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Innovations And Sustainability Strategies In The Upland Agriculture Of Northern Vietnam: An Agent-Based Modeling Approach

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Vietnam, like most developing countries across Southeast Asia, has boosted farm outputs by introducing new crops, production methods and other agricultural innovations. Unfortunately, this process has increased soil erosion and water pollution and caused many other environmental problems. Now a new EEPSEA study has assessed this situation. It looks at the environmental trade offs that are involved in upgrading people's livelihoods through agricultural improvement. It also investigates how the negative impacts of such changes can be mitigated.

The study is the work of Dang Viet Quang from the University of Hohenheim, Germany. It provides details of how agricultural innovations have harmed the environment. It shows that a land tax policy could be used to reduce these environmental problems. Such a tax, however, will have a negative impact on farmers' livelihoods. Hence, this policy will be strongly resisted given that the North West Region has the highest poverty rate in Vietnam. The study therefore recommends that farmers should be helped to implement sustainable animal husbandry innovations so that their standard of living is not unduly affected.

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March, 2010

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INNOVATIONS AND SUSTAINABILITY STRATEGIES IN THE UPLAND AGRICULTURE OF NORTHERN VIETNAM: AN AGENT-BASED MODELING APPROACH

Dang Viet Quang

EXECUTIVE SUMMARY

The government of Vietnam, together with several international organizations, has disseminated various innovations in agriculture throughout the northern uplands of Vietnam, without taking into account soil erosion, which negatively affects the sustainability of both the natural environment and human livelihoods. Using Mathematical Programming-based Multi-Agent Systems (MP-MAS), an agent-based simulation model, this study assesses the impacts of the agricultural innovations on soil nutrients and soil erosion as well as on the income of local farm households. It develops a possible conservation policy and measures the trade-off between soil conservation and household income if the featured policy were to be implemented. The results show that growing maize and cassava cause a large quantity of long-term soil nutrient loss. A land tax policy can be applied to reduce the amount of soil loss. Nevertheless, it is recommended that agricultural innovations in animal husbandry should be identified and disseminated to compensate for the loss of household income when the government applies a strict soil conservation policy. Additionally, the determinants for propagation of agricultural innovations are identified by ordered logit regression model to provide the indicators of early adopters for extension workers so that they can perform the dissemination work more appropriately.

1.0 INTRODUCTION

1.1 Problem Statement

Rapid population growth in Vietnam has put pressure on the land and forest. Within 50 years (1943 – 1993), the forest area of Vietnam had decreased from 19 million ha to 9 million ha, an annual loss of 200 thousand ha on average (Nguyen Quoc Anh 2000). Land used for crops has been more intensively cultivated while fallow periods have shortened. As a result, the fertility of topsoil has significantly reduced (Truong Manh Tien 2003).

Environmental degradation can cause floods, lake siltation, desertification, droughts, and low crop yields. It is mostly people in mountainous areas that are experiencing the consequences of these changes because they predominantly rely on agriculture and have few alternative sources of income. In particular, the northern mountainous region of Vietnam, accounting for 30% of Vietnam's land area, is vulnerable. Its ten provinces have the highest poverty rate in the country, ranging from 55% to 78%, in spite of the significant economic development of the whole country (Minot and Baulch 2002).

At a national level the government of Vietnam, recognizing the problems of poverty and deforestation, has considered these issues as long-term priorities. In the Vietnam development goals (VDGs), the poverty rate is targeted to fall by 40% and forest cover to expand to 43% by 2010. A program of reforestation and a national strategy for poverty alleviation have been simultaneously implemented: The 5 Million Ha Forestation Program (661)[1] and the Comprehensive Poverty Reduction and Growth Strategy (CPRGS). The government expects these programs to increase forest cover and to reduce poverty to the target levels of the VDGs. However, in Vietnam, poverty positively correlates with forest cover, as poor people are often concentrated in large areas of forest (Sunderlin et al., 2006). The national target programs therefore have some conflict and overlap.

At a farm level, agricultural land has been allocated to individual farm households for settlement, and forest land has been given to them to ensure better management. Nevertheless, the ethnic minority peoples of the upland regions have traditionally relied on the forest to maintain their livelihoods. Their traditional farming methods rely on slashing and burning the forest for swidden agriculture. They cut timber for housing and collect non-timber forest products (NTFPs) for furniture, medicine, food, and clothing. Collecting NTFPs can generate 33% of cash income for forest dwellers living near a market (Quang and Anh 2006). In this sense, land allocation and community-based forest management is not cost-effective.

In an effort to protect the forest and reduce poverty the government of Vietnam, together with international organizations, has disseminated various agriculture innovations since the 1990s. The aim has been to enhance the livelihoods of ethnic minority people whilst reducing their dependence on the forest. Innovations promoted by

[1] The program is commonly knows as "program 661" because it implements Decision № 661/QĐ – TT issued by the Prime Minister.

the government were disseminated through the extension system, which has extension workers in every district. International organizations promoted their innovations through agricultural specialists, consultants, farm-level training and demonstrations.

As a result of population growth and new market opportunities, households of ethnic minorities have gradually settled in a permanent place, adopted innovations, and discontinued swidden agriculture. In 2003, a SFDP (The Social Forestry and Development Project) evaluation report in Yen Chau, Son La Province, showed that 97.9% of the households grew improved maize, 71.1% grew improved paddy rice, and 88.1% used fertilizers in upland fields. The households in Yen Chau are better-off because they have applied agricultural innovations, invested more into agricultural production and sold more products (Phuong and Foerster 2003). Nevertheless, intensive land use has created environmental problems as growing crops such as maize and cassava on sloping land has caused soil degradation due to erosion and the shortening of fallow periods (Young 1990). Therefore current practices do not seem to be sustainable.

The above issues have raised a large number of questions for policy-makers in Vietnam in terms of maintaining an equilibrium between the livelihoods of local people and ecological conservation (e.g. How large should the area of forest be? How large should the area of upland crops be in order to reduce soil erosion and to avoid floods during the monsoon? How much fertilizer should farmers use to compensate for lower soil fertility? Which activities should be introduced to generate income for farmers in order to lessen pressure on the forest? etc.). The equilibrium between livelihood and ecology conservation is determined by many factors: markets, agricultural innovations, soil nutrients, hydrology and social networks etc. An approach to analyze these interrelated questions should ideally integrate knowledge from different scientific disciplines.

A useful tool for combining knowledge from different disciplines is quantitative modeling using Mathematical Programming-based Multi-Agent Systems (MP-MAS), a modeling tool developed at the University of Hohenheim (Berger et al., 2007). This agent-based model can serve as a framework to integrate both socio-economic and bio-physical models to simulate sustainable resource use in agriculture and forestry (ibid.). Le (2005) developed a MAS model for one region in Vietnam, called the Vietnam-Land Use Dynamics Simulators. Le mainly focused on land use changes over time but did not include the fluctuation of market prices, the diffusion of innovations, changes in soil nutrients, and the availability of water. Previous studies using MP-MAS have integrated economic models simulating decision-making with biophysical models simulating hydrology (Berger 2001) and soil nutrients (Schreinemachers et al., 2007). Such integrated models can be used as a tool for researchers to inform policy-makers about the possible impacts of agricultural policies and the diffusion of innovations, as well as to quantify trade-offs between different development goals.

1.2 Research Objectives

1.2.1 General objective

The overall objective of this study is to explore how innovations can contribute to both sustainable agriculture and the economic wellbeing of farm households in the upland regions of Vietnam.

1.2.2 Specific objectives

To identify the determinants of innovation diffusion in upland agriculture of northern Vietnam through analyzing the diffusion paths of previously introduced innovations.

To develop and calibrate an integrated land use model for upland agriculture based on MP-MAS and to ex-ante evaluate innovations developed within The Uplands Program.

To explore the impacts of the diffusion of various agricultural innovations on environmental quality (sustainability) and the economic wellbeing of farm households.

To identify what policy measures would be needed to ensure that these agricultural innovations contribute to sustainability and wellbeing.

2.0 RESEARCH METHODOLOGY

2.1 Research Questions

- What agricultural innovations are in the pipeline or have recently been promoted in Yen Chau District?
- What factors affect the diffusion of agricultural innovations among farm households in Yen Chau District?
- What are the environmental and social impacts of these innovations as they are perceived by both farmers and researchers?
- What is the trade-off between sustainability and economic welfare?
- How are alternative scenarios explored by MAS relevant to agricultural policies at district level?

2.2 Variables and Factors to be Measured

2.2.1 Research question 1

Information about past and future innovations was gathered through group interviews in each study village prior to an individual-based questionnaire survey. Among the identified innovations, the major ones were selected for data analysis.

2.2.2 Research question 2

Ordered logistic regression was used to identify factors that were important in the innovation diffusion process. This statistical model regresses the adoption decision on a set of explanatory variables.

Explanatory variables are personality characteristics (attitudes), socio-economic characteristics (education, available labor, dependency ratio, farm resources, access to credit, etc.), perceptions about innovations, and social capital (social networks, relationship with village headman, neighbors, extension workers etc.).

Based on the explanatory variables that were shown to be significant, and based on similarities in innovation attributes, the diffusion of other innovations that have not yet been introduced can be simulated *ex-ante*. For this, we used an agent-based model; in which each agent represents a real-world farm household. One advantage of agent-based modeling is the capture of agent-interaction in the communication of innovations, which gives a realistic representation of real-world diffusion processes.

2.2.3 Research question 3

In terms of farmers' perspectives, questionnaires were used to ask the farmers how the adopted agricultural innovations impacted on soil fertility and their wellbeing. These qualitative criteria were quantified into five grades: very bad, bad, no affect, good and very good, corresponding to -2, -1, 0, +1 and +2 respectively. These grades represented negative and positive impacts of the adopted innovations.

To assess the potential impact of innovations on the wellbeing of farm households as well as the sustainability of the ecosystem, a Multi-Agent Systems (MAS) model[2] was used. MAS models of land-use/cover change (MAS/LUCC) couple a cellular component that represents a landscape with an agent-based component that represents human decision-making (Parker et al., 2003). MAS/LUCC models have been applied in a wide range of settings (for overviews see Janssen 2002, Parker et al., 2003) yet have in common that agents are autonomous decision-makers who interact and communicate and make decisions that can alter the environment.

MAS/LUCC applications have been based on various software platforms; the most popular ones being Cormas, NetLogo, RePast, and Swarm (Railsback et al., 2006). The present study uses a platform called MP-MAS, which stands for Mathematical Programming-based Multi-Agent Systems (MP-MAS) and is a freeware software application developed at the University of Hohenheim (Schreinemachers 2006; Berger et al., 2007).

Generally, the concept of the model can be depicted as shown in Figure 1, in which input data are entered into an optimization module, separately for each agent, which simulates decision-making.

[2] The concepts of Agent-Based Modeling (ABM) and Multi-Agent Systems (MAS) are used interchangeably.

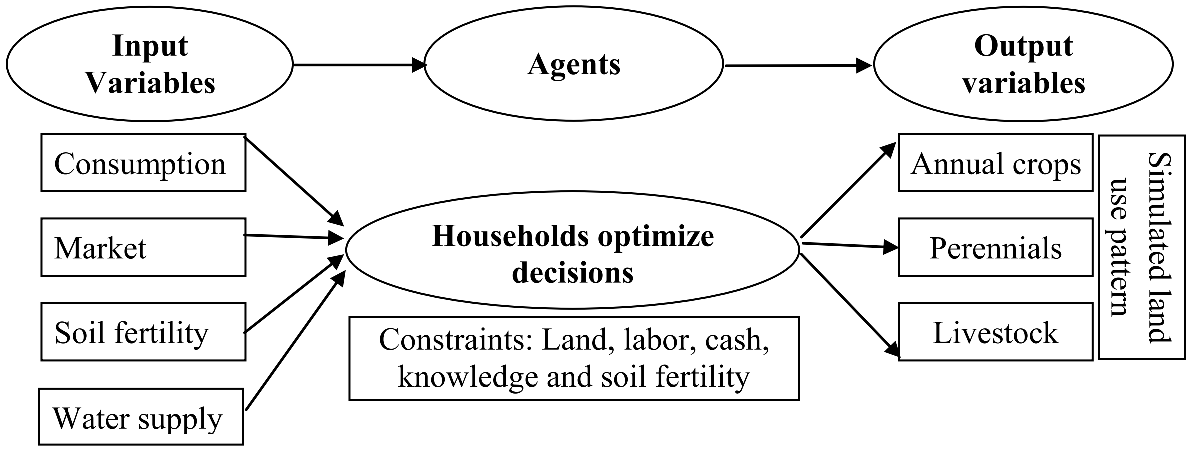


Figure 1. Conceptual frame

In an agent-based model, each farm household is considered as a separate computational agent. Based on its resource constraints in a given period, its knowledge about innovations, perceptions about crop and livestock yields, and perceptions about output prices each agent decides independently what crops to grow, how much inputs to apply, how much to sell and how much to consume. Agents react to the dynamics of markets, changes in the fertility of their soil, communication networks, and consumption needs. Figure 2 depicts the structure of the MP-MAS.

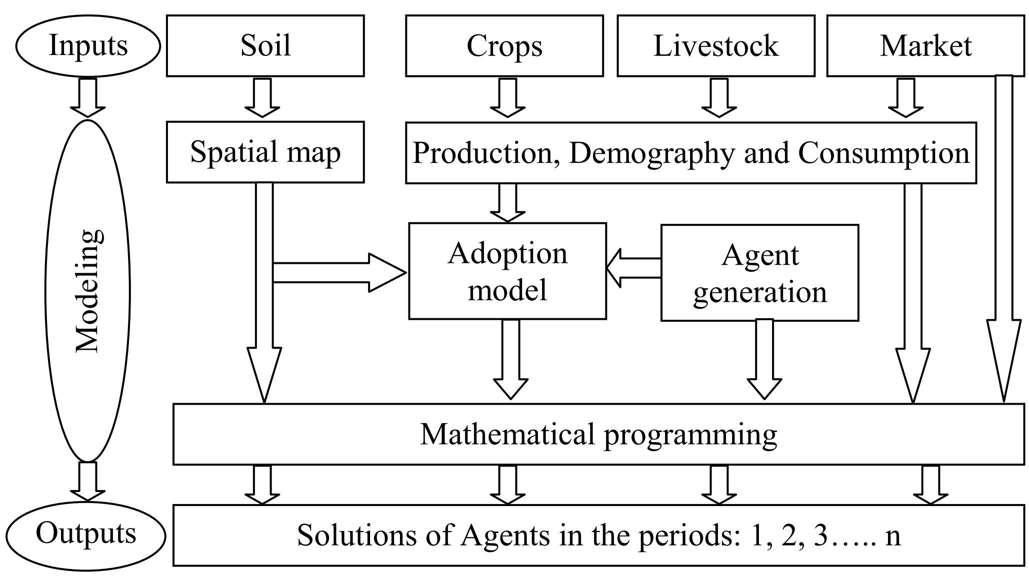


Figure 2. The structure of MP-MAS

The use of whole farm programming has the advantage that it facilitates a straightforward integration with biophysical models (Schreinemachers and Berger 2006), which is a feature previously exploited by so-called 'bio-economic models' (Janssen and van Ittersum 2007). The MP-MAS developed for this study is integrated with Tropical Soil Productivity Calculator (TSPC). TSPC is a soil nutrient model based on balance equations between nutrient additions (from fertilizers, decomposition of organic matter, deposition) and nutrient removal (from harvesting, erosion, leaching) (Schreinemachers 2006).

This integrated model allowed us to quantify the environmental impact of innovation diffusion in terms of soil nutrients (N, P, K). Since several innovations are based on the increased use of agrochemicals, mostly mineral fertilizers and pesticides, we additionally assessed the environmental impact in terms of quantities of agrochemicals used (in kilograms). Table 1 summarizes the main output indicators of the model.

Table 1. Main output indicators of the simulation model

Economic indicators	**Environmental indicators**
Per capita incomes (VND/MAE)	Available soil nutrients (kg/ha)
	Soil erosion (kg soil/ha)
	Nutrient balance (kg/ha)

Note: MAE =Male Adult Equivalent

In MP-MAS the economic component that simulates the land-use decisions uses whole farm mathematical programming. The economic component is calibrated using statistical analysis of farm household survey data while the bio-physical model is calibrated using the yield response function estimated from experimental data. The following eight sections describe the main components of the economic and bio-physical models in detail.

MP-model

A linear programming (LP) model is at the core of the multi-agent system used in this study. It is used as a tool for agents to make their decisions. With the given resource constraints, the agents optimize their benefit, make decisions for different activities and develop the production plans for one period.

In an integrated model as MP-MAS, LP plays an important role because it integrates other models, such as bio-physical models, cost-benefit analysis of perennial crops, and raising animals etc. with the decision making process of agents.

Generally, the linear program can be described as:

$$\sum_{i=1}^{n} b_{ij} x_i \leq y_j \qquad \text{(Equation 1)}$$

$$\text{Maximize function } f(X) = \sum_{i=1}^{n} p_i x_i \qquad \text{(Equation 2)}$$

where i is the variable number, j is the equation number, x_i is the i variable, y_j is the constraint of the j equation, b_{ij} is the coefficient of the i activity in the j equation, p_i is the price of the i activity. With given b_{ij}, y_j and p_i, maximizing function $f(X)$, the x_i will be identified. In the case of Chieng Khoi, i are the integer numbers from 1 to 940 while j are the integer numbers from 1 to 334. The structure of the linear programming model is described in Table 2.

The LP described in Table 2 was developed to capture a mixed farming system comprising of annual crops, perennials, livestock, pigs and poultry. It integrates the farming system with other on-farm and off-farm activities such buying inputs, selling products, hiring in labor and hiring out labor. Additionally, credits, savings, investment decisions, consumption, expenditure and seasonal labor allocations are endogenously included into the linear programming model.

Using linear programming, MP-MAS integrates other models through technical coefficients, market prices in objective function and resource endowment. The bio-physical model is integrated with LP through the yield and biomass estimated from the TSPC model. The market component is linked with LP through prices in the objective function. The cost benefit analysis of perennial crops and cattle are related to LP through productivity, labor needed, initial costs, and future expectations.

Currently, the prices in the market component are set as constants over periods of time. The prices and other technical coefficients were obtained from the 2008 household survey. The market prices and technical coefficients are described in the following sections.

Table 2. Structure of LP developed for Chieng Khoi sub-catchment

MAX $f(X)=\sum_{i=1}^{940} p_i x_i$	Activities	Sell farm output	in/out	Buy inputs/pay the environmental tax	Take a short-term credit	Adopt technologies	Raise animals	Grow seasonal crops	Land for perennial crops and grassland	Labor for perennial crops and animals	Feed stock	Manure	Land transfers	Sell farm output in future years	Other transfer activities	Sign	Right-hand side
Constraints	n / m	12	24	25	2	14	75	1103	5	4	48	2	48	5	7		
Price vector		+p	±p	-p	±p									+p			Max
Investments	48							+1								≤	Y
Cash	1				+1											≤	Y
Labor	1														+1	=	Y
Land	48								+1				+1			≤	Y
Irrigation	12							+b								≤	Y
Animals	36						+1									≤	Y
Perennials	21								+1							≤	Y
Access to technology	15			1	1	-1		1	1							≤	0
Capital used	3				-1		+b									≤	0
Input used	11			-1			+b	+b								≤	0
Labor used	3						+b		+1	-1						=	0
Animal feed	1						+b				-1					≤	0
Land used	3						+b		-1							=	0
Balances	132	+1	±1	-1			-b	±b	+1	+1	+1	+1	-1	+1	-b	=	0
Income balance	1	+p	±p	-p	±p										-1	≤	0
Soil nutrient balance	144							+b					-b			≤	0
Soil erosion	49			-1				+b					-b			≤	0

Note: "+" is positive value, "-" is negative value and "±" means the value can be either negative or positive. "b" is technical coefficient.

Market price

Current price levels for agricultural outputs, inputs, and purchased food products are actually calculated from survey data. The average prices of outputs and inputs are applied in the market component. All prices are average value estimated from survey data (Table 3).

Table 3. Prices used in market components

Unit: Thousand VND/kg

Products	Prices	Inputs	Prices
Maize (seed)	2.050	Improved maize seed	24.00
Cassava (dried)	1.365	Sticky rice seed	7.50
Rice (un-husked)	3.813	Hybrid rice	22.00
Mango	4.186	NPK composed	2.30
Goat	16.536	Urea	5.60
Goat offspring	22.057	Potassium	5.10
Cow	20.441	Fodder for poultry	4.40
Calf	34.681	Fodder for pigs	5.85

Source: survey data 2008

In addition to Table 3, the price of labor used in the model is 30 thousand VND/labor day and the interest rate of short-term credit is applied at 2%. This rate is still used as the default of the MP-MAS model.

Technical coefficients

Generally, the technical coefficients used in the LP matrix can be categorized into labor, seed, fertilizers and productivity. The productivity of crops is estimated using the crop growth model (TSPC) over the years. Cattle and perennial crops have been estimated with livestock and perennial components. The data described in Tables 4 and 5 are used for annual crops only. In the model, the fertilizer used for each crop is segmented into three levels (Table 4). Hence, on each plot of land, the agents can decide to grow crops with either no, low or high input, depending on their endowment resources: labor and capital. Table 5 shows the seasonal labor for each crop. According to the farmers, they normally put down fertilizer with soil preparation or weeding. This infers that the quantity of chemical fertilizers does not affect the total labor used in each cropping activity. This was also checked by regression model. There was no significant correlation between the number of labor days and the total amount of chemical fertilizers used for each crop. Hence, it was assumed that for each crop the labor used at the three different input levels was the same when applying the LP matrix (Table 5).

Table 4. Fertilizers and seeds used for annual crops

Unit: kg/ha

Crops/fertilizers	**NPK (5-10-3)**	**Urea**	**Potassium**	**Manure**	**Seed quantity**
Rice 1 season no input	0.00	0.00	0.00	2115.67	70
Rice 1 season low input	339.00	137.50	48.00	3173.50	70
Rice 1 season high input	678.00	275.00	96.00	6347.00	70
Rice 2 season no input	0.00	0.00	0.00	4336.33	140
Rice 2 season low input	678.00	275.00	96.00	6347.00	140
Rice 2 season high input	1418.00	558.00	190.00	13009.00	140
Maize no input	0	0	0	0	0
Maize low input	248.00	59.33	8.00	248.00	20
Maize high input	496.00	118.67	16.00	496.00	20
Cassava no input	0	0	0	0	0
Cassava low input	130.00	12.00	0.67	0.00	0
Cassava high input	260.00	24.00	1.33	0.00	0
Intercropping no input	0	0	0	0	12
Intercropping low input	161.93	32.20	5.60	0.00	12
Intercropping high input	323.87	64.40	11.20	0.00	12

Source: 2008 survey data

Table 5. Labor used for annual crops

Unit: man-day/ha

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rice 1 season	0	0	0	0	0	89	82	56	56	112	0	0	395
Rice 2 season	94	84	60	60	124	89	82	56	56	112	0	0	818
Maize	0	23	23	22	24	0	24	0	91	0	0	0	207
Cassava	62	26	26	19	20	0	20	20	0	0	62	62	318
Intercropping	35	26	26	23	16	0	16	16	18	0	35	35	247

Source: 2008 survey data

Innovation diffusion model

The analysis of innovation diffusion in this research is based on the theory of innovation diffusion, developed by Rogers (1995). Rogers categorized adopters into five groups: innovators, early adopters, early majority, late majority and laggards. The diffusion of an innovation through a population roughly follows an S-shaped curve (Rogers, 1995). This S-curve of innovation diffusion can be explained by the rate and the speed of innovation diffusion (Batz et al., 1999). Batz et al., (2003) used these speed and rate indicators to predict technology adoption in dairy farms in Kenya. For MP-MAS in Vietnam, it currently uses the probability of five groups as in default model, which respectively are 0-0.025, 0.025-0.16, 0.16-0.5, 0.5-0.84 and 0.84-100.

Agent initialization and resource constraints

In MP-MAS, agents are randomly initialized based on Monte Carlo techniques (Berger et al., 2007) in which a small number of randomly selected sample households can be used to generate a whole population. In order to artificially generate agents using this methodology, the sampled households are categorized into clusters that are subgroups of the population characterized by land area (Figure 3). Each cluster represents the upper bound and the upper value of different resource endowments (Berger and Schreinemachers, 2006). Similarly, in ArgGIS, a spatial randomizer is also used to distribute the location of non-surveyed households as well as their plots of land (Schreinemachers, 2006). When applied MP-MAS, the agents are randomly selected from each cluster corresponding to the location of households and their land on the spatial map.

The land area as well as other resources (e.g. labor and capital) would be various among the farm households. However, within a farm, the agricultural resources are bounded by so-called “resource constraints”. In this research, the constraints on farmers (e.g. land, labor, capital) are identified and used to construct a mathematical programming model to simulate the adoption and land use decisions of each household over time. The resource constraints of each cluster are described in Appendix 2.

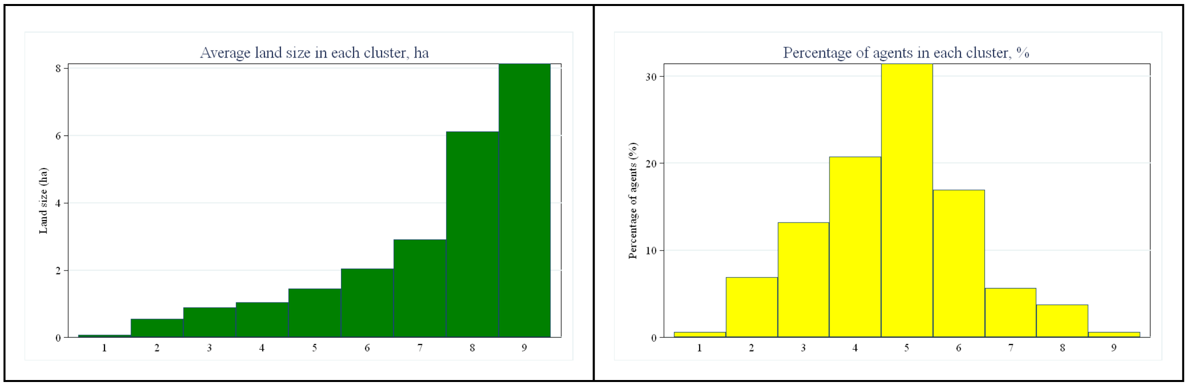


Figure 3. Clustering the agents

On-farm and off-farm activities

Farmers select production activities based on their opportunity costs. For example, if farmers can get more money from off-farm activities they will leave on-farm activities to do off-farm activities. This behavior is captured in the MP-MAS model using an estimate of the opportunity costs of farm work. As estimated from the household survey, when farmers hire out their labor the most popular wage rate is 30 thousand VND per day per person.

Demography, household consumption and market prices

The MP-MAS model simulates the decisions of farm households based on the dynamics of markets, soil nutrients and demography over time. However, currently the input and output prices collected by the survey conducted in 2008 are being used as constant over the time. Another factor that changes over the years is the age of the farm household members, which is based on secondary data on age and sex-specific fertility and mortality rates. After each year, the age of each household member is updated. The labor supply is adjusted accordingly.

In Vietnam, especially in remote areas, people mainly rely on their own food production. They initially produce what they need for their consumption. Food security, therefore, depends on the dynamics of agricultural production while the market in that place is often imperfect. Communication between buyers and sellers is often asymmetric. A three-stage consumption model comprising models for savings, total expenditure and food expenditure was proposed to be calibrated from the survey data (Schreinemachers and Berger 2006). However this was not done for this research. The basic consumption model used in the research was applied with 50% of self-sufficiency and minimum consumption per head was 400 thousand VND per year (survey data 2008).

Soil nutrients and spatial data

Regarding soil nutrients, the modeling has been done with regard to soil type and topography. The nutrients of each soil type and the yield of crops were identified in collaboration with other scientists working on the same program. More specifically, the Tropical Soil Productivity Calculator (TSPC) was used to calculate the yield for MP-MAS. In TSPC, the yields of crops are estimated based on the soil nutrient maps (N, P, K, slope length and soil erodibility) and the yield respond functions of different crops (Schreinemachers, 2006) (Appendix 1).

2.2.4 Research question 4

One objective of the Doi Moi Reform in Vietnam was the modernization of agriculture through the adoption of innovations (together with structural reforms), such as the adoption of hybrid varieties of maize and rice. Although this strategy has generally benefited farm households in the mountainous areas, it is presently unclear if this development is sustainable. Large areas of upland fields, previously used to grow maize and cassava, have been degraded to such an extent that virtually no topsoil remains and the natural recovery of the soil's fertility is precluded. Therefore, the successful diffusion of some innovations, although having short-term benefits, has compromised the long-term sustainability of the system and the long-term wellbeing of the farming population.

These changes in soil fertility and their feedback effect on the economic system are difficult to quantify directly as they are long-term processes (e.g. hybrid maize was introduced in the late 1980s). Simulation modeling might therefore offer a shortcut to real-world observation over an extended period of time, as changes can be analyzed in a virtual environment over many years, both into the past and into the future.

Trade-offs between the reduction of soil erosion, defined as a criteria for sustainability, and economic welfare can be analyzed using scenario runs. First, a baseline scenario is set up that best reflects the current situation and current drivers of change. Then alternative scenarios are set up that alter the basic assumption. For example assuming that in order to conserve the soil the government imposes a soil conservation policy by collecting a tax in the area with high erosion. The alternative scenario is then compared to the baseline scenario using quantity of soil loss to represent sustainability and income per capita to represent economic welfare. The relationship between reduction of soil loss and income per capita can be graphed to depict the trade-offs between sustainability and economic welfare of farm households.

2.2.5 Research question 5

The possibility of scenario testing not only allows the opportunity to quantify trade-offs between economic and environmental goals, it also allows exploration of alternative forms of policy intervention that could remedy the adverse consequences of some developments. This could include a possible subsidy for mineral fertilizers, or improved access to credit to stimulate fertilizer use in the uplands. Or this could include the promotion of soil conservation techniques that could make farming on steep slopes more sustainable. Again, using scenario runs the potential benefits and costs in terms of environment and wellbeing can be assessed, which has great relevance to policymaking.

The simulation model can hence be used as a virtual laboratory to explore alternative policy interventions. An additional advantage of agent-based modeling is the possibility of not only assessing the average effect of a policy change, but also the distributional effects of a such change. This allows the researcher to explore questions such as: If credit was available at lower interest rates, which agents would benefit? Will the poor benefit as well? Will inequality increase or decrease as compared to no policy change? If the poor do not benefit then what additional measures would be required to reach the poor?

2.3 Study Site and Data Collection

2.3.1 Study site

The Northwest of Vietnam has a high share of ethnic minority people who are engaged in farming but are relatively disadvantaged in terms of access to markets, government institutions, and infrastructure. The Northwest of Vietnam also has the highest poverty rate in Vietnam. Agricultural research in Vietnam has traditionally focused on the highly productive lowland agriculture that meets the demands of most of the food supply and agricultural export. Mountainous areas are relatively under-researched, which is the reason why the University of Hohenheim and several Vietnamese universities selected this area for their research in the year 2000.

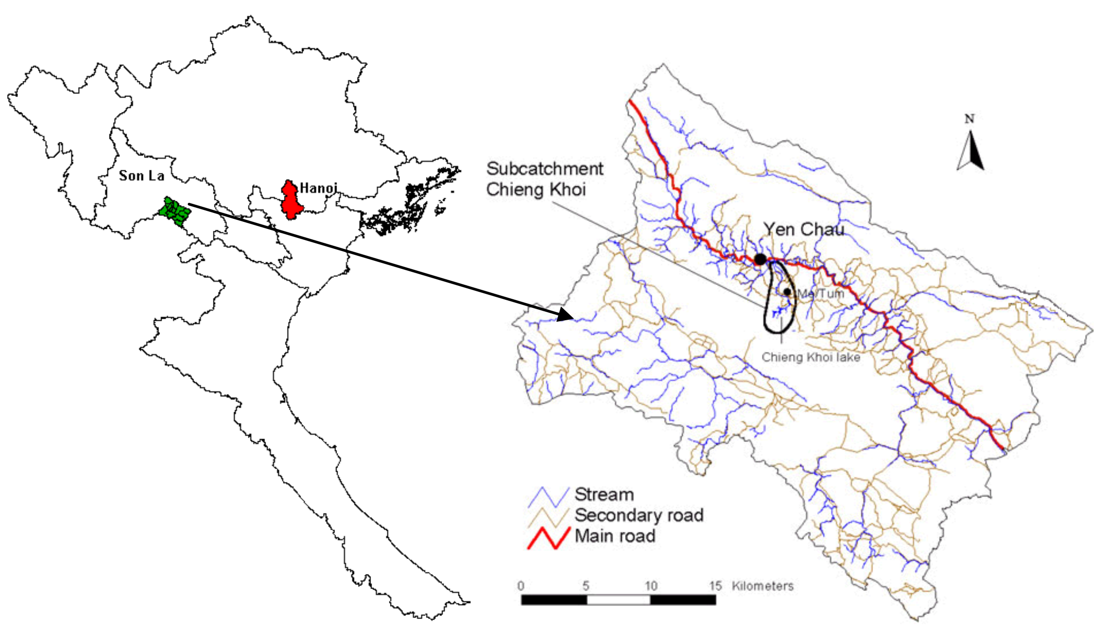


Figure 4. The selected study sub-catchment

This collaboration between the University of Hohenheim and several Vietnamese universities has focused on the Yen Chau District of Son La Province, which is an area that can be considered representative of the larger Northwest region. Long-term relationships between government institutions and researchers are important in Vietnam because research activities are under relatively strict scrutiny by the government. A further reason for selecting the Yen Chau District is that much research has already been conducted in this area and previous data can be used for the present research (see http://www.uni-hohenheim.de/sfb564_db/index.html for a project database).

Table 6. The selected sub-catchments in Yen Chau District

Feature	Description
Distance to the district's center	2-3 km
Road quality	Earth road
Elevation	300-800m
Ethnicity	Black Thai

Source: Field reports and *Atlas of Vietnam*, Cartographic Publishing House of Vietnam

Within Yen Chau District the study was carried out in one sub-catchment, depicted in Figure 4. The selected sub-catchment is located in the Chieng Khoi commune and is mostly populated by Black Thai people. The watershed in Chieng Khoi comprises of a system of streams and one lake at ~300-800 masl (Table 6). The selected sub-catchment in Chieng Khoi includes five villages and 471 households (Table 7).

Table 7. Village profile of selected sub-catchments

Villages	Households (no)	Population (person)	Ethnicity
Ban Put	100	456	Black Thai
Ban Me	113	516	Black Thai
Ban Tum	121	582	Black Thai
Ban Ngoang	69	317	Black Thai
Ban Dong	68	330	Black Thai
Total	**471**	**2201**	

Source: 2008 survey data

2.3.2 Data collection

Data were collected using both semi-structured interviews (SSI) and structured interviews (SI). The SSIs were conducted in the form of group discussions using a checklist. The location of each household was identified using GPS points which were gathered before the start of each individual interview.

The SIs were conducted with individual households using questionnaires. The sample households were selected at random from a list of households collected from each village headman. In each village, about 34% of the households were selected for an interview. In total, 159 households were interviewed (Table 8).

Table 8. Number of households selected at random

Nº	Villages	**Total households** (number)	**Surveyed households** (number)	**Surveyed households** (%)
1	Ban Put	100	38	38
2	Ban Me	113	42	37
3	Ban Tum	121	38	31
4	Ban Ngoang	69	21	30
5	Ban Dong	68	20	29
	Total	471	159	34

Source: 2008 survey data

3.0 THE PAST AND POSSIBLE FUTURE INNOVATIONS

On the one hand, the adoption of innovations in agriculture often help farmers to increase their profits. On the other hand, farm households only adopt agricultural innovations when they receive full information on the innovation and have no constraints to apply (Schreinemachers et al., 2006).

Studies on agricultural innovations are not new. Since the middle of the last century many studies have been conducted on the adoption of modern rice varieties (Herdt and Capule, 1983). Evaluation reports of development projects also mention the adoption of new varieties (Phuong et al., 2003). In this study 15 agricultural innovations that were adopted in the past and four innovations which will possibly be adopted in the future were identified (see Table 9).

However, not all of the agricultural innovations were fully adopted and used by the farm households because the adoption process not only depends on profit but also on an explanation of the attributes of the innovations (e.g. advantage, compatibility, complexity, trial ability, and observability) (Roger 1995). In Chieng Khoi sub-catchment some of the innovations listed in Table 9 were disseminated to local farmers by the government but were poorly adopted, such as apricots, cotton, mulberry and silkworms. Meanwhile hybrid or improved maize, cassava and rice were adopted at a high rate by users. Pineapple, longan and litchi were used by less than 50% of farm households (Figure 5). In addition, maize, cassava and rice are the main pattern in the cropping system of Chieng Khoi (Table 10). The innovations related to maize, rice and cassava will be taken account into the impact assessment.

As depicted in Figure 5, improved pigs were expected to be adopted at a high rate in order to improve the wellbeing of farm households by reducing the dependence on land. However, the adoption of this innovation is still low because farmers do not yet know how to raise this pig. The qualitative data in the 2008 survey showed that the mortality rate of the pig was still high while farmers tried to raise improved pigs. It is, therefore, expected to be more successful in the future.

Table 9. Agricultural innovations in Chieng Khoi

Innovations in the past 15 years	**Possible innovations in the future**
- Hybrid maize	- Improved pigs
- Improved cassava	- Applying new practices for mango trees
- Improved sticky rice	- New management methods for fish ponds
- Hybrid ordinary rice	- Rubber
- Chemical fertilizers on sloping land	
- Pineapples	
- Longans	
- Litchi	
- Apricots	
- Cotton	
- Mulberry and silkworms	
- Growing grass for livestock	
- Improved pigs	
- Goats	
- Improved fish	

Source: 2008 survey data

In the Chieng Khoi sub-catchment the communal government has a policy of eliminating the raising of goats because goats often destroy other cropping activities if the owners are not careful. Raising goats is also considered as an innovation in the impact assessment.

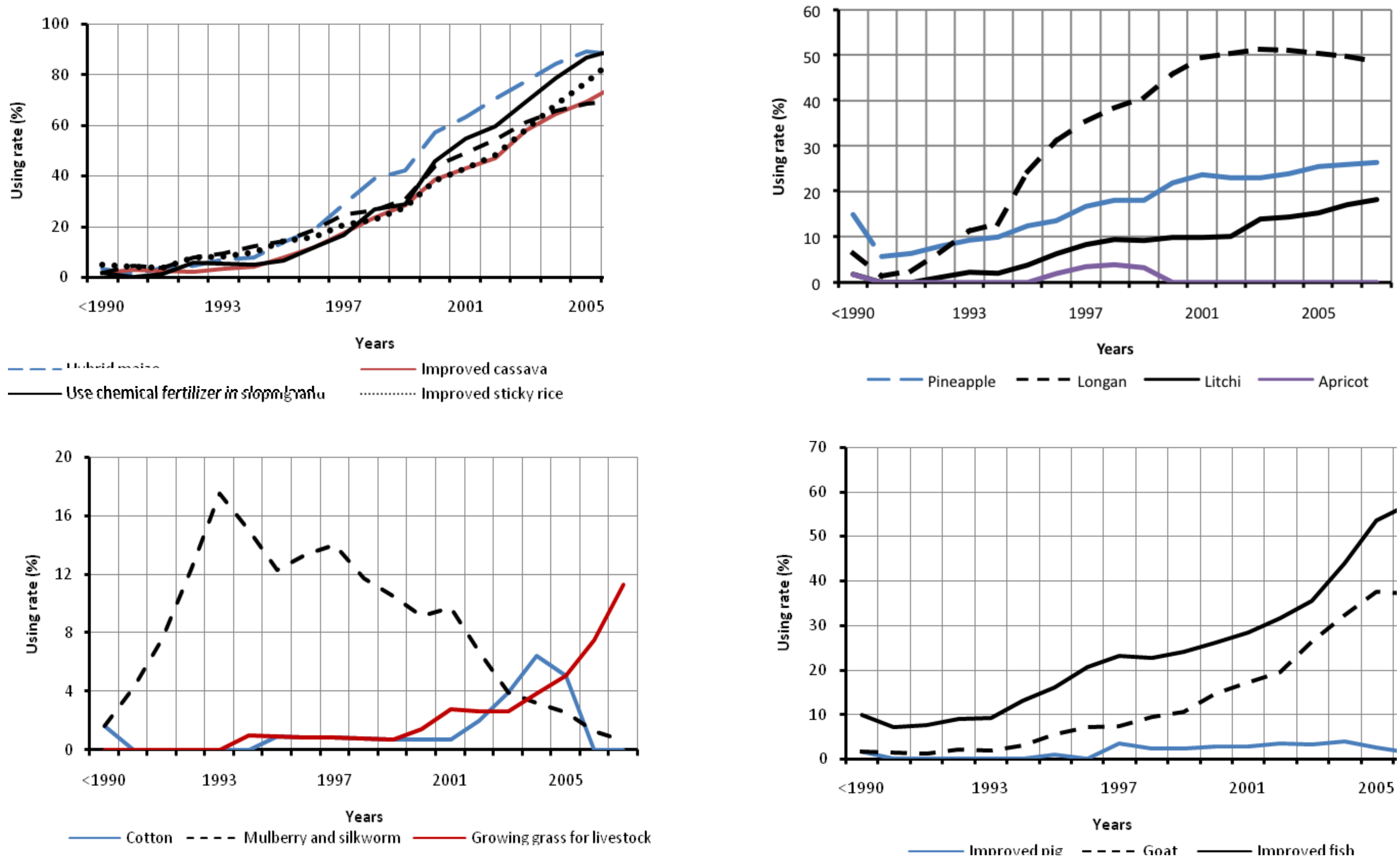


Figure 5. Adoption of agricultural innovations

Source: 2008 survey data

Generally, the innovations which will be taken into account for the impact assessment are improved maize, improved cassava, chemical fertilizers, goats and improved pigs.

Regarding the possible future innovations, the improved pigs, new practices for growing mango trees and new management methods for fish ponds are currently studied by the Uplands Program[3]. For rubber, the provincial authority of Son La is presently planning to plant rubber trees on sloping lands. However, nobody knows whether these innovations will be adopted by local farmers or not.

Table 10. Agricultural land use by crop

Village		Crop area (ha)	By type of crop (ha)					
			Paddy rice	**Maize**	**Cass.**	**Maize - cassava intercrop**	**Veg.**	**Rented out/ fallow**
Chieng Khoi		**467**	**73.66**	**124.38**	**92.49**	**171.32**	**0.84**	**4.04**
1	Ban Put	103	13.59	15.23	17.60	56.34	0.00	0.00
2	Ban Me	103	17.16	27.22	25.56	30.82	0.61	1.94
3	Ban Tum	125	21.85	43.88	36.89	21.89	0.15	0.29
4	Ban Ngoang	77	11.48	32.79	5.55	24.94	0.00	2.00
5	Ban Dong	60	10.80	9.10	3.56	36.92	0.00	0.00

Source: 2008 survey data

4.0 DETERMINANTS OF INNOVATION ADOPTION

In order to identify the factors related to the adoption of the major agricultural innovations mentioned in the previous section, an ordered logistic regression was applied in which the dependent variable is the year of adoption and explanatory variables include: household characteristics, resource endowments and communications (Table 12). These 29 independent variables were selected from a correlation matrix of an initial list of variables. Variables with high correlation coefficients were excluded because of multicollinearity. Regarding the dependent variable, the non-adopters were categorized into a zero group.

As depicted in Figure 5, hybrid maize, improved cassava, sticky rice, ordinary hybrid rice and chemical fertilizers on sloping land were adopted 15 years ago by a few farm households. Currently, adoption reaches to more than three-fourths of the households (Table 11). To analyze the probability of early versus late adoption, an ordered logistic regression was applied without the non-adopter in zero categories.

[3] For more information about these innovations, refer to the following website: https://www.uni-hohenheim.de/sfb564/

For improved pigs and raising goats, as the number of adopters are not large enough to run this model, the ordered logistic regression was applied for the whole samples. The results of the ordered logistic regression of innovation adoption are presented in Table 13.

Table 11. Adoption rate of selected innovations

No	Village	Improved sticky rice	Hybrid rice	Hybrid maize	Improved cassava	Chemical fertilizers	Raising goats	Improved pigs
1	Ban Put	97	76	95	87	95	29	13
2	Ban Me	90	88	95	88	95	57	14
3	Ban Tum	97	87	97	95	97	63	13
4	Ban Ngoang	86	52	90	67	90	57	0
5	Ban Dong	100	65	100	65	95	55	10
	Total	**94**	**77**	**96**	**84**	**95**	**52**	**11**

Source: 2008 survey data

Table 12. Explanatory variables

Variables	Description
Household characteristics	
Gender of household head	Dummy variable with 1 representing male
Age of household head	This variable represents the experience of the household
Party membership of household head	Dummy variable with 1 representing party membership of the household head
Dependency ratio	Number of people younger than 16 and older than 60 divided by the number of active laborers
All adult education	Total education level of all household members older than 16
Occupation of head (farming)	Dummy variable with 1 representing farming
Occupation of head (official)	Dummy variable with 1 representing official
Resource endowments	
Current available cash	The available cash which farmer earns in 2007 in million VND
Credit from bank	Dummy variable with 1 representing credit from bank

Variables	Description
Credit from trader	Dummy variable with 1 representing credit from trader
Credit from friend	Dummy variable with 1 representing credit from friend
Credit from neighbor	Dummy variable with 1 representing credit from neighbor
Credit from relatives	Dummy variable with 1 representing credit from relative
Paddy area	Total area of paddy in ha
Upland area	Total area of sloping land in ha
Communications	
Agricultural training course	Frequency of participation (time/year)
Extension worker	Frequency of appointment (time/year)
Television – vtv2	Frequency of watching VTV2 (time/month)
Talking with neighbor	Frequency of talking to neighbor (time/month)
Agricultural shop	Frequency of access to agricultural shop (time/year)
Staff from companies	Frequency of talking with staff from company (time/year)
Talking with outsider	Frequency of talking with outsider (time/year)
Commune center	Frequency of access to commune center (time/year)
District center	Frequency of access to district center (time/year)
Agricultural official	Frequency of appointment (time/year)
Village headman	Frequency of meetings with village headman (time/year)
Network 1	Dummy variable with 1 for the households that consider headman to be the most important
Network 2	Dummy variable with 1 for the households that consider their neighbors to be the most important
Network 3	Dummy variable with 1 for the households that consider extension workers to be the most important

4.1 Improved Sticky Rice

For many years, sticky rice has been the staple food of the people of Thai origin in this study area. To sustain food security in the area, an improved sticky rice variety (N87) has been disseminated. Many households have adopted N87 and the adoption rate reaches almost 94% (Table 11). As described in Table 13, the determinants of improved sticky rice adoption are informal credit from traders, communication with neighbors, outsiders, agricultural shops and the district center, and the current cash income of farm households. Regarding informal credit, the log odds of adoption are negatively correlated with *credit from trader*. This means that the households who can get credit from traders adopted the improved sticky rice in the past, or in other words, they adopted the improved rice before the households who could not access this financial source. A similar assessment can be generated for communication channels. The households who more often *talk with neighbors*, more often access *agricultural shops* or more often access the *district center* were likely to adopt improved sticky rice in the earlier years while the others adopted in the latter years. The households who can earn more cash at present actually adopted improved sticky rice earlier than others. Only the households who more often had *contact with outsiders* adopted the improved rice in the latter years. Generally communication with traders, neighbors and the agricultural shop significantly affects a household's adoption of improved sticky rice.

4.2 Hybrid Rice

Unlike sticky rice, ordinary rice is not a staple food of ethnic Thai people even though it has a higher productivity. The local people have adopted ordinary hybrid rice and have grown it on a small area of paddy for food used occasionally because they consider ordinary rice to be food for visitors, who are not familiar with sticky rice. The adoption rate of hybrid rice was only 77% and it was disseminated more than 15 years ago. As described in Table 13, the log odds of hybrid rice adoption are significantly negatively correlated with *head occupation* of farming, *credit from neighbor*, *paddy area* and *agricultural official*. In general, households with a head doing farm work were more likely to adopt hybrid rice earlier than others. For a household with a head doing other work the odds of adoption in recent years versus adoption in the previous year was 0.117 times smaller.

Regarding credit, households who can obtain credit from their neighbors tend to adopt hybrid rice before others. The same conclusion applies to the *paddy area* variable. Farm households with a larger paddy area have a greater probability of adopting hybrid rice. Concerning communication, households who more often contact extension workers or agricultural officials are more likely to adopt the hybrid rice in the previous year at a significant level of 95% confidence. Inversely, households who talk more often with outsiders are more likely to adopt the hybrid rice in recent years (Table 13).

In conclusion, the determinants of hybrid rice adoption are the *occupation of head*, *informal credit from neighbor, paddy area* and as a consequence of meeting with *extension worker* or *agricultural official*. This implies that the extension function of the District People's Committee was well executed with regard to the propagation of ordinary hybrid rice.

4.3 Hybrid Maize Varieties

Maize has become an important income source for local people in Yen Chau. On average, it contributes 20.5% to the total income of farm households (Figure 6). The farmers, therefore, often try to adopt the new hybrid maize in order to gain a better yield. The major varieties of hybrid maize currently adopted by local farmers are

CP888 and VN10. The current adoption rate is 96% (Table 12). This rate has increased since the 1990s (Figure 5).

Table 13. Coefficient of ordered logistic regression

Variables	**Improved sticky rice**		**Hybrid rice**		**Hybrid maize**		**Improved cassava**		**Chemical fertilizers**		**Raising goats**		**Improved pigs**	
Gender of household head	0.306		0.057		0.359		-1.520	**	1.004		0.852		-1.615	
Age of household head	-0.020		-0.031		-0.004		-0.009		-0.007		-0.005		0.062	
Party membership of head	-0.869		-0.586		-0.902		0.079		-0.213		0.640		2.358	
Dependency ratio	0.497		0.292		1.007	**	0.537		0.581		0.199		-1.249	*
All adult education	0.085		0.030		0.119	*	-0.002		0.010		0.050		-0.297	
Head occupation (farming)	-0.795		-2.143	***	-0.180		0.025		0.209		1.996	**	2.514	
Head occupation (official)	-0.019		-0.943		1.177		0.643		0.991		1.766	*	3.706	
Credit from bank	-0.508		-0.677		-0.063		0.196		0.334		0.074		0.455	
Credit from trader	-3.113	*	0.085		-1.666	***	-3.325		-0.145		2.163		-34.585	***
Credit from friend	3.161		-1.486		2.033	***	0.481		0.823		2.596		-31.909	***
Credit from neighbor	0.273		-0.882	**	-0.261		-1.711	***	0.135		-1.817		-30.794	***
Credit from relatives	0.043		-1.070		0.629		0.843		0.488		0.377		-33.223	***
Paddy area	-1.060		-2.854	*	-2.683	**	-1.463		-0.291		4.131	*	6.555	*
Upland area	-0.170		0.053		-0.941	***	-1.187	***	-0.284		-0.284		-0.025	
Agricultural training course	-0.417		0.310		0.289		-0.102		0.194		0.189		1.204	
Extension worker	0.075		-0.143	**	0.008		0.151		-0.180	***	-0.038		-0.631	
Television – vtv2	0.004		-0.021		-0.040	***	0.008		-0.039	***	-0.041	*	0.002	
Talking with neighbor	-0.012	***	-0.007		-0.001		0.001		0.004		-0.001		-0.162	
Agricultural shop	-0.070	*	-0.015		-0.062		-0.008		0.022		0.221	***	0.260	
Staff from companies	-0.035		0.130	**	0.098		-0.208		0.061		-0.283		0.678	*
Talking with outsider	0.015	**	0.005		0.024	***	0.015	*	0.010		0.005		-0.002	
Commune center	-0.004		-0.001		0.001		-0.008	**	-0.008	**	0.007		-0.171	**
District center	-0.085	***	-0.043		-0.009		-0.102	***	0.014		0.017		0.187	***
Agricultural official	-0.029		-0.056	**	0.000		-0.052		-0.002		-0.244		-0.278	
Village headman	-0.013		-0.003		-0.010		-0.017	***	-0.023	*	-0.033	**	-0.039	
Network 1	-0.055		-0.270		0.082		0.436		-0.187		-0.104		1.753	
Network 2	0.616		1.057		1.112	*	0.889		0.056		0.099		0.772	
Network 3	-0.139		0.080		-0.824		0.408		-0.043		-0.009		3.733	*
Current available cash	-0.006	**	0.001		-0.003		0.005		0.008		-0.003		0.032	
LR Chi2	104.29		105.94		125.07		105.35		107.97		43.46		8859.69	
Prob>Chi2	0.00		0.00		0.00		0.00		0.00		0.04		0.00	
Pseudo R^2	0.06		0.07		0.07		0.07		0.06		0.07		0.26	
Log Likelihood	-377.51		-303.04		-373.06		-324.06		-353.03		-289.75		-70.20	

Note: "*", "**", "***" are significant at 90%, 95% and 99% respectively

Similar to other innovations, the adoption of hybrid maize also depends on household characteristics, endowment resources and social relations. As described in Table 13, the log odds of hybrid maize adoption were positively correlated with the dependency ratio and education of households. The households with a higher dependency ratio or higher level of education were more likely to adopt hybrid maize in later years. In this case, education does not play an important role in innovation adoption. Children and old people are the constraint for the adoption of this innovation.

Regarding credit, the variable *credit from trader* is negatively correlated with the log odds of adoption while *credit from friend* has a positive correlation. It shows that households that can get credit from traders adopted the hybrid maize in the former years while the households who get credit from their friends tend to adopt hybrid maize in the latter years. It implies that the household adoption of hybrid maize is closely related to traders and their business relationships (Table 13).

In terms of resource endowment, the negative correlation between land area and log odds of adoption shows that households who have a larger land area are more likely to adopt hybrid maize than others (Table 13).

For communication, the households who more often watch VTV2 are likely to adopt hybrid maize earlier while the households that have more frequent contact with outsiders are likely to adopt hybrid maize at a later period. Additionally, the variable *network 2* positively correlated with the log odds of adoption at a significant level of 90% (Table 13). This means that the households who consider their neighbors to be the most important communication channel are more likely to adopt hybrid maize at a later stage.

In general, the determinants of hybrid maize adoption are *dependency ratio, education,* informal *credit from trader and friend, land area, watching VTV2,* frequency of contact with *outsiders* and opinion of households about their *neighbor*.

4.4 Improved Cassava

In addition to maize, cassava also makes a large contribution to income, accounting for 15.5% of total income (Figure 6). Previously farmers grew local cassava which had a longer life cycle and contained less concentrated starch. They grew this variety for three years and got 3 kg of dried cassava from 10 kg of fresh root. The new variety, with a life cycle of one year and a higher rate of concentrated starch, has been disseminated since the 1990s. Currently, the adoption rate of this variety is 84% (Table 11).

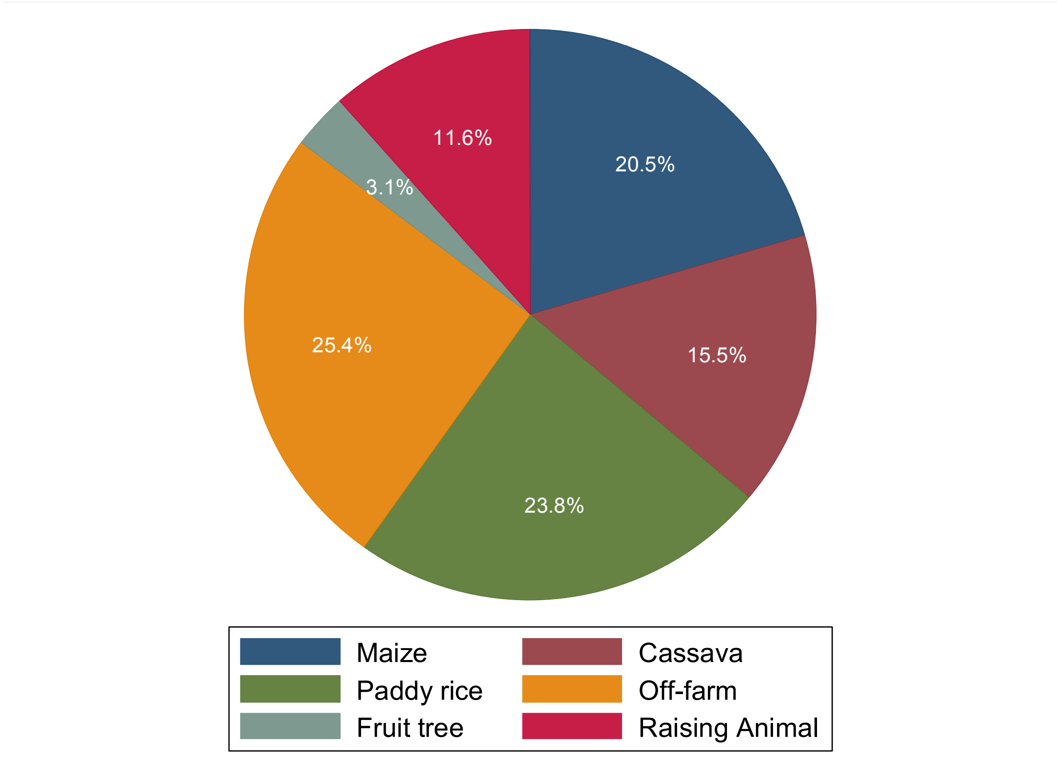


Figure 6. Contribution of different activities to household income

Whether to adopt or not to adopt improved cassava depends on the *gender of the household head, informal credit from neighbors, upland area,* contact with *outsiders, village headman*, and *commune and district center* at a significant level of more than 90%, as shown in Table 13. More specifically, for the households with a male head, the log odds of adoption is 1.52 times lower compared to that of households with a female head (Table 13). This generates the conclusion that households headed by a male are likely to adopt improved cassava before households headed by a female. A similar explanation applies to *upland area* and *credit from neighbor*. The households who have more sloping land or can get credit from their neighbors are likely to adopt improved cassava before others. Concerning communication, the households that have more regular contact with *village headman, district* or *commune center* have a higher probability of adopting improved cassava before others. Inversely, the households who talk more often with *outsiders* are likely to adopt improved cassava after others.

In conclusion, the determinants of improved cassava adoption are the *gender of the household head*, *sloping land area*, *informal credit from neighbors*, frequency of contact with *village headman*, *outsiders*, *communal* and *district centers*.

4.5 Use of Chemical Fertilizers on Sloping Land

Chemical fertilizers can improve the productivity of crops. Traditionally, local people did not put chemical fertilizers on maize and cassava. However over the past decade maize and cassava have become the main commercial farming output and as people have received more income from this activity, they have started applying best practice in order to maximize their profit. They now apply chemical fertilizers when growing hybrid maize and improved cassava in order to gain better productivity. The chemical fertilizers regularly used are urea, mixed NPK and potassium.

As described in Table 13, the adoption of chemical fertilizers mainly relies on the social relations of farm households. As far as communications are concerned, the coefficient of *extension worker* and *television – vtv2* are negatively significant at 99% of confidence. This shows that the households who have contact with *extension workers* or *watch VTV2* more regularly are more likely to adopt chemical fertilizers than others.

Similarly, the coefficients for *commune center* and *village headman* are also significant at 90% and 95% respectively (Table 13). Controlling for all other variables, if the frequency of access to *commune center* or *village headman* increases one unit then the log odds of adoption reduce by 0.008 and 0.23, respectively. Households who more often contact the *commune center* or *village headman* are more likely to adopt chemical fertilizers.

Generally, the determinants of chemical fertilizer adoption are *frequency of contact with extension worker, village headman, commune center* and *watching VTV2*. The odds ratio of the variables in Table 18 are close to one. This explains that when one of these variables increases one unit while others keep constant the odds ratio of recent adoption versus adoption in the previous years is slightly reduced at a rate close to one.

4.6 Raising Goats

Raising goats is not a new activity in the mountainous region; it appeared in Chieng Khoi in the 1990s. However, local farmers have only adopted this activity fairly recently because goat meat has become a specialty food in many restaurants. Therefore, raising goats, a generally easy task, can generate more income for farmers. Raising goats has been adopted at a rate of 52% (Table 11). The log odds of adoption positively correlate with *occupation of head, paddy area* and *agricultural shop* (Table 13). This shows that the households were the head is either farming or a government official are more likely to have recently adopted raising goats. For resource endowment, the households who have a larger area of paddy tended to have adopted raising goats in recent years and had a higher probability of adoption. The high coefficient and odds ratio of paddy area implies that this variable strongly affects the adoption of raising goats. The same explanation can be applied to the *agricultural shop* variable. The households with more regular contact with agricultural shops had a higher probability of adoption and were more likely to have adopted raising goats recently.

The negative significant correlation happens to the variables of *television-VTV2* and *village headman* (Table 13). These variables explain that the households who more frequency watch VTV2 and have meetings with the village headman are more unlikely to adopt raising goats or to have adopted raising goats in the past. When the value of one of these variables increases one unit, the odds ratio of recent adopter versus non-adopter and adopter in the past is 0.96 times smaller.

In summary, the determinants of the adoption of raising goats are *head occupation*, *paddy area*, frequency of contact with *agricultural shop*, appointments with *village headman* and *watching vtv2.*

4.7 Improved Pigs

As depicted in Figure 5, improved pig breeds appeared in the Chieng Khoi sub-catchment many years ago. However, these breeds were not broadly adopted. The adoption rate of improved pigs is only 11% (Table 11) – the reason being that farmers still don't know how to look after this breed. Improved pigs often die when farmers try to keep them. Labor and financing are other constraints on this activity. As described in Table 13, the dependency ratio and informal financial credit are all negatively correlated to the odds of adoption. The farm households with a higher dependency ratio, meaning households containing older people and fewer children, have a lower probability of adopting the improved pig breed. In the case of credit, all informal credit variables are strongly correlated with the log odds of adoption at a significant level of 99% and coefficients have a high negative value (Table 13). This implies that the households who get informal credit from a trader, friend, neighbor or relatives have a very low probability of adopting the improved pig breed compared to that of others. Meanwhile the odds ratios of these variables are almost zero (Table 18). It can be concluded that the households who receive credit from informal sources absolutely do not adopt this innovation.

Another variable that has a negative correlation with the log odds of adoption is *commune center.* The households that have more regular access to the commune center are less likely to adopt the improved pig breed.

Households that have a higher probability of adopting the improved pig breed have a larger paddy area, more frequent contact with staff from companies, travel more often to the district center or are households who consider extension workers to be the most important channel of information. All of these variables are significantly positively correlated to the log odds of adoption (Table 13). The coefficient of *paddy area* and *network 3* are relatively higher than others (Table 13), implying the strong influence of these variables on the adoption of the improved pig