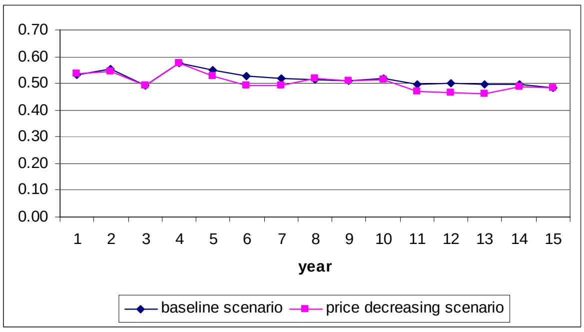


Figure 172: Performance index of all indicators of crop price decreasing scenario comparing to baseline scenario
Source: Simulation

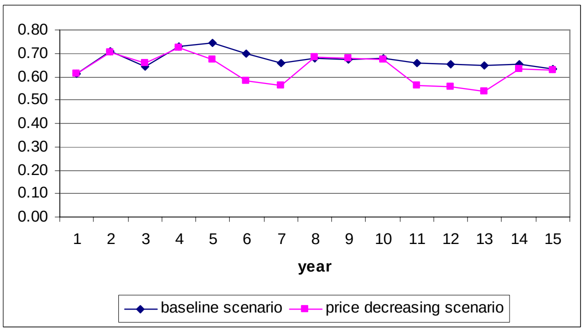


Figure 173: Sustainability index of household income indicator of crop price decreasing scenario comparing to baseline scenario
Source: Simulation

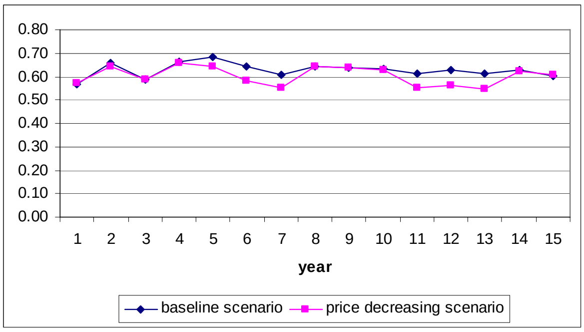


Figure 174: Sustainability index of net farm income indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

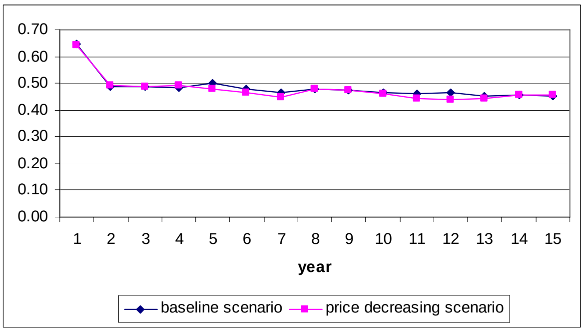


Figure 175: Sustainability index of household capital indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

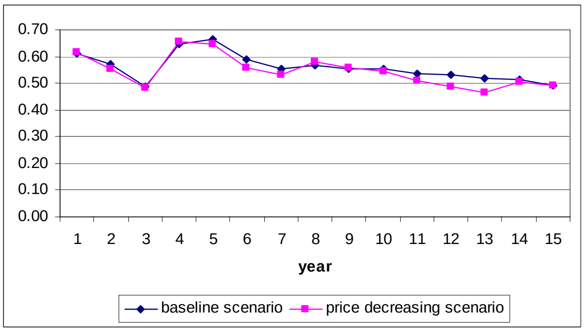


Figure 176: Sustainability index of household saving indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

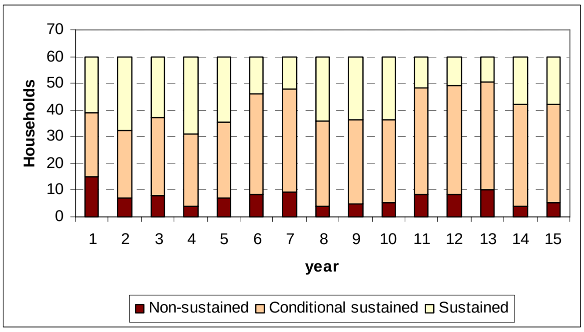


Figure 177: Number of households in each sustainable class classified by sustainable score of household income indicator of crop price decreasing scenario

Source: Simulation

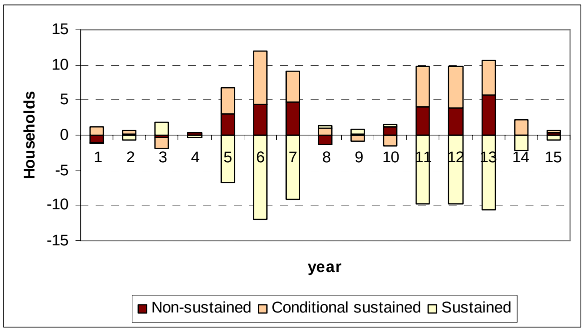


Figure 178: Change of number of households in each sustainable class classified by sustainable score of household income indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

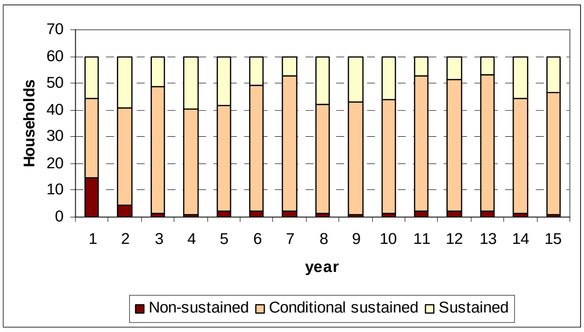


Figure 179: Number of households in each sustainable class classified by sustainable score of net farm income indicator of crop price decreasing scenario

Source: Simulation

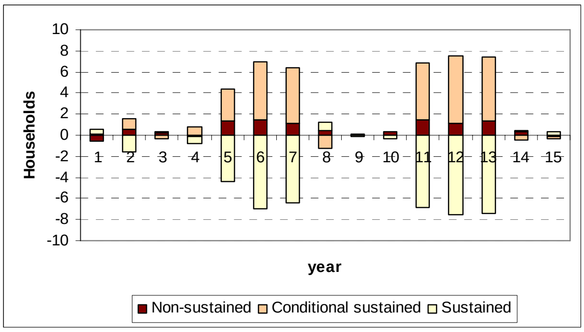


Figure 180: Change of number of households in each sustainable class classified by sustainable score of net farm income indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

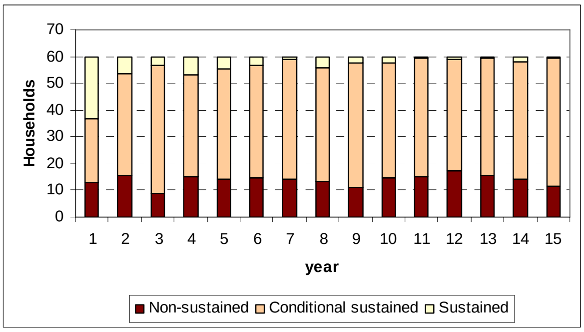


Figure 181: Number of households in each sustainable class classified by sustainable score of household capital indicator of crop price decreasing scenario

Source: Simulation

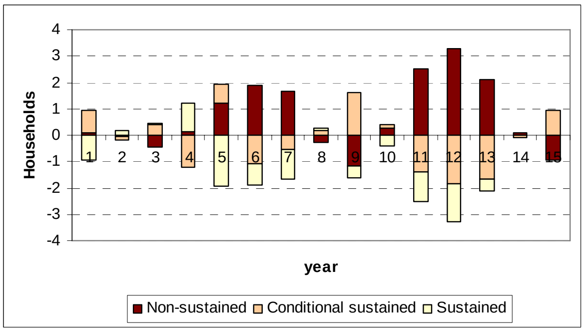


Figure 182: Change of number of households in each sustainable class classified by sustainable score of household capital indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

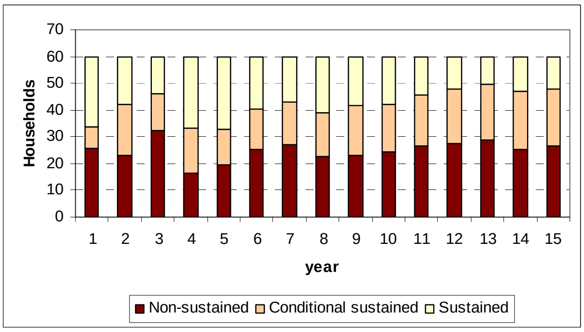


Figure 183: Number of households in each sustainable class classified by sustainable score of household saving indicator of crop price decreasing scenario

Source: Simulation

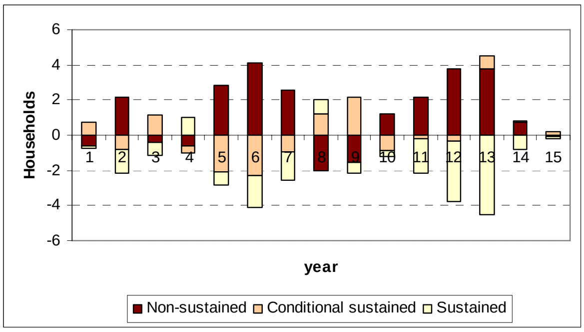


Figure 184: Change of number of households in each sustainable class classified by sustainable score of household saving indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

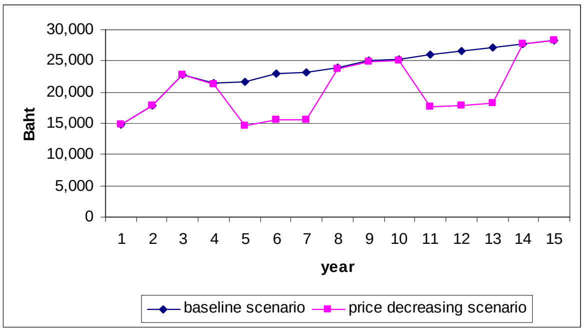


Figure 185: Average net crop income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

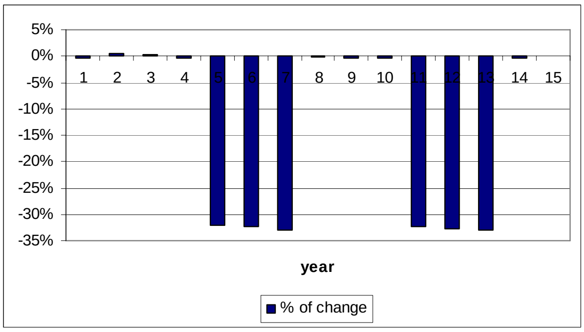


Figure 186: Percentage change of average net crop income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

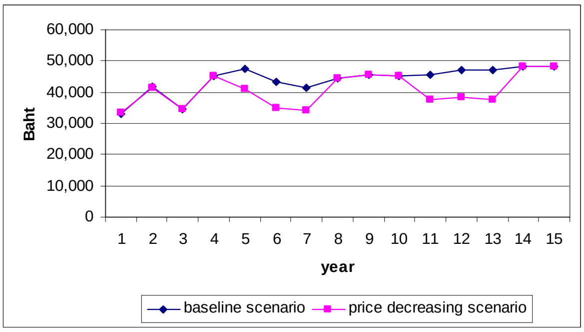


Figure 187: Average net farm income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

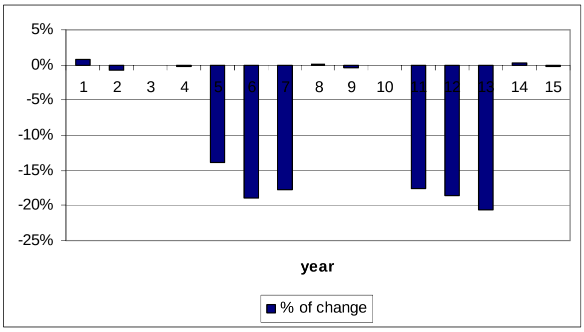


Figure 188: Percentage change of average net farm income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

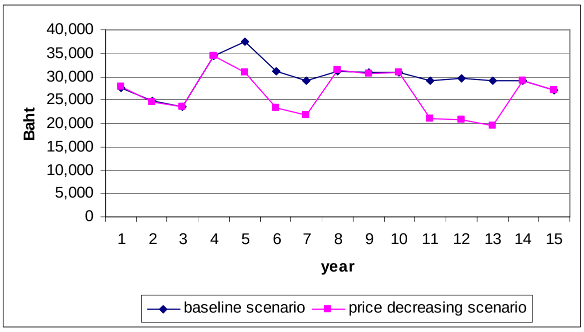


Figure 189: Average net household income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

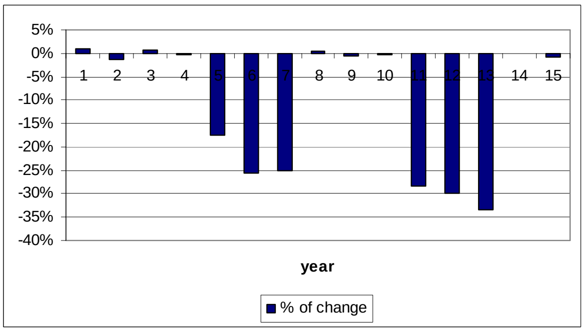


Figure 190: Percentage change of average net household income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

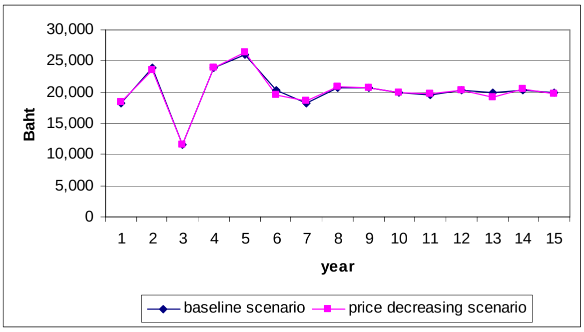


Figure 191: Average net livestock income of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

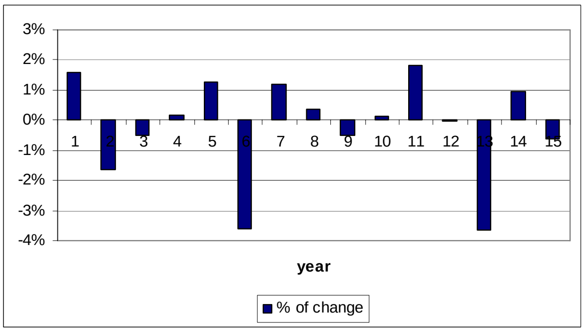


Figure 192: Percentage change of average net livestock income of crop price decreasing scenario comparing to baseline scenario
Source: Simulation

However, for the year later in which crop price is decreasing, selling additional livestock for cash does not occur, because of the limitation of livestock. Generally, the household has to use a number of livestock for consumption and religious ceremony, thus the required livestock varies annually by household. If all available livestock are used for consumption, the household does not have available livestock for selling at the time of a cash deficit. Households then pursue cash acquisition by borrowing from the village fund and neighbours, resulting in increasing amounts of borrowed money compared to the baseline (Figure 193). In 2007 which is the first year of a decline in the crop price, loans are higher and increasing faster than the baseline until the end of simulation.

When considering the social and environmental conditions, the results show only small change caused by the random effects occurring during simulation, which happens with a stochastic model (Gilbert and Troitzsch, 1999). The small change influences only a small variation from baseline results of SIs of social and environment indicators presented in Figure 194 – 196.

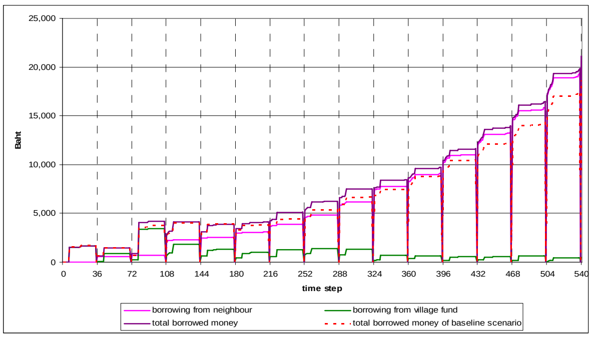


Figure 193: Average amount of loan from each source of households of crop price decreasing scenario comparing to baseline scenario
Source: Simulation

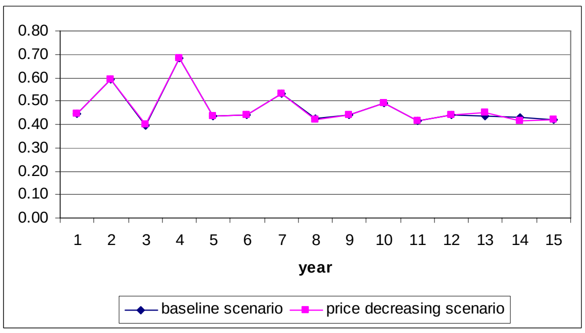


Figure 194: Sustainability index of food security indicator of crop price decreasing scenario comparing to baseline scenario
Source: Simulation

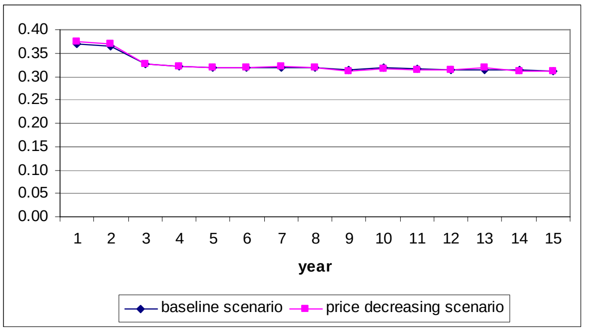


Figure 195: Sustainability index of top-soil erosion indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

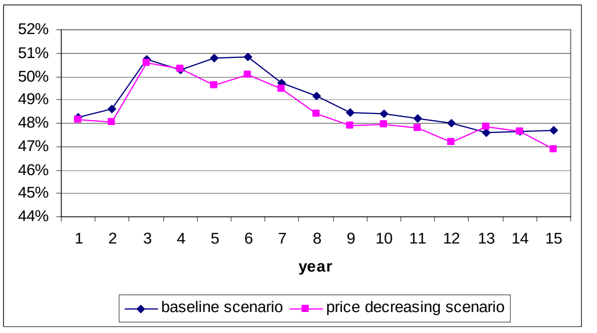


Figure 196: Sustainability index of fallow period indicator of crop price decreasing scenario comparing to baseline scenario

Source: Simulation

6. General discussion

This chapter provides the crucial perspectives regarding this study. The introduction in section 6.1 explains the objectives and the general results of this study. In section 6.2, limitations of this study are pointed out, and the issues which have affected the study's results are discussed. In section 6.3 and 6.4, policy recommendations and recommendations for further studies are proposed and explained.

6.1 Introduction

This study aimed to evaluate the sustainability of farming systems in the case study area, Bor Krai village, located in Northern Thailand. To capture and extrapolate the sustainability situation of the farming systems, a Multi-Agent Systems (MAS) model was developed under the study framework. The model was structured by integration of the sustainability concept, farming systems approach, and Agent-Based modelling approach.

Modelling of the MAS model in this study introduced the concept of an integrated model, which links together the socioeconomic and biophysical components of the target farming systems. In addition, the complexity of the systems were captured through the MAS model whereby the systems' heterogeneity, interaction, and dynamic processes were involved (Schreinemachers, 2006). The systems' heterogeneity was integrated by considering the individual characteristics of the social agents, and their environment as the spatial biophysical elements. Interactions among these elements were considered as the systems' interactions which comprise of interactions between agent to agent, agent to their environment, and environment to environment. Systems dynamics were processed through each time step of the model's simulation. A time step was designed to correspond to 10 days, and the consequences of each previous time step determines the outcome of the current time step. By 15 years long run simulation, the target farming systems dynamics were extrapolated as emergence of systems' complexity over time.

In general, the study results provide an understanding of the study area farming systems. In addition, this application shows the potential to assess and extrapolate the sustainability situation of the study area's farming systems so that the study research questions can be well addressed. The application contributes an alternative way to model farming systems in a bottom-up approach which associates various microdecisions that are individually carried out by the stakeholders in the area (Matthews et al., 2005). The framework can also support and enhance policy decision making for sustainable development in the area by including some degree of stakeholder participation and multidisciplinary integration.

In some instances, the results show that the study area is in an unsustainable situation. The critical issues were presented and ranked. Food security is the most critical issue in the study area followed by the issue of household saving, household capital, top-soil erosion, household income, fallow period, and net farm income respectively. Also, scenario analysis was carried out and the results of implementing a sustainability improvement policy scenario, and significantly altered socioeconomic and biophysical factor scenarios, were presented. The results of the policy to improve the sustainability situation scenario shows the possibility of improving all of the area’s sustainability conditions –economic, social, and environment conditions. For the scenario of changing biophysical factors, the results of the drought scenario show that during drought periods the sustainability situation becomes better because of reduced soil erosion. In addition, the results indicate that the effect of a reduction in rainfall reduces fruit tree yield and the dynamic of the annual crop planted area. Also, the results of the drought scenario show the ability of the farm household agents to cope with drought whereby they behave in different degree but in the same way of farm household behaviour found in the area. For the scenario of an increase in rainfall, the results are the opposite in that the sustainability situation of the study area becomes worse because of more soil erosion due to the heavy rains. However, this condition insignificantly affects the other sustainability issues of the area. In the case of economic factor change, the crop shock price event was introduced and the results show that the consequences directly affect household cash income. Therefore, acquisitions of cash for farm household agents are captured and this behaviour corresponds to the behaviour found in reality.

6.2 Contributions of the study to the MAS model development

This study can be considered as an application of the Multi-Agent Systems (MAS) approach to an agricultural economics study. The CatchScapeFS MAS model was calibrated to the particular area for the study purposes. Contributions of the present study to the development of the CatchScapeFS model can be considered in three parts which are biophysical component, socioeconomic component, and sustainability assessment component and output arrangement part.

Contributions to biophysical component

The model was developed based on the CatchScape3 model (Becu et al., 2003). The CatchScape3 model was selected as the model's architecture is flexible to meet the study objectives. In addition, the model provides the biophysical modules which are applicable to the study. However, with the specific characteristics of the study area, the socioeconomic component from CatchScape3 model needs to be revised as to its biophysical component, where some features also need to be adjusted to represent the study area. Therefore, contributions of this study to the model development start by adjustment of the biophysical objects' attributes inherited from the CatchScape3 model to the biophysical description of the study area. In addition, adjustment of these objects was also performed relying on relationships to the socioeconomic component objects. For example, the crop object was adjusted in its attributes to include information about its owner, planting and harvesting dates, growing season, access to support, etc. in order to facilitate those information for the farm agent which later will be used in decision making processes.

Also, contributions of this study to the biophysical component can be seen in development of the soil erosion module and livestock and forest product objects. The soil erosion module was based on the USLE model (Wischmeier and Smith, 1978) and implemented at plot level. Through this module, the annual soil erosion amount was quantified and each year of simulation the soil loss information were collected and used to calculate the annual soil erosion for the top-soil erosion indicator. Livestock and forest product objects including their dynamic procedure were developed to represent farm and off-farm activities of the study farming systems. The modules were additionally introduced into the CatchScape3 model as they are a significant component of the farming systems' operations.

Contributions to socioeconomic component

The present study's contribution to the socioeconomic component can be considered as the development of the entire social layer of the CatchScapeFS model. Based on the CatchScape3 model, the farm household agents and all other social elements e.g. traders, agricultural product markets, labour market, government agencies etc. were modeled with their heterogeneous characteristics and dynamic methods. In addition, the present study applied the qualitative analysis and Monte Carlo techniques to generate the farm agent population. The qualitative analysis was introduced together with the quantitative analysis in order to identify farm sample behaviour groups based on their characteristics and behaviour. The Monte Carlo techniques were adopted to create generated farm agents out of the existing farm samples. This application advances the study CatchScapeFS model with consistency between sample and population distributional characteristics.

In the farm household decision making processes, the present study contributes the application of financial decision making parameters which are annuity, net present value and payback period for livestock activity decisions. These economic factors were assumed and used by the farm agents to determine whether to invest in animals taking into account other factors such as the initial investment, selling price and household preference. In addition, the present study contribution to this component can be also shown in the stage of model validation. For this, the diagram participatory elicitation approach was applied and this contribution advances the present model to communicate and involve the area stakeholders for model development and validation.

Contributions to sustainability assessment component and output arrangement

For contributions to this part, the theoretical processes of sustainability evaluation were applied and implemented to the present study model. To evaluate sustainability, the individual household performance corresponding to defined indicators was captured and used to present the area's sustainability at the village level. At the village level, the area sustainability situation was presented through Sustainability index and Performance index which enables the present study model to identify the priority sustainability issues which need to be improved and allows comparisons of the sustainability situation across the issues or indicators. The indicator and threshold value determination framework of this study advances the present model to identify sustainability indicators and its sustainable classes that represent the study area's sustainability. In addition, applying the framework with MAS modelling, the present study model can be used to present the dynamics of the area's sustainability in long run intervals, which is a methodological development upon the previous works, Praneetvatakul and Sirijinda (2003 and 2005), under the Uplands Program of the University of Hohenheim.

The last contribution of the study to the CatchScapeFS is the development of Visual Basic for Application (VBA) modules in Excel program to arrange a huge amount of output data. With these modules, outputs of simulations were arranged in a convenient form for the further analyses. In addition, the modules reduce the time required for comparing scenarios and for creating graphs of outputs to facilitate the model result interpretation.

6.3 Limitations of the study

The MAS application model of this study, like other models of research and studies, is built upon assumptions and restrictions. These limitations and their consequences are listed in this section.

Absence of Data

Even though a huge amount of the required data was collected, there are still some absences of static data of local product and input prices. This directly affected the estimation of the trend price function used for price determination at simulation time periods where existing data did not exist. However, in this study the trend price functions used for this model version were plausible because the statistic data at regional level recorded by Thai government agencies was used instead.

In addition, the experimental data of top-soil erosion in the study area was not available. Calibration of the top-soil erosion module is based on the data of soil erosion at the regional scale presented by Land Development Department (2000) and Land Development Department (2002). This probably affects the results of the top-soil erosion and the sustainability situation of the study area. Therefore, development for the next version requires field experiment data in order to get more precise soil erosion values for model calibration. Based on this experimental data, the specific soil erosion module could be integrated so as to provide a more accurate estimation of soil erosion in reality. However, the current results given by this model version are also reasonable, as the amounts of erosion are within the range of literatures presented above.

Population dynamic

This model version captures growth of the village population but the possibility of migration of villagers is not included. However, there are reasons behind doing so. Firstly the other land areas around the village are occupied and the forest area is intensively controlled. Therefore, opportunity to migrate to other areas is quite low. Secondly, in general the villagers have low skill levels and low levels of education, and therefore opportunity to migrate for jobs in other regions which are far away from the village is rather limited. Thirdly, support from outside such as government agencies and NGOs has reduced the pressure of food security and resource use in the area. This therefore decreased the degree of tension of living in the area. Lastly, information on the migration decision is limited and still not explicitly clear to determine this procedure. Due to these reasons, the results of the current version of model are therefore probably affected by some degrees of disregard to migration. The food security and fallow period sustainability situation maybe slightly higher than in reality due to some migrations. In the future version of the model, the explicit migration module can be integrated and this will enhance the ability to capture the population dynamics of the study area and extrapolate the sustainability situation of the study area.

Resource distribution dynamic

Even though the current model can capture growth of the population in the study area, the model is limited on the dynamics of resource distribution. For example, the number of households is set as a constant and the land holding area is distributed based on survey data which does not change while the number of household members probably increases. In this case, separation of households is not considered, resulting in a slightly overestimated sustainability situation, because we do not consider the possibility of the household splitting. If the households with low available resources are going to separate, the tension of resource scarcity is likely to increase, and this will lead to a reduction of the sustainability situation. In the future, this aspect can be captured but the behaviour of household separation and consequently resource redistribution should be explicitly defined.

Soil fertility dynamic

Soil fertility dynamics are another aspect which are not included in this study because information concerning the change of soil fertility subject to each kind of planted crop or fallow is not available. In order to get such information, agricultural science field experiments and research are required to carry out how soil fertility dynamics change in regard to crops planted and fallow periods used. For the current model version, soil fertility is set at a constant medium level of fertility throughout the simulation period. This probably results in a slight over or under estimation of the actual yield estimation which then affects household food security, household income, and fallow period sustainability situation. However, the model is flexible and able to integrate dynamic processes of soil fertility in the future version of the model.

6.4 Policy recommendations

Based on the study results, the policies which have the potential to improve the sustainability situation of the study area are presented as follows.

1. Based on the scenario analysis, the results of the sustainability improvement policy implementation scenario shows improvements in the sustainability of farming systems in the study area. Therefore, introduction of high yield variety of upland rice and maize to the households, and a recommendation of 0.16 ha (1 rai[18]) mango production to the farm households who produce only annual crops is a potential policy option to improve sustainability of farming systems in the study area. However, achievement of this policy requires research and financial support for high yield variety crop development that should also take into account the suitability of crops to the poor soil fertility condition in the area. Furthermore, in the case where high yield variety development has been achieved, introduction to households should be combined with recommendations for agricultural conservation practices so as to avoid environment problems of soil erosion and degradation. These recommended conservation practices could include terracing, cropping along the area's contour, adjustment of the slope area, growing erosion resistant crop etc.

[18] Common Thai area unit which 1 rai = 0.16 hectare

2. In the study area, cash crop income of the farm households is mainly obtained from mixed crops grown in the main crop plot such as local bean, local melon, and pumpkin. The cash crop options are naturally limited by low fertility of the soil. Research efforts to develop cash crop alternatives such as vegetables, annual crops, or fruit trees are required in order to improve the cash household income from crops. Similar to the previous recommendation, introduction of the potential cash crop options should be pursued and should also include suggestions of the agricultural conservation practices which will enhance the environmental sustainability of the study area.

3. In the baseline scenario, the results show a decline in household savings which is caused by an increase in private expenditures as the number of members increase. Suggestion and support for raising livestock and off-farm activities such as weaving and development of tourism are some of the ways which would increase household cash income and contribute to an improvement of the sustainability in the study area. In addition, for the period until reaching development of research relying on the previous two recommendations this option can be a short-run policy to improve sustainability situation.

4. As the study area is located in the National Reserved Forest area which contains plenty of natural resources and ecological systems, activities performed in this area should consider environmental and resource conservation. In addition, stimulation of environment and resource protection awareness to stakeholders has to be executed and achieved. As such, the CatchScapeFS model, which represents characteristics and behaviours of the area, can be used as a tool to promote the common view among multilateral stakeholders regarding agriculture and sustainability situation. Furthermore, usage of the model for mediation to promote and support collective decision making to attain collective management that is a general objective of multi-agent model development in the way of companion modelling approach (Barreteau, 2003) is also possible.

5. Due to the high population growth caused by the imbalance of the age structure whereby around 47% of total population is in below 20 years old and the culture of the village where villagers normally get married at a young age, 14 – 16 years old, tension of consumption needed under limitation of land resource is seriously increasing. Existing agricultural lands are intensively used by shortening fallow periods and this can threaten the recovery of land fertility which finally leads to degradation of the land. Therefore,

introduction of birth control in this area is also necessary. In parallel, understanding by households of the population growth impacts should be realized in order to reach cooperation without cultural conflicts.

6.5 Recommendations for further research

As mentioned before, this version of the model is developed based on some limitations and assumptions, and also this model application is focused on the specific area with particular modules integrated for specific study purposes. Therefore, recommendations to be used as guidelines of research and model development in further research and applications are proposed as follows.

1. Regarding the potential of the model which is able and flexible to integrate interdisciplinary knowledge, in further study applications and development of the model integration of modules representing more details of systems would introduce more realism. For example, it is possible to integrate the nutrient soil dynamic model, price determination model, resource management and allocation model, social behaviour model, mathematical programming model, etc to the model. However, all these module descriptions and details should be designed depending on the research's question (s). Also, integration of these models requires numerous data; thus, availability of data and possibility of data acquisition should be considered. In addition, development to be in a more interdisciplinary model requires multidisciplinary research which needs researchers in relevant areas that are included in the model. Thus, in further study, the trade-off between the benefits and resource requirement costs in order to develop the model should be considered.

2. As this model version is applied for a specific study area, application of CatchScapeFS model for further studies needs to assess the compatibility of the model components and structure for the new study area. In addition, in order to assess the sustainability of a further study area, indicators and their priorities to represent the sustainability situation of the study area should be revised.

3. Based on this study framework which applies farming systems sustainability assessment under a Multi-Agent Systems (MAS) model, further application under MAS model can be extended to different sustainability approaches e.g. sustainable rural livelihood, sustainable land management, sustainable development, etc. However, development of

indicators to represent and assess sustainability should consider the issues of indicator characteristics. The indicators developed under this study framework should be able to be quantified at household level, and the indicators should have dynamic aspects so that their development overtime can be extrapolated. Also, the relationship and trade-off effects between indicators which may influence the overall sustainability situation should be considered. Furthermore, the sustainability assessment in different approach can be involved in order to support the sustainability evaluation of this study which is assessing the area's sustainability through household level performance. For example, development of a framework to integrate macro level indicators such as the Gini coefficient which is used to represent income distribution in the area should be considered.

4. The CatchScapeFS model developed relying on object-modelling approach in this study has captured heterogeneous farm household characteristics and behaviour which are interacting to each other and their environment space. In reference to this and all results of this study, the model can be considered as a laboratory for social science research in order to monitor the system's dynamics and impacts of policy interventions. Therefore, a framework with the application of object-oriented modelling is one of the alternatives for further studies that intend to investigate consequences of policy interventions. However, decisions to apply this approach should take into account the requirement of data, computer programming skills, and other resources necessary to carry out the research within the study limitations.

5. The CatchScapeFS model can be used as a tool for further studies in order to test and monitor the effects of potential policies which can be implemented in the Bor Krai village. Also, the model is flexible enough to capture and investigate impacts of farming systems caused by changes in farm households' behaviour. Further, the model can be used as a tool to promote a common view of the overall village systems, as well as supporting collective decision making by stakeholders in systems.

6.6 Recommendations for newcomers to MAS application research

The critical issues and problems experienced from the present study under the MAS approach are discussed in this section. Suggestions to guide newcomers who are applying the MAS approach in the research are also provided.

1. Conducting the research with MAS application, researchers are required to learn computer programs and programming. This requirement is necessary in various stages of model development which are the input preparation stage, model programming stage, and output arrangement stage. In the input preparation and output arrangement stage, the newcomers need to learn how to use computer programs to analyze and arrange the data and output into the form that the MAS model requires or the researchers need. The programs can be used in these stages such as MS Excel, MS Access, GIS ArcView, ArcGIS, SPSS, Stata and etc. Among the alternative programs the researchers have to choose the programs which can deliver desirable outputs which are compatible with the MAS model application. For example, to analyze the model parameters from the survey data or arrange simulation outputs, the MS Excel, MS Access, SPSS or Stata program can be chosen to analyze and arrange them. However, for research with an extensive scope, a number of analyses and preparations are required and sometimes these processes take a long time to achieve. Therefore, using those programs through an additional programming function is an option to shorten the computational time. With this, the newcomers need to learn computer programming, for example, Stata or VBA code to manipulate the Stata, MS Excel or MS Access program to do the tasks automatically and quickly.

In the model programming stage, the newcomers have to learn a computer programming language to implement the conceptual model into computer form. This process can be very time consuming for beginners. Therefore, numerous suggestions from expert programmers in the initial phase of the language learning are greatly required. In addition, during the code learning stage the learners should keep in mind and imagine how those codes can be applied in other cases and how to code if we need the program to do in particular way. Thinking of these issues can help the beginners to learn the computer language efficiently and quickly.

2. Because the MAS approach can integrate many disciplines, this requires the newcomers to learn other disciplinary knowledge to develop an integrated model. This can increase the time required for the research and consequently additional resources are needed. However, this depends on the research questions and the scope of study. The newcomers can design the scope of the study to fit within the time frame with available resources. Development of the model can be based on assumptions which simplify the part of the other

disciplines and leave them as an academic interest for the further studies. In the case that extensive structure of the application model cannot be avoided, suggestions from the specialists in respective fields can be greatly helpful and be a quicker way to learn the required knowledge.

3. In the case that the MAS approach is applied to develop an integrated model, development of the model requires a huge amount of data which can be either quantitative or qualitative. This depends on the objectives and scope of the study. Therefore, at first, newcomers should consider the study objectives and scope in which the study can be achieved within available resources and data. However, in the case that the required data cannot be obtained, introducing assumptions based on theory and literature when data is absent can be an option and later the model can be revised to implement those specific data which probably needs additional experiment and time. For example, in the present study the data about soil fertility dynamic in the area are missing. Obtaining those data can be pursued by additional field experiment research which requires time and financial support. In this situation, the assumption of constant soil fertility was made. At the same time, the state variable such as number of years of fallow was used to represent the trend of soil fertility change based on literature instead of implementing directly the effects of the crop yield from the soil fertility change.

Summary

Introduction

Due to an increase in environmental problems and resource degradation, economic development should be pursued with consideration of environmental functions and the supply and quality of natural resources. Monitoring and assessment of whether the development approaches a sustainable path are required to provide information for policy development. This becomes increasingly important – especially for marginal areas where the environment and natural resources are sensitive. The study area is located in the mountainous area of Northern Thailand with abundant natural resources and a healthy ecological environment. However, population growth, land limitation, and external factors – such as market forces – are inducing change and pressure on resource utilization. The resources are intensively used and farming systems are changing to more commercial practices. Therefore, the region's long term sustainability needs investigation.

Objectives

This study aims at assessing the sustainability of the farming systems in the study area under the sustainability concept, farming systems approach and Multi-Agent Systems (MAS) approach. The first objective of this study is to describe the characteristics of the farming systems in the study area. The second objective is to develop and use a MAS model to evaluate sustainability of the study area. The last objective is to use the model to present sustainability of farming systems under different scenarios based on changes of significant factors and policy intervention. In addition, the ability of the systems to cope with and recover themselves from these changes is examined.

Methodology

The sustainability of the farming systems in the study area was assessed through defined indicators representing three conditions: the economic, social and environmental condition. The indicators were defined based on the framework of indicator determination to serve the objectives and methodology of this study. The selected indicators for this study are: household income, net farm income, household capital, household saving, food security, top-

soil erosion and fallow period. For these indicators the following sustainability classes were defined: Sustained (S), Conditional sustained (C), and Non-sustained (N) class.

Evaluation of sustainability was carried out at two levels: the household and the village level. At the household level the sustainability situation was evaluated based on the individual farm household performance corresponding to each indicator. The sustainability at village level was assessed through the Sustainability index (SI) when single indicators are considered and the Performance index (PI) in which a group of indicators is regarded. The dynamics of the sustainability situation at household and village level were extrapolated over 15 years (2003 – 2017) in order to examine the sustainability of the study area's farming systems.

The MAS model was developed and named CatchScapeFS. The model structure relies on descriptions of the farming systems in the study area. The MAS approach was applied in order to capture the complexity and extrapolate the long-term sustainability situation in the study area. The model composes of two components: a biophysical and a socioeconomic component. The biophysical component is based on the CatchScape3 model. It consists of biophysical models: a hydrological model, a crop model, a water balance model and a soil erosion model, which are embedded in the landscape model of the study area (represented in spatial grid cells as plots of one rai or 0.16 ha). The socioeconomic component is composed of farm household agents and other social elements. The farm household samples were classified based on the similarity of characteristics and behaviour into the market, subsistence, and partnership oriented group. The Monte Carlo technique was applied to generate farm agents out of the existing farm household samples.

The CatchScapeFS model was designed according to the object-oriented modelling approach. The CORMAS platform was selected as a capable tool to facilitate modelling and simulation. During a simulation time step covering 10 days, activities in six principal phases including activities in eight phases of farm agent household activities are executed. The model was validated and tested for its stability. Validation was conducted by social validation and statistic data comparison validation. The results of the model validation and stability test showed the reliability of using the model to serve the study objectives.

Main results

Sustainability of study area at the household level

The results show unsustainability over time in the study area. The number of households in the Sustained class (S) decreases whereas the number in the Non-sustained (N) and Conditional sustained class (C) tend to increase. For the economic condition, unsustained aspects occurred because of rising private household expenditure and decreasing capital products on the farm. For the social condition, the results show an increase of the households' rice deficit and rice acquisition in the long run which enhances the area's unsustainability. For the environmental condition, erosion and shortening fallow aspects induce the area's unsustainability. The area's erosion is severe and increases over time. For the fallow aspect, the average fallow period is shortening because of intensive land use in order to produce for consumption – which potentially induces land degradation in the long run.

Sustainability of the study area at village level

Similar to the results at household level, the findings show that farming systems in the study area are not sustainable. Unsustainability was observed by a declining Performance index (PI) and declining Sustainability indexes (SIs) of all indicators in the long term. By considering PI values with the trends, the area's sustainability in economic condition is better than the social and especially environmental condition. This can be explained by relative high SI values for the economic indicators compared to the SIs of the social and environmental indicators. By considering all SIs and their dynamic trend, sustainability issues can be ranked to determine the sustainability issues which need to be improved. Food security is the most unsustained issue followed by the issues of household saving, household capital, top-soil erosion, household income, fallow period, and net farm income respectively.

Scenario analysis

The scenarios were the implementation of a policy to improve sustainability and occurrence of unexpected events through changes of biophysical and economic factors. The scenario of the sustainability improving policy is defined as introduction of a high yield variety of upland rice and maize including introduction of mango to the households who currently only produce annual crops. Unexpected events due to the change of biophysical factors were simulated with a drought and rain increasing scenario. A decreasing crop price scenario represented an unexpected event due to the change of an economic factor.

Implementation of proposed sustainability improvement policy

The results show that the sustainability in the study area is obviously improved; represented by an increase of the PI value with a positive trend over time. In addition, the SIs of many indicators increase in this scenario, except the SI of household saving, which was rather constant. The PI of economic indicators improves with a higher number of households in the sustainable class when considering the household income, net farm income and household capital indicators. For the social condition, PI and SI values of food security increase because of a reduced rice deficit. For the environmental condition, the PI value of the environmental indicators increases because of a reduction of soil erosion and a longer fallow periods. It can be concluded that this scenario provides a policy option which potentially leads to an improvement of the sustainability situation in the study area.

Drought scenario

The results show that the study area was still unsustainable similar to the baseline scenario. However, the results show a slightly better PI during drought with a higher value and a slower decrease over time. These are the effects of the trade-offs between the indicators. The top-soil erosion indicator (influenced by decreasing rain) becomes better. This positive effect compensates for the negative effects regarding household savings, food security and fallow period indicators – which all declined. In addition, the simulation results presented the adaptation and reaction of farm agents to drought. Drought is perceived and causes a delay in planting to avoid damage. This induced a variation of the planted area. However, the variation becomes lower because of adaptation as the farm households learn from their experiences. During drought, an increase in the rice and maize deficiency occurred. The average amount of borrowed rice increased over time and the rice acquisition of the farm agents is performed by borrowing from the village rice bank and neighbours In addition, the farm agents acquire maize by collecting wild vegetables to feed their animals. Furthermore, the results indicate the ability of the farm households to cope with and to recover to some extent from a drought.

Rain increasing scenario

In this scenario, the study area was still unsustainable, similar to the baseline. However, for this scenario, the top-soil erosion is worse because of the increasing rainfall. The PI of economic indicators slightly increased in the first year with increasing rain because of the rising income from livestock production. However, this was caused by random effects influencing the model's initial stage. For the social condition, there are only small random changes compared to the baseline scenario. For the environmental condition, the PI and SIs of environmental indicators become worse due to an increase of top-soil erosion.

Price decreasing scenario

The results show that the area's sustainability is worse compared to the baseline. A reduction of the crop price directly affects household income and cash – which consequently generates a cash deficit problem. However, due to the area characteristics and household behaviour, there is no effect on resource use because prices do not influence the farm agents' decision making. The PI of this scenario declines faster than in the baseline. This was affected by the decrease of the SIs of the economic indicators which decreased during the periods of the price fall. The households are confronted with a decline in cash which results in a deficiency of cash. Cash acquisition of the households is performed by selling livestock and borrowing from the village fund and neighbours. For the social and environmental condition, there are only small changes due to random effects.

Policy recommendations

Based on the study results, policies to improve sustainability of the study area farming systems are recommended. Firstly, to improve the area's sustainability, the introduction of high yield variety of upland rice and maize with conservation practices as well as the introduction of mango to the farm households who currently produce only annual crops is recommended. Secondly, diverting research efforts to develop cash crop alternatives is required in order to improve household cash income. Thirdly, the promotion and support for raising livestock and off-farm activities, such as weaving and the development of tourism, should be performed in order to increase household cash income. Fourthly, awareness raising measures for stakeholders concerning environmental and resource protection have to be executed and achieved. For this, the CatchScapeFS model can be used as a tool to promote a common view between stakeholders. Fifthly, the introduction of birth control in this area is also necessary. Simultaneously, an understanding of households' regarding the effects of population growth should be created in order to obtain the villagers' cooperation without cultural conflicts.

Recommendations for further research

Guidelines for further studies and applications are recommended. Firstly, development of the model to be more realistic could be undertaken by representing more details of the systems, for example, introducing a nutrient soil dynamic model. However, this should be based on the considered research question (s) and should consider both the marginal benefits and marginal costs of development. Secondly, application of the CatchScapeFS model to other study areas would need to consider the compatibility of the model components and structure of the characteristics in the new study area. In addition, if applied to new areas the indicators to represent sustainability of the study area should be revised. Thirdly, applications following this study framework can be extended to different sustainability approaches – such as sustainable rural livelihood or sustainable land management. However, the compatibility and relationship of the indicators with the study framework should be considered. Fourthly, a framework through application of object-oriented modelling is recommended as an alternative for further studies to investigate the consequences of policy interventions. However, resource requirements for any research application should be taken into account. Fifthly, the CatchScapeFS model can be used as a tool to test and monitor the effects of potential policies which can be implemented into Bor Krai village. Also, the model can be used as a tool to promote a common view of the overall village systems as well as to support collective decision making managed by stakeholders of the systems.

Recommendations for newcomers to MAS application research

Suggestions from the present study for newcomers have been proposed. The first recommendation to deal with the MAS application research is that newcomers have to learn the computer programs and programming. Learning programming with advice of programming experts at the beginning period and attention of newcomers to apply the code in different circumstances are highly recommended. Secondly, development of an integrated model in multidisciplinary research requires learning the academic knowledge from other disciplines. Therefore, determining the study objectives within the possible extent, introducing assumptions to simplify the additional disciplines, and consulting specialists to learn the required knowledge within a short time frame are suggested. Lastly, the development of integrated model requires a huge amount of data. Therefore, in the case which required data cannot be obtained, introducing assumptions based on theory and literature is recommended.

German summary (Zusammenfassung)

Einleitung

Durch zunehmende Umweltprobleme und Ressourcenabbau sollte bei der wirtschaftlichen Entwicklung der Erhalt einer funktionsfähigen Umwelt sowie der natürlichen Ressourcen berücksichtigt werden. Um Informationen für die Entwicklung von Politikmaßnahmen zu gewinnen ist es erforderlich, die Entwicklung des Untersuchungsgebietes hinsichtlich ihrer Nachhaltigkeit zu beobachten und zu beurteilen. Dies wird insbesondere für von der Natur benachteiligte Regionen mit sensiblen natürlichen Ressourcen immer wichtiger. Die Untersuchungsregion liegt in den Berggebieten in Nordthailand mit reichlich natürlichen Ressourcen und einer ökologisch gesunden Umwelt. Jedoch induzieren Bevölkerungswachstum, limitierte Flächenverfügbarkeit und externe Faktoren wie z.B. die Kräfte des Marktes Veränderungen und Druck auf die Ressourcennutzung. Im Untersuchungsgebiet werden die Ressourcen intensiv genutzt und die landwirtschaftlichen Bewirtschaftungssysteme zunehmend kommerzialisiert. Deshalb muss die langfristige Nachhaltigkeit des Gebietes untersucht werden.

Ziele

Das Ziel dieser Studie ist die Untersuchung der Nachhaltigkeit des Untersuchungsgebietes und der landwirtschaftlichen Bewirtschaftungssysteme mit Hilfe eines Konzeptes über die Nachhaltigkeit, eines Ansatzes über das landwirtschaftliche Bewirtschaftungssystem und eines Multi-Agent System (MAS) Ansatzes. Das erste Ziel dieser Studie ist die Beschreibung der landwirtschaftlichen Bewirtschaftungssysteme in der Untersuchungsregion. Das zweite Ziel ist, ein MAS Modell zu entwickeln und anzuwenden, um die Nachhaltigkeit des Untersuchungsgebietes zu bewerten. Schließlich soll das Modell angewendet werden, um die Nachhaltigkeit landwirtschaftlicher Bewirtschaftungssysteme unter verschiedenen Szenarien darzustellen, mit denen Veränderungen signifikanter Faktoren und Politikinterventionen simuliert werden. Dabei wird die Fähigkeit des Systems untersucht, mit den Veränderungen zurechtzukommen bzw. sich von diesen zu regenerieren.

Methode

Die Nachhaltigkeit der landwirtschaftlichen Bewirtschaftungssysteme in der Untersuchungsregion wurde mithilfe von definierten Indikatoren beurteilt, die drei verschiedene Zustandsebenen beschreiben – die wirtschaftliche, die soziale und die Umweltebene. Die Indikatoren wurden basierend auf dem Framework zur Bestimmung von Indikatoren definiert, um den Zielen und der Methode dieser Studie gerecht zu werden. Die in dieser Studie gewählten Indikatoren sind Haushaltseinkommen, Netto-Betriebseinkommen aus der Landwirtschaft, Vermögen der Haushalte, Sparaktivitäten der Haushalte, Ernährungssicherheit, Bodenerosion und Brachedauer. Für diese Indikatoren wurden verschiedene Nachhaltigkeitsklassen definiert, in die die einzelnen Haushalte entsprechend ihrer Nachhaltigkeit hinsichtlich des jeweiligen Indikators eingeordnet wurden. Die drei Nachhaltigkeitsklassen bestehen aus der Klasse der nachhaltigen Haushalte (S), der Klasse der eingeschränkt nachhaltigen Haushalte (CS) und der Klasse der nichtnachhaltigen Haushalte (N). Diesen Klassen wurden Nachhaltigkeitspunkte von 0 bis 10 zugeordnet.

Die Bewertung der Nachhaltigkeit wurde auf zwei Ebenen durchgeführt, der Haushalts- und der Dorfebene. Auf der Haushaltsebene wurde die Nachhaltigkeit basierend auf deren individueller Leistung hinsichtlich der einzelnen Indikatoren bewertet. Die Nachhaltigkeit auf Dorfebene wurde mit dem Nachhaltigkeitsindex (SI) beurteilt, wenn einzelne Indikatoren betrachtet werden und dem Leistungsindex (PI), wenn eine Gruppe von Indikatoren betrachtet wird. Die Nachhaltigkeitsentwicklung auf Haushalts- und Dorfebene wurde über 15 Jahre (2003 – 2017) extrapoliert, um die Nachhaltigkeit der landwirtschaftlichen Bewirtschaftungssysteme in der Untersuchungsregion darzustellen.

Das MAS Modell wurde entwickelt und „CatchScapeFS“ genannt. Die Modellstruktur basiert auf der Beschreibung der landwirtschaftlichen Bewirtschaftungssysteme in der Untersuchungsregion. Der MAS Ansatz wurde angewendet, um die Komplexität der Untersuchungsregion abzubilden und deren Nachhaltigkeitssituation langfristig zu extrapolieren. Das Modell setzt sich aus zwei Komponenten zusammen, einer biophysikalischen und einer sozioökonomischen Komponente. Die biophysikalische Komponente basiert auf dem CatchScape3 Modell. Es besteht aus folgenden biophysikalischen Modellen: einem hydrologischen Modell, einem landwirtschaftlichen Produktionsmodell, einem Wasserbilanzmodell und einem Bodenerosionsmodell, integriert in ein Landschaftsmodell der Untersuchungsregion mit einem Raster von einem rai (d.h. 0.16 ha). Die sozioökonomische Komponente besteht aus landwirtschaftlichen Haushalten und anderen sozialen Elementen als Agenten im Modell. Die Stichproben der landwirtschaftlichen Haushalte wurden anhand ihrer Eigenschaften und ihres Verhaltens in eine marktorientierte, eine subsistenzorientierte Gruppe und eine partnerschaftsorientierte Gruppe klassifiziert. Zur Generierung landwirtschaftlicher Modellagenten aus der Stichprobe der existierenden landwirtschaftlichen Haushalte wurde die Monte Carlo Technik angewendet.

Das CatchScapeFS Modell wurde dem objektorientierten Modellansatz entsprechend entwickelt. Der CORMAS Rahmen wurde gewählt, um die Modellierung und Simulation zu vereinfachen. Während eines Simulationszeitintervalls, das 10 Tagen entspricht, werden sechs Hauptphasen abgebildet, die acht Phasen der Haushaltsaktivitäten landwirtschaftlicher Agenten beinhalten. Das Modell wurde hinsichtlich seiner Stabilität validiert und getestet. Die Validierung erfolgte durch soziale Validierung und durch einen Vergleich mit statistischen Daten. Die Ergebnisse der Modellvalidierung und des Stabilitätstests ergaben, dass sich das Modell zur Analyse der Studienziele eignet.

Hauptergebnisse

Nachhaltigkeit der Untersuchungsregion auf Haushaltsebene

Die Ergebnisse zeigen keine nachhaltige Entwicklung der Untersuchungsregion. Die Zahl der nachhaltigen Haushalte (S) geht zurück, wogegen die Zahl der nicht (N) bzw. eingeschränkt nachhaltigen (C) Haushalte eher zunimmt. Hinsichtlich der wirtschaftlichen Lage vermindern zunehmende private Haushaltsausgaben und abnehmender landwirtschaftlicher Produktionswert die Nachhaltigkeit. Die Verschlechterung der Nachhaltigkeit in sozialer Hinsicht zeigt sich an einem langfristig zunehmenden Mangel an Reis. Durch Erosion und verkürzte Brache ist der Zustand der Umwelt nicht nachhaltig. Die Erosion im Untersuchungsgebiet ist erheblich und nimmt im Betrachtungszeitraum zu. Durch die intensive Landnutzung, die zur Versorgung der Bevölkerung erforderlich ist, verkürzt sich die Dauer der Brache und folglich degradiert langfristig der Boden.

Nachhaltigkeit der Untersuchungsregion auf Dorfebene

Entsprechend der Ergebnisse auf Haushaltsebene zeigen die Ergebnisse auf Dorfebene, dass die landwirtschaftlichen Bewirtschaftungssysteme der Untersuchungsregion nicht nachhaltig sind. Dies zeigt sich an dem langfristig abnehmenden Leistungsindex (PI) und an den für alle Indikatoren rückläufigen Nachhaltigkeitsindices (SI). Betrachtet man die Entwicklung der PI Werte, ist die Nachhaltigkeit der Untersuchungsregion in wirtschaftlicher Hinsicht weniger gefährdet als in sozialer Hinsicht und insbesondere hinsichtlich des Umweltzustandes. Dies basiert auf vergleichsweise hohen SI Werten der ökonomischen Indikatoren im Vergleich zu den sozialen und Umweltindikatoren. Betrachtet man alle Nachhaltigkeitsindices und deren Entwicklung, kann für die verschiedenen Nachhaltigkeitsaspekte eine Rangfolge hinsichtlich der Dringlichkeit ihrer Verbesserung erstellt werden. Die Ernährungssicherung war der am wenigsten nachhaltige Problembereich, gefolgt vom Sparen der Haushalte, dem Haushaltsvermögens, der Bodenerosion, dem Haushaltseinkommen, der Brachedauer und dem landwirtschaftlichen Einkommens.

Szenario Analyse

Als Szenarien wurden zum einen die Implementierung von Politikmaßnahmen zur Verbesserung der Nachhaltigkeit erstellt und zum anderen das Eintreffen unerwarteter Ereignisse durch die Veränderung biophysikalischer und wirtschaftlicher Faktoren. Das Politikszenario zur Verbesserung der Nachhaltigkeit basiert auf der Einführung einer Hochertragssorte bei Hochlandreis und Mais sowie der Einführung des Anbaus von Mango bei den Haushalten, die bisher keine Dauerkulturen anbauen. Das Wetterszenario, bei dem sich extreme Trockenheit und Regenfälle abwechseln, wurde erstellt, um die Auswirkungen unerwarteter Ereignisse durch die Veränderung biophysikalischer Eigenschaften zu analysieren. Mit dem Preisszenario, das durch Produktpreisschwankungen gekennzeichnet ist, werden die Auswirkungen unerwarteter Ereignisse hinsichtlich ökonomischer Faktoren untersucht.

Implementierung von Politikmaßnahmen zur Verbesserung der Nachhaltigkeit

Die Ergebnisse zeigen, dass sich die Nachhaltigkeit des Untersuchungsgebietes durch Implementierung geeigneter Politikmaßnahmen offenkundig verbessert. Dies wird durch die

Zunahme des Leistungsindexes (PI) und dessen positive Entwicklung im Betrachtungszeitraum deutlich. Außerdem steigen die Nachhaltigkeitsindices (SI) vieler Indikatoren in diesem Szenario, mit Ausnahme des SI der Haushaltsersparnisse, der nahezu konstant bleibt. Der PI der wirtschaftlichen Indikatoren verbessert sich durch eine größere Zahl nachhaltiger Haushalte in Bezug auf das Haushaltseinkommen, das landwirtschaftliche Nettoeinkommen und das Haushaltsvermögen. Betrachtet man die soziale Lage, zeigt sich eine Verbesserung des PI und des SI der Ernährungssicherung durch ein vermindertes Reisdefizit. Hinsichtlich des Umweltzustandes zeigt sich eine Zunahme des PI Wertes der Umweltindikatoren, die aus einer Reduzierung der Bodenerosion und Verlängerung der Brachedauer bei der Bodennutzung resultiert. Schließlich kann festgehalten werden, dass die Politikmaßnahmen in diesem Szenario zu einer deutlichen Verbesserung der Nachhaltigkeitssituation in der Untersuchungsregion führen.

Dürreszenario

Die Ergebnisse dieses Dürreszenarios zeigen ähnlich wie das Basisszenario, keine Nachhaltigkeit des Untersuchungsgebietes. Allerdings zeigt sich ein etwas höherer PI während der Dürre bei geringerem Rückgang im Betrachtungszeitraum. Dies entsteht durch trade-offs zwischen Indikatoren. Der Bodenerosionsindikator verbesserte sich durch den Rückgang der Niederschläge. Dieser positive Effekt kompensiert die negativen Effekte verminderter Haushaltsersparnisse, geringerer Ernährungssicherheit und geringerer Brachedauer. Außerdem zeigen die Simulationsergebnisse die Reaktionen und Anpassungen der Farmagenten bei Dürre. Trockenheit wird wahrgenommen und verursacht verspätetes Pflanzen zur Schadensvermeidung. Dies führt zu Variationen in der Anbaufläche. Allerdings verminderte sich die Variation im Verlauf der Betrachtungsperiode, da die landwirtschaftlichen Haushalte aus der Vergangenheit lernen und sich anpassen. Während der Dürre vergrößert sich das Reis- und Maisdefizit. Die durchschnittlich geliehene Reismenge steigt im Betrachtungszeitraum an. Die Reisakquisition der Farmagenten erfolgt durch das Ausleihen von Reis bei der kommunalen Reisbank sowie bei Nachbarn. Außerdem akquirieren die Farmagenten Maisersatz durch das Sammeln von Wildpflanzen für die Fütterung ihres Viehs. Darüber hinaus zeigen die Ergebnisse die Fähigkeit der landwirtschaftlichen Haushalte, mit Trockenheit in gewissem Umfang zurechtzukommen und sich regenerieren zu können.

Niederschlagsszenario

Die Ergebnisse dieses Szenarios mit zunehmenden Niederschlägen zeigen ähnlich wie das Basisszenario keine Nachhaltigkeit des Untersuchungsgebietes. Bei diesem Szenario verstärkte sich die Bodenerosion durch die Zunahme der Niederschläge. Im ersten Jahr der Niederschlagszunahme verbessert sich der Leistungsindex (PI) der ökonomischen Indikatoren leicht, da das Einkommen aus der Tierproduktion zunimmt. Bei der sozialen Lage sind im Vergleich zum Basisszenario nur geringfügige Veränderungen, vor allem bedingt durch Zufallseffekte in der Ausgangssituation erkennbar. Der Umweltzustand verschlechterte sich durch zunehmende Bodenerosion. Entsprechend gehen der Leistungsindex und der Nachhaltigkeitsindex der Umweltindikatoren zurück.

Preisrückgangszenario

Bei diesem Szenario mit sinkenden Preisen verschlechtert sich die Nachhaltigkeitssituation des Untersuchungsgebietes im Vergleich zum Basisszenario. Ein Rückgang der Produktpreise wirkt sich direkt auf das Einkommen und die Geldmittel aus und führt folglich zu Liquiditätsproblemen. Allerdings zeigten sich aufgrund der Merkmale des Untersuchungsgebietes und des Haushaltsverhaltens keine Auswirkungen auf die Ressourcennutzung. Preise beeinflussen die Entscheidungen der Farmagenten nicht. Der Leistungsindex (PI) der ökonomischen Indikatoren vermindert sich bei diesem Szenario stärker als beim Basisszenario, da die Nachhaltigkeitsindices (SI) der einzelnen ökonomischen Indikatoren während der Perioden mit Preisrückgängen zurückgehen. Auf die Haushalte kommt ein Rückgang der Geldmittel zu, der zu Liquiditätsproblemen führt. Die Haushalte erwerben Geldmittel durch den Verkauf von Tieren aus dem Bestand und durch das Ausleihen von Geld beim kommunalen Fond und bei Nachbarn. Auf der sozialen und Umweltebene ergeben sich nur geringfügige Änderungen durch Zufallseffekte.

Politikempfehlungen

Basierend auf den Ergebnissen der Studie werden Politikmaßnahmen zur Verbesserung der Nachhaltigkeit der landwirtschaftlichen Bewirtschaftungssysteme in der Untersuchungsregion empfohlen. Erstens wird die Einführung von Hochertragssorten bei Hochlandreis und Mais in Verbindung mit Umweltmaßnahmen empfohlen sowie die Einführung des Mangoanbaus in landwirtschaftlichen Haushalten, die bisher keine

Dauerkulturen anbauen. Zweitens sind Forschungsaktivitäten zum Anbau alternativer Verkaufsfrüchte erforderlich, um die Bareinnahmen der Haushalte zu verbessern. Drittens sollten durch Werbung und Unterstützung Tierhaltungs- und außerlandwirtschaftliche Aktivitäten wie z.B. das Weben und die Entwicklung des Tourismus gefördert werden, um das Haushaltseinkommen zu steigern. Viertens sollte eine Schärfung des Bewusstseins für Umwelt- und Ressourcenschutz bei allen Betroffenen erreicht werden. Dafür kann als Werkzeug zur Förderung einer gemeinsamen Haltung der Betroffenen das CatchScapeFS Modell angewendet werden. Fünftens ist die Einführung der Geburtenkontrolle in diesem Gebiet erforderlich. Gleichzeitig sollte das Verständnis der Haushalte hinsichtlich der Auswirkungen des Bevölkerungswachstums verbessert werden, um die Zusammenarbeit der Dorfbewohner ohne kulturelle Konflikte zu erreichen.

Empfehlungen für weitere Forschung

Folgende Leitlinien für weitere Studien und Anwendungsmöglichkeiten werden empfohlen. Erstens kann das Modell durch eine stärker detaillierte Abbildung des Systems verbessert werden, z.B. durch die Integration eines dynamischen Boden-Nährstoffmodells. Allerdings sollten bei der Weiterentwicklung des Modells sowohl die relevanten Forschungsfragen als auch der Grenznutzen und die Grenzkosten der Entwicklung berücksichtigt werden. Zweitens muss bei der Anwendung des CatchScapeFS Modells auf andere Untersuchungsgebiete die Kompatibilität der Modellkomponenten und Modellstruktur in Bezug auf die Merkmale der neuen Untersuchungsregion berücksichtigt werden. Außerdem müssen die Indikatoren zur Beurteilung der Nachhaltigkeit der Untersuchungsregion bei der Anwendung des Modells auf andere Gebiete entsprechend angepasst werden. Drittens kann die Modellanwendung dieser Studie für verschiedene Ansätze der Nachhaltigkeitsbetrachtung erweitert werden wie z.B. die Betrachtung einer nachhaltigen ländlichen Existenzgrundlage oder eines nachhaltigen Flächenmanagements. Allerdings sollte die Kompatibilität der Indikatoren mit dem Studienrahmen berücksichtigt werden. Viertens wird als Alternative für weitere Studien zur Analyse der Auswirkungen von Politikinterventionen die Anwendung der objektorientierten Modellierung empfohlen. Dabei sollte bei allen Forschungsanwendungen auch der Ressourcenbedarf berücksichtigt werden. Fünftens kann das CatchScapeFS Modell als Instrument zur Analyse und Beobachtung der Auswirkungen potentieller Politikmaßnahmen genutzt werden, die in Bor Krai Village implementiert werden könnten. Außerdem kann das Modell als Instrument zur Förderung einer gemeinsamen Haltung gegenüber dem gesamten Dorfsystemen angewendet werden und ebenso um gemeinschaftliche Entscheidungen der einzelnen Betroffenen in ihrem System zu fördern.

Empfehlungen für Neueinsteiger in die MAS Anwendungsforschung

Als erstes wird Neusinsteigern in die MAS Anwendungsforschung empfohlen, die Anwendung von Computerprogrammen und die Programmierung zu erlernen. Dafür ist insbesondere in der Anfangsphase die Anleitung durch Programmierexperten empfehlenswert, so dass die Neueinsteiger die Anwendung der Programmiersprache für verschiedene Sachverhalte erlernen. Zweitens erfordert die Entwicklung von integrierten Modellen in der interdisziplinären Forschung umfangreiche Kenntnisse aus anderen Disziplinen. Dafür wird empfohlen, die Forschungsziele entsprechend auszurichten bzw. zu begrenzen, vereinfachende Annahmen zu treffen, um Spezialkenntnisse aus anderen Disziplinen zu integrieren und Experten aus den einzelnen Fachgebieten zu konsultieren. Schließlich erfordert die Entwicklung von integrierten Modellen eine riesige Datenmenge. Falls die erforderlichen Daten nicht verfügbar sind, wird empfohlen, basierend auf Theorie und Literatur entsprechende Annahmen zu treffen.

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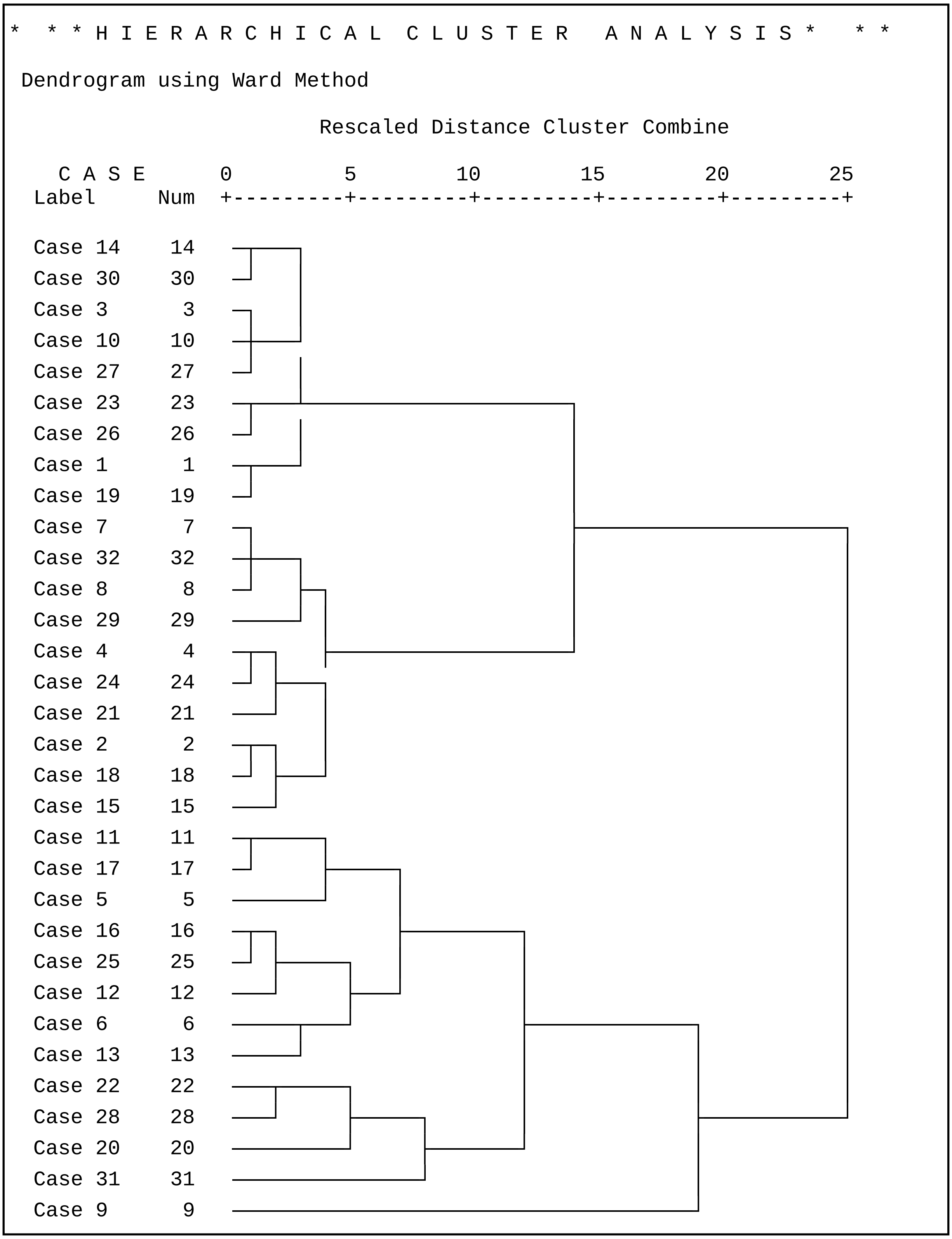
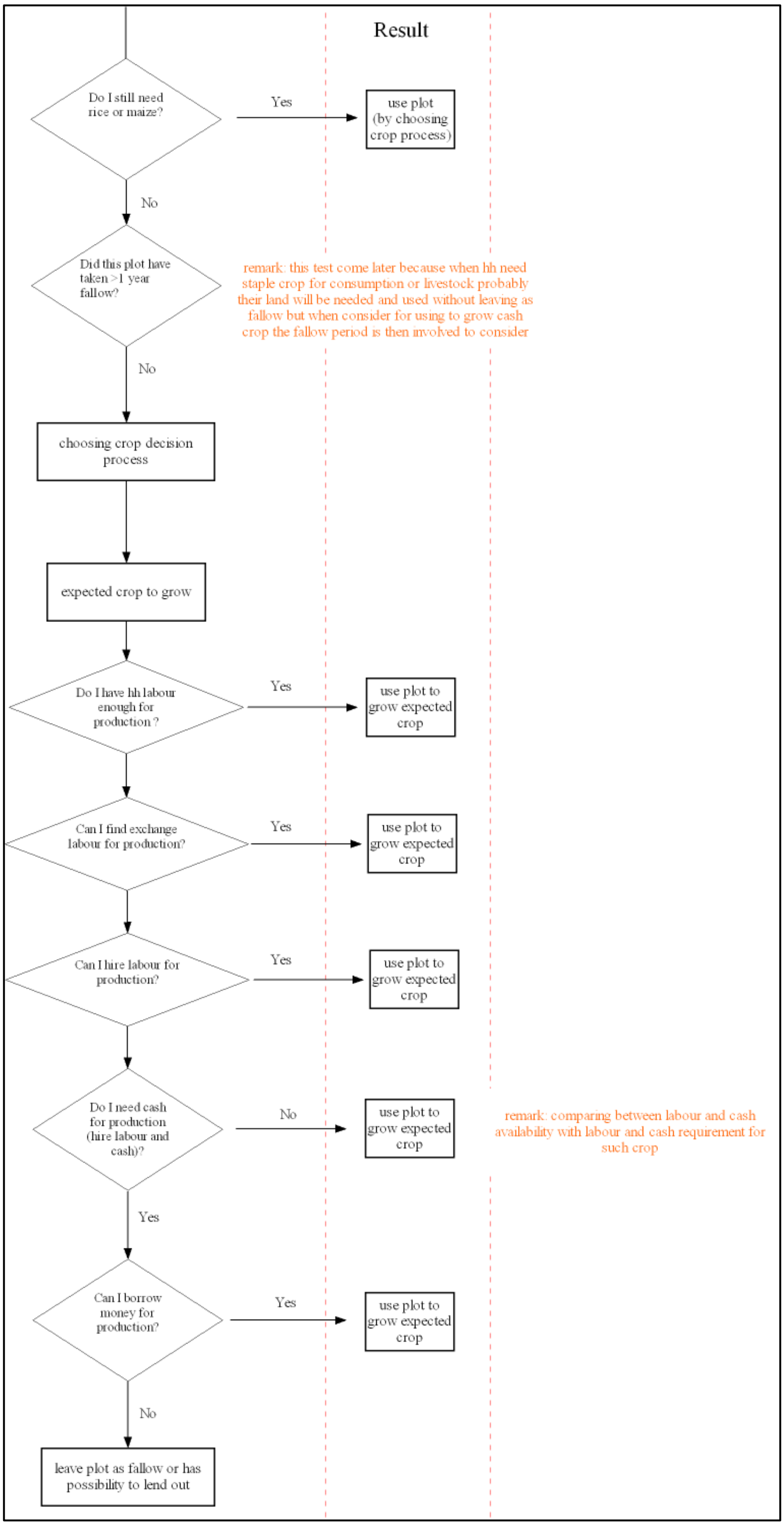
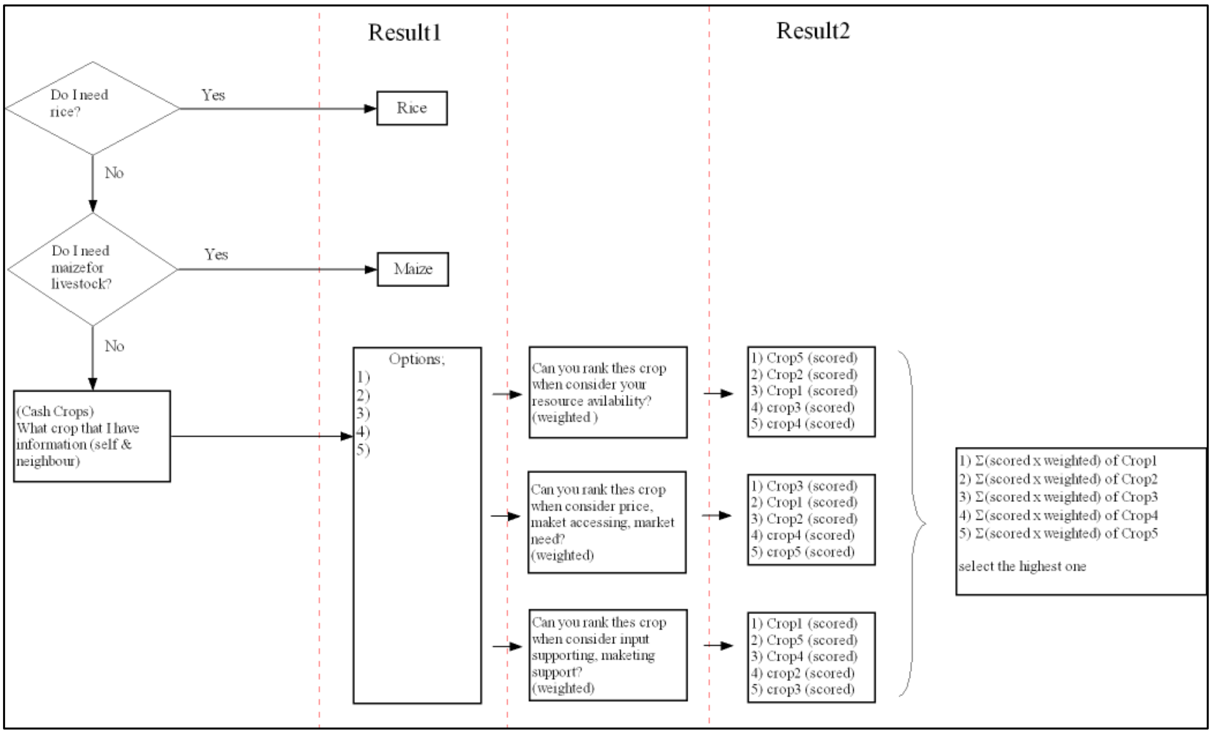
Appendix



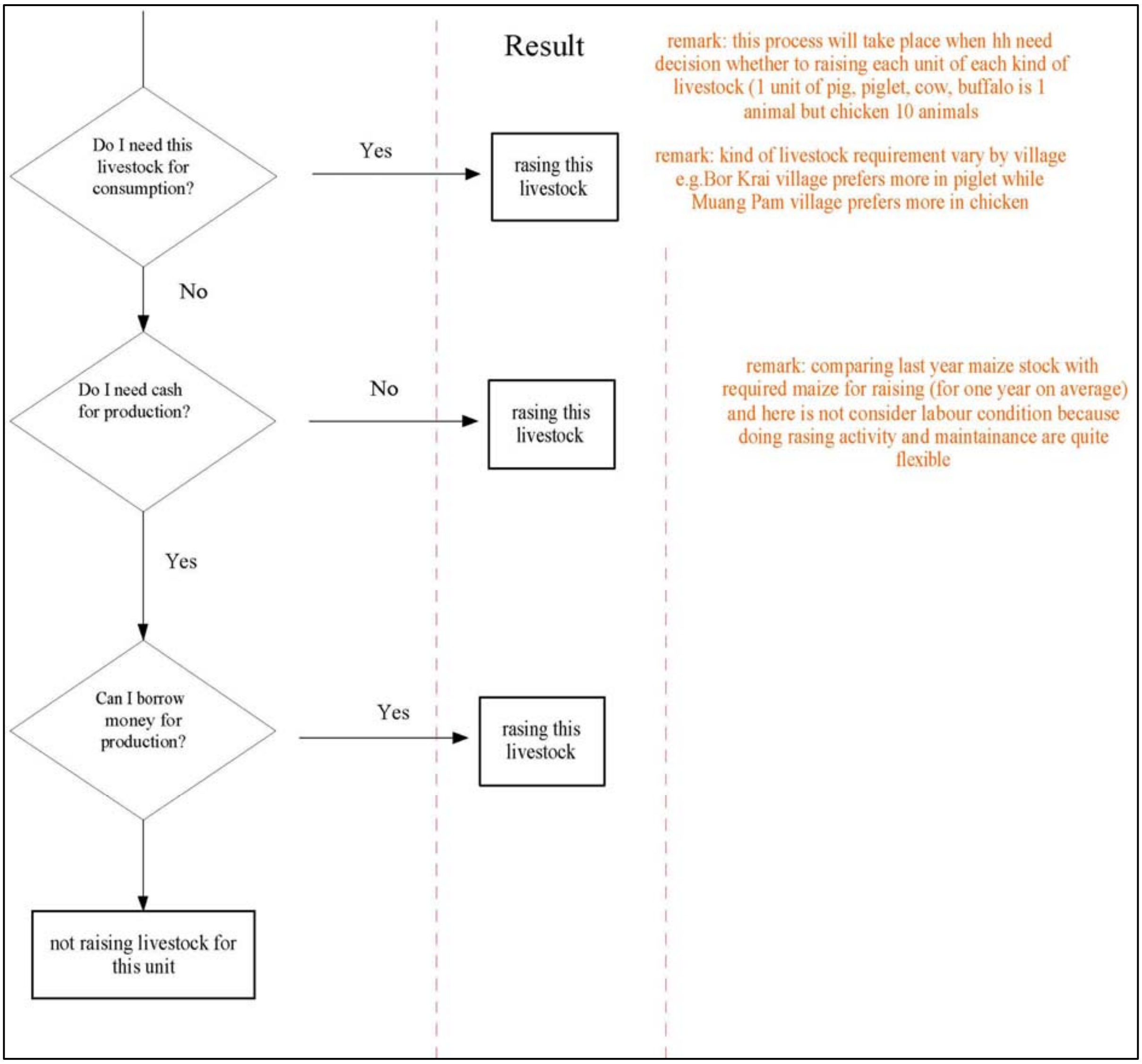
Appendix figure 1: Dendrogram result from cluster analysis



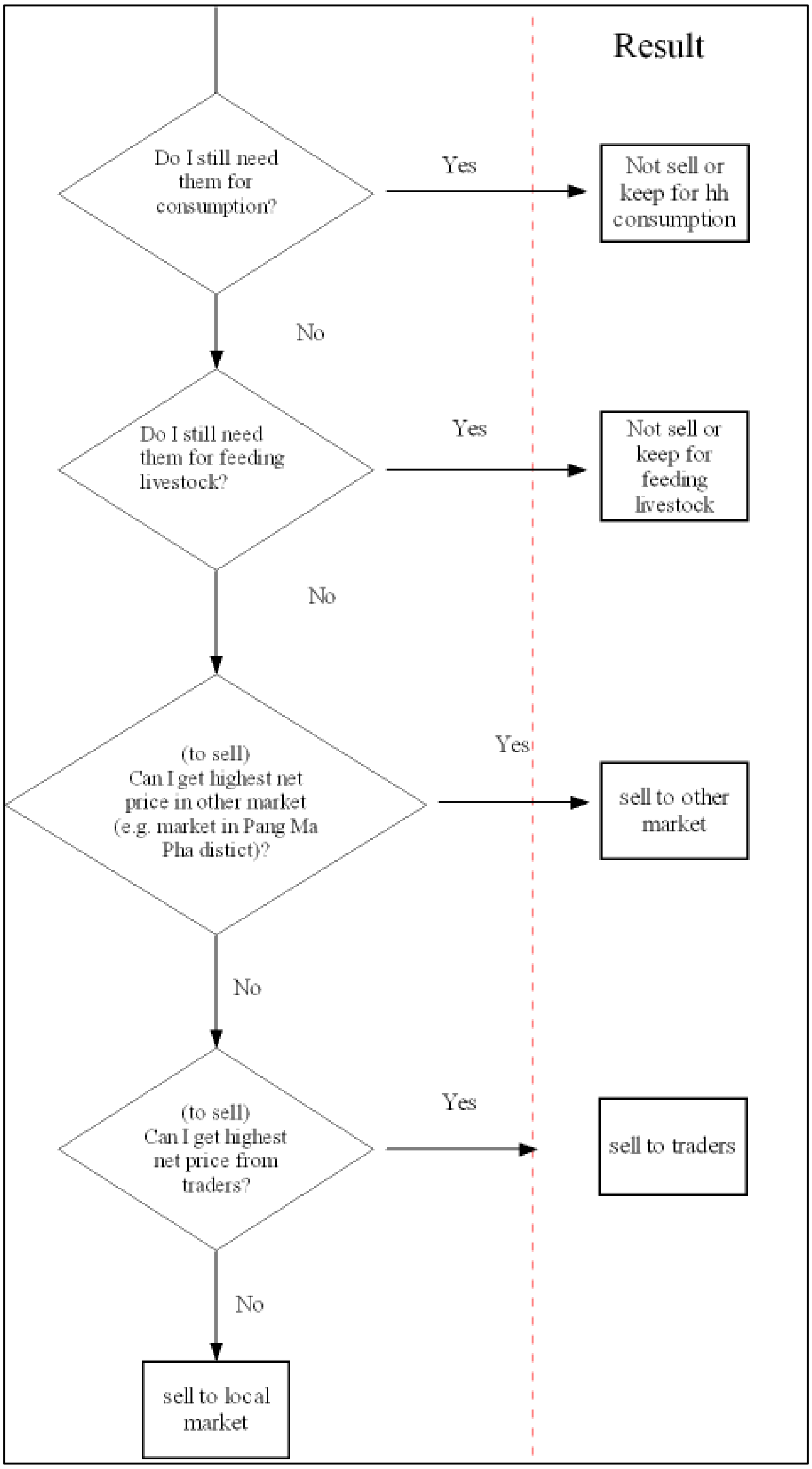
Appendix figure 2: Using plot decision making chart diagram



Appendix figure 3: Choosing crop decision making chart diagram



Appendix figure 4: Raising livestock decision making chart diagram



Appendix figure 5: Selling crop product decision making chart diagram

Description of the "Using plot activity" programming code

"usePlotDecision"

```
| noCropPlots sortedPlots lastYearUsed noCropPlots1 riceGrown |
noCropPlots := self plots select: [:p | p hasNoCrop & (p isPreparingLand not)].
"use plot which is used in last year for maize or other crop"
lastYearUsed := OrderedCollection new.
noCropPlots do:[:p | CatchScapeFS currentYear = 1
                ifTrue:[ (p cropHistory at: CatchScapeFS currentYear) isEmpty
                        ifFalse:[ riceGrown := 0.
                                (p cropHistory at: CatchScapeFS currentYear)
                                do:[:his | his = #riceUpland | (his = #riceUplandNew)
                                        ifTrue:[ riceGrown:= riceGrown + 1]].
                                riceGrown > 0
                                  ifTrue:[ lastYearUsed add: p]]]
                                  ifFalse:[ (p cropHistory at: (CatchScapeFS currentYear - 1)) isEmpty
                                        ifFalse:[ riceGrown := 0.
                                                (p cropHistory at: (CatchScapeFS currentYear -1))
                                                do:[:his | his = #riceUpland | (his = #riceUplandNew)
                                                        ifTrue:[ riceGrown:= riceGrown + 1]].
                                                riceGrown > 0
                                                  ifTrue:[ lastYearUsed add: p]]]].
lastYearUsed do:[:p | self usePlotForOtherCrop: p].

noCropPlots1 := self plots select: [:p | p hasNoCrop & (p isPreparingLand not)].
sortedPlots := noCropPlots1 asSortedCollection: [:x :y | x countFallowPeriod > y countFallowPeriod].
sortedPlots do: [:p | self usePlot: p].
```

"usePlot:"

```
usePlot: aPlot
| expectedCashCropToGrow test qtLabourLack qtMoneyLack qtMoneyLack2 selectedRice selectedMaize |

self doIStillNeedRice & (self canIPlantRiceAtThisSeason)
    ifTrue:[ CatchScapeFS currentScenario = 1 "improve sus policy"
            ifTrue:[ selectedRice := self strategy intendedRiceToGrow.
                    self plant: selectedRice onPlot: aPlot.
                    self riceLackInYearUpdate.
                    self recordPlantedPlotAt: aPlot For: selectedRice]
            ifFalse:[ self plant: #riceUpland onPlot: aPlot.
                    self riceLackInYearUpdate.
                    self recordPlantedPlotAt: aPlot For: #riceUpland]]
    ifFalse:[self doIStillNeedMaize  & (self canIPlantMaizeAtThisSeason)
            ifTrue:[ CatchScapeFS currentScenario = 1 "improve sus policy"
                    ifTrue:[ selectedMaize := self strategy intendedMaizeToGrow.
                            self plant: selectedMaize onPlot: aPlot.
                            self maizeLackInYearUpdate.
                            self recordPlantedPlotAt: aPlot For: selectedMaize]
                    ifFalse:[ self plant: #maizeGrain onPlot: aPlot.
                            self maizeLackInYearUpdate.
                            self recordPlantedPlotAt: aPlot For: #maizeGrain ]]
"using plot for cash crop"
            ifFalse:[ CatchScapeFS currentScenario = 1 "improve sus policy"
                     ifTrue:[ self doIHaveFruitPlotYet
                            ifFalse:[ CatchScapeFS currentYear > 4 &(CatchScapeFS currentDate = 1)
                                    ifTrue:[ aPlot plantedFlag isNil not
                                            ifTrue:[ self halt]
                                            ifFalse:[ self plant: #mango onPlot: aPlot]]]
                            ifTrue:[ (((aPlot countFallowPeriod - 1) quo: 36) +1 > 2)
                                ifTrue:[expectedCashCropToGrow := self strategy intendedCashCropToGrow.
                                    expectedCashCropToGrow isNil
                                        ifFalse:[(self canIPlantAtThisSeason: expectedCashCropToGrow)
                                            ifTrue:[ test := 0.
                                                qtLabourLack := self howMuchLabourIsLackingFor:
expectedCashCropToGrow.
                                                qtLabourLack > 0
                                                  ifTrue:[ (self canIFindExLabourFor: qtLabourLack)
                                                  ifFalse:[qtMoneyLack :=  (self
howMuchMoneyIsLackingToHireLabourFor: qtLabourLack).
```

```
                                                qtMoneyLack > 0
                                                  ifTrue:[  (self canIBorrowMoneyFor: qtMoneyLack For: #crop)
                                                  ifFalse:[ test := 1]]]].
                                                test =0
                                                  ifTrue:[ (self doIHaveMoneyToGrowFor:
expectedCashCropToGrow)
                                                  ifFalse:[ qtMoneyLack2 := (self howMuchMoneyIsLackingFor:
expectedCashCropToGrow).
                                                       qtMoneyLack2 > 0
                                                       ifTrue:[ (self canIBorrowMoneyFor: qtMoneyLack2 For:
#crop)
                                                       ifFalse:[test :=1]]]].
                                                test =0
                                                  ifTrue:[self plant: expectedCashCropToGrow onPlot: aPlot.
                                                       self recordPlantedPlotAt: aPlot For:
expectedCashCropToGrow]
                                                  ifFalse:[ ]
]
]]]]
                    ifFalse:[ (((aPlot countFallowPeriod - 1) quo: 36) +1 > 2)
                         ifTrue:[ expectedCashCropToGrow := self strategy intendedCashCropToGrow.
                              expectedCashCropToGrow isNil
                                ifFalse:[ (self canIPlantAtThisSeason: expectedCashCropToGrow)
                                     ifTrue:[ test := 0.
                                          qtLabourLack := self howMuchLabourIsLackingFor:
expectedCashCropToGrow.
                                          qtLabourLack > 0
                                            ifTrue:[ (self canIFindExLabourFor: qtLabourLack)
                                            ifFalse:[ qtMoneyLack :=  (self
howMuchMoneyIsLackingToHireLabourFor: qtLabourLack).
                                                 qtMoneyLack > 0
                                                   ifTrue:[  (self canIBorrowMoneyFor: qtMoneyLack For: #crop)
                                                   ifFalse:[ test := 1]]]].
                                          test =0
                                            ifTrue:[ (self doIHaveMoneyToGrowFor: expectedCashCropToGrow)
                                            ifFalse:[ qtMoneyLack2 := (self howMuchMoneyIsLackingFor:
expectedCashCropToGrow).
                                                 qtMoneyLack2 > 0
                                                   ifTrue:[ (self canIBorrowMoneyFor: qtMoneyLack2 For: #crop)
                                                   ifFalse:[test :=1]]]].
                                          test =0
                                            ifTrue:[self plant: expectedCashCropToGrow onPlot: aPlot.
                                                 self recordPlantedPlotAt: aPlot For: expectedCashCropToGrow]
                                            ifFalse:[ ]
]
]]]]]
```

"usePlotForOtherCrop: aPlot"

```
| expectedCashCropToGrow test qtLabourLack qtMoneyLack qtMoneyLack2 selectedMaize |

self doIStillNeedMaize  & (self canIPlantMaizeAtThisSeason)
    ifTrue:[ CatchScapeFS currentScenario = 1 "improve sus policy"
              ifTrue:[ selectedMaize := self strategy intendedMaizeToGrow.
                   self plant: selectedMaize onPlot: aPlot.
                   self maizeLackInYearUpdate.
                   self recordPlantedPlotAt: aPlot For: selectedMaize]
              ifFalse:[self plant: #maizeGrain onPlot: aPlot.
                   self maizeLackInYearUpdate.
                   self recordPlantedPlotAt: aPlot For: #maizeGrain ]]
"using plot for cash crop"
    ifFalse:[ CatchScapeFS currentScenario = 1 "improve sus policy"
              ifTrue:[ self doIHaveFruitPlotYet
                   ifFalse:[ CatchScapeFS currentYear > 4 &(CatchScapeFS currentDate = 1)
                        ifTrue:[ aPlot plantedFlag isNil not
                             ifTrue:[ self halt]
                             ifFalse:[ self plant: #mango onPlot: aPlot]]]
                   ifTrue:[  (((aPlot countFallowPeriod - 1) quo: 36) +1 > 2)
                        ifTrue:[ expectedCashCropToGrow := self strategy intendedCashCropToGrow.
                             expectedCashCropToGrow isNil
```

```
                                    ifFalse:[ (self canIPlantAtThisSeason: expectedCashCropToGrow)
                                        ifTrue:[ test := 0.
                                            qtLabourLack := self howMuchLabourIsLackingFor: expectedCashCropToGrow.
                                            qtLabourLack > 0
                                              ifTrue:[ (self canIFindExLabourFor: qtLabourLack)
                                                    ifFalse:[  qtMoneyLack :=  (self howMuchMoneyIsLackingToHireLabourFor:
qtLabourLack).
                                            qtMoneyLack > 0
                                              ifTrue:[  (self canIBorrowMoneyFor: qtMoneyLack For: #crop)
                                                     ifFalse:[ test := 1]]]].
                                            test =0
                                              ifTrue:[ (self doIHaveMoneyToGrowFor: expectedCashCropToGrow)
                                                     ifFalse:[ qtMoneyLack2 := (self howMuchMoneyIsLackingFor:
expectedCashCropToGrow).
                                                          qtMoneyLack2 > 0
                                                            ifTrue:[ (self canIBorrowMoneyFor: qtMoneyLack2 For: #crop)
                                                                ifFalse:[test :=1]]]].
                                            test =0
                                              ifTrue:[self plant: expectedCashCropToGrow onPlot: aPlot.
                                                    self recordPlantedPlotAt: aPlot For: expectedCashCropToGrow]
                                              ifFalse:[ ]
]
]]]]
        ifFalse:[ (((aPlot countFallowPeriod - 1) quo: 36) +1 > 2)
              ifTrue:[expectedCashCropToGrow := self strategy intendedCashCropToGrow.
                  expectedCashCropToGrow isNil
                    ifFalse:[ (self canIPlantAtThisSeason: expectedCashCropToGrow)
                        ifTrue:[ test := 0.
                            qtLabourLack := self howMuchLabourIsLackingFor: expectedCashCropToGrow.
                            qtLabourLack > 0
                              ifTrue:[ (self canIFindExLabourFor: qtLabourLack)
                              ifFalse:[  qtMoneyLack :=  (self howMuchMoneyIsLackingToHireLabourFor:
qtLabourLack).
                            qtMoneyLack > 0
                              ifTrue:[  (self canIBorrowMoneyFor: qtMoneyLack For: #crop)
                                    ifFalse:[  test := 1]]]].
                            test =0
                            ifTrue:[ (self doIHaveMoneyToGrowFor: expectedCashCropToGrow)
                                  ifFalse:[ qtMoneyLack2 := (self howMuchMoneyIsLackingFor:
expectedCashCropToGrow).
                                     qtMoneyLack2 > 0
                                     ifTrue:[ (self canIBorrowMoneyFor: qtMoneyLack2 For: #crop)
                                           ifFalse:[test :=1]]]].
                            test =0
                            ifTrue:[self plant: expectedCashCropToGrow onPlot: aPlot.
                                  self recordPlantedPlotAt: aPlot For: expectedCashCropToGrow]
                            ifFalse:[ ]
]
]]]]
```

Description of the "Consuming rice activity" programming code

"consumeRice"

```
| qt |
qt := self numberOfMember * 13.
qt = 0 ifTrue:[ self halt].
self riceStore >= qt
    ifTrue:[self riceStore: self riceStore - qt.
            CatchScapeFS hhiRecordRevenue: (Array with:#riceConsume with: (qt * (Parameter readCurrentCropPrice: #riceUpland)))
forHH: self id] "SM"
    ifFalse:[self borrowRice].
```

"borrowRice"

```
| nbStepsUntilNextHarvest qt qtBorrowed |

CatchScapeFS currentDate <= 24
    ifTrue:[  nbStepsUntilNextHarvest := 24 - (CatchScapeFS currentDate)]
    ifFalse:[  nbStepsUntilNextHarvest := 24 + (36 - (CatchScapeFS currentDate))].
qt := self numberOfMember * 13.
qtBorrowed :=  qt - self riceStore.
self remRiceLackTocropKBFor:qtBorrowed.
CatchScapeFS socRecordRiceLackResult: qtBorrowed forHH: self id. "SM"
(self borrowToRiceBank: qtBorrowed)
    ifFalse:[ (self borrowRiceToNeighbour: qt)
              ifFalse:[self buyRiceToCropTrader: qt]].
```

"borrowToRiceBank: qt"

```
self village riceBank < qt
    ifTrue:[^ false]
    ifFalse:[ self village riceBank > qt
              ifTrue:[ self village riceBank: (self village riceBank - qt).
                       self getRice: qt.
                       self remRiceBorrowingFromRiceBankAmount: qt.
                       ^true]
              ifFalse:[^false]].
```

"borrowRiceToNeighbour: qt"

```
flag := false.
self neighbours do:[:n| flag ifFalse:[(n willYouLendMeRiceFor: qt)
                                  ifTrue:[  self borrowRiceFor: qt toMr: n.
                                            flag := true]]].
^flag
```

"buyRiceToCropTrader: qt"

```
| mLack aCrop aStep mLack2 mLack3 |
(self contactTrader willYouSoldMeYourRiceFor: qt)
    ifTrue:[ (self doIHaveMoneyToBuyRiceFor: qt)
            ifTrue:[(self buyRiceFor: qt toMr: (self contactTrader)).
                    CatchScapeFS hhiRecordCost: (Array with: #cashBuyRiceForConsume with: (qt * (Parameter readCurrentCropPrice:
#riceUpland))) forHH: self id] "SM"
            ifFalse:[ aCrop := 'riceUpland'.
                    aStep := CatchScapeFS currentDecade.
                    mLack := ((Parameter readCropPrice: aCrop atDate: aStep) * qt) - self cash.
                    mLack2 := (self moneyFromAddedCropSelling) - mLack.
                    mLack2 >= 0
                        ifTrue:[(self buyRiceFor: qt toMr: (self contactTrader)).
                                CatchScapeFS hhiRecordCost: (Array with: #cashBuyRiceForConsume with: (qt * (Parameter
readCurrentCropPrice: #riceUpland))) forHH: self id] "SM"
                        ifFalse:[ mLack3 := (self  howMuchCanISellMyLivestockFor: mLack2 abs) - (mLack2 abs).
                                mLack3 >= 0
                                    ifTrue:[ (self buyRiceFor: qt toMr: (self contactTrader)).
                                            CatchScapeFS hhiRecordCost: (Array with: #cashBuyRiceForConsume with: (qt * (Parameter
readCurrentCropPrice: #riceUpland))) forHH: self id] "SM"
                                    ifFalse:[ (self canIBorrowMoneyFor: mLack3 For: #hhConsumption)
                                            ifTrue:[ (self buyRiceFor: qt toMr: (self contactTrader)).
```

```
                    CatchScapeFS hhiRecordCost: (Array with: #cashBuyRiceForConsume with: (qt *
(Parameter readCurrentCropPrice: #riceUpland))) forHH: self id "SM"]
                ifFalse:[ self halt.]]]]]
```

Description of the “Recovering themselves from cash shortage activity” programming code

“cashChecking”

```
| mLack positive hour hh adCSell sellSet livestockCanSell mLive orederOfSell liveSellColl sortedLiveSellColl price nbCow nbBuffalo
infWage wagePerDay |
infWage := Parameter readCurrentInflationRateForWage: CatchScapeFS currentYear.
positive := false.
self cash < 0
    ifTrue: [ mLack := (self cash) abs.
            adCSell := self moneyFromAddedCropSelling.
            adCSell > mLack
              ifTrue:[ positive := true]
              ifFalse:[ mLack := mLack - adCSell].

"livestock selling"
positive ifFalse:[ sellSet := OrderedCollection new.
            livestockCanSell := self allLivestockCanISell.
            mLive := 0.
            nbCow := (self livestocks select:[:ls | ls typeOfLivestock = #cow]) size.
            nbBuffalo := (self livestocks select:[:ls | ls typeOfLivestock = #buffalo]) size.
            livestockCanSell size > 0
              ifTrue:[ nbBuffalo > nbCow
                    ifTrue:[ orederOfSell := #(#chicken #pig #buffalo #cow)]
                    ifFalse:[ orederOfSell := #(#chicken #pig #cow #buffalo )].
                        orederOfSell do:
                        [:od | liveSellColl := livestockCanSell select:[:liv | liv typeOfLivestock = od].
                        sortedLiveSellColl := liveSellColl asSortedCollection:[:x :y | x age < y age].
                        1 to: sortedLiveSellColl size do:
                        [:i | positive
                           ifFalse:[ (sortedLiveSellColl at: i) keepFlag isNil
                           ifTrue:[ (self contactLivestockTrader traderWillYouBuyMyLivestock: (sortedLiveSellColl at:
i))
                                  ifTrue:[ self sellThisLivestock: (sortedLiveSellColl at: i).
                                        sellSet add: (sortedLiveSellColl at: i).
                                        price := Parameter readCurrentLivestockPrice: (sortedLiveSellColl at: i)
typeOfLivestock at: (sortedLiveSellColl at: i) age.
                                        mLive := mLive + price.
                                        mLack := mLack - price.
                                        mLive > mLack
                                          ifTrue:[ positive := true]]
                                                   ]]]]].
            self livestocks removeAll: sellSet].

"hireling labour"
positive
ifFalse:[ wagePerDay := 100 * infWage.
        hour := (mLack/wagePerDay) asFloat.
        (self contactLabourMarket willYouHireMeAsHiredLabourFor: hour)
          ifTrue:[ self hhLabourDailyAV: self hhLabourDailyAV - hour.
                self cash: self cash + (hour * wagePerDay).
                CatchScapeFS hhiRecordRevenue: (Array with: #cashHirelingIncome with: (hour * wagePerDay)) forHH: self id.
"SM"
                self contactLabourMarket labourNeed: self contactLabourMarket labourNeed - hour.
                positive := true.]
          ifFalse:[ hh := self contactLabourMarket howManyHourOfHiredLabourINeed.
                hh > 0
                ifTrue:[ self hhLabourDailyAV: self hhLabourDailyAV - hh.
                      self cash: self cash + (hh * wagePerDay).
                      CatchScapeFS hhiRecordRevenue: (Array with: #cashHirelingIncome with: (hh * wagePerDay)) forHH: self
id. "SM"
                      self contactLabourMarket labourNeed: self contactLabourMarket labourNeed - hh.
                      mLack := mLack - (hh * wagePerDay)]]].

"borrow money"
positive
ifFalse:[ (self canIBorrowMoneyFor: mLack For: #hhConsume)
            ifFalse:[  self halt]]]
```

Description of the “Raising livestock decision activity” programming code

“raisingExtra”

```
| dailyMoneyNeed lab option cost nbCash nbLabour labNeed nbRaise flagRaise borrowedMoney |
lab := 0.
self numberOfMember = 2
        ifTrue:[ lab := (2 * 80)].
self numberOfMember = 3
        ifTrue:[ lab := (2 * 80) + (1 * 40) ].
self numberOfMember = 4
        ifTrue:[ lab := (2 * 80) + (2 * 40) ].
self numberOfMember > 4
        ifTrue:[ lab := (2 * 80) + (2 * 40) + ((self numberOfMember - 4) * 20)].
lab <= 0
     ifTrue:[ self halt].
borrowedMoney := 0.
self borrowMoneyInfo isEmpty
     ifTrue:[ borrowedMoney := 0]
     ifFalse:[ self borrowMoneyInfo do:[:info | borrowedMoney := borrowedMoney + (info at: 2)]].
dailyMoneyNeed := (self numberOfMember * 160 * 36) + borrowedMoney + self debt.
(self cash - dailyMoneyNeed) > 0
     ifTrue:[ (lab - self averageLabourThatINeedAtEachStepForCropAndLivestock) > 0
                  ifTrue:[ option := self strategy orderedLivestockToRaiseFor: self.
                              option isEmpty
                                  ifFalse:[ 1 to: option size do:
                                               [:i | flagRaise := false.
                                                    CatchScapeFS currentYear = 1
                                                         ifFalse:[ (self doIHaveThisLiveStockEnoughToKeepForRaiseFor: (option at: i))
                                                                     ifTrue:[ flagRaise := true]
                                                                     ifFalse:[ flagRaise := false].
                                                    flagRaise ifTrue:[ cost := (Parameter readLivstockCashAt: -10 with: (option at: i)).
                                                                   nbCash := (self cash - dailyMoneyNeed) // cost.
                                                                  nbCash > 0
                                                                       ifTrue:[ labNeed := (Parameter readLivstockLabourAt: (CatchScapeFS
currentDate) with: (option at: i)).
                                                                                nbLabour := (lab - self
averageLabourThatINeedAtEachStepForCropAndLivestock) // labNeed.
                                                                  nbLabour > 0
                                                                       ifTrue:[ nbRaise := nbLabour min: nbCash.
                                                                                self raisingLivestock: (option at: i) with: nbRaise]]]]]]]
```

Curriculum vitae

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Education

1997	B.Sc., Agricultural Economics, Kasetsart University, Thailand
2001	M.S., Agricultural Economics, Kasetsart University, Thailand
2004 – present	Ph.D. candidate of the University of Hohenheim, Germany as a scholarship holder of the German Academic Exchange Service (Deutscher Akademischer Austauschdienst: DAAD)

Occupational Experiences

2001 – present	A lecturer of the Department of Agricultural and Resource Economics, Faculty of Economics, Kasetsart University, Thailand

Research Experiences

Jul 1997 – Apr 2001	Research Assistant for Thai-Australia collaborative project entitled Integrated Water Resource Assessment and Management Framework: A Case Study of the Upper Chao Phraya Headwater, Northern Thailand
Dec 1998 – Jan 1999	Socio-Economic survey for Thai-Australia collaborative project entitled Integrated Water Resource and Management Framework Project, Northern Thailand
Jan – Feb 2000	Research Training at the Australian National University, Canberra, Australia for the Integrated Water Resource and Management Framework Project
Dec 2002 – Dec 2003	A researcher of the research project entitled A Financial Analysis of Persimmon Production in Thailand
Aug 2005 – Dec 2006	The researcher of the research project entitled Application of Multi-Agent Systems Simulation to Investigate the Sustainability of Farming Systems in Mountainous Area of Northern Thailand: A Case Study of Bor Krai Village, Pang Ma Pha District, Mae Hong Son Province

Teaching Experiences

2001 – 2005 Courses taught at Kasetsart University, Thailand;

Principles of Agricultural Marketing

Agricultural Product Price

Quantitative Analysis in Agricultural Economics I

Marketing and Pricing of Agricultural Inputs

Using Computer Program in Agricultural Economics Analysis

Bisher erschienene Forschungsberichte:

1/2006 **Gamer, Wilhelm, Jürgen Zeddies:** Bilanzen von potenziell umweltbelastenden Nährstoffen (N, P, K und S) der Landwirtschaft in Baden-Württemberg

2/2006 **Pohl, Tobias, Oliver Henniges:** Ausdehnungspotenzial des Zuckerrohranbaus in Zentral-Süd-Brasilien unter Berücksichtigung ökonomischer, ökologischer und sozialer Aspekte

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6/2006 **Zeddies, Jürgen:** Rohstoffverfügbarkeit für die Produktion von Biokraftstoffen in Deutschland und in der EU-25 (deut. Version)

The Availability of Raw Materials for the Production of Biofuels in Germany and in the EU-25 (engl. Version)

7/2006 **Zeddies, Jürgen, Ludwig Gekle:** Zur Weiterentwicklung der Beitragsbemessung in der Landwirtschaftlichen Berufsgenossenschaft Baden-Württemberg

8/2008 **Potchanasin, Chakrit:** Simulation of the Sustainability of Farming Systems in Northern Thailand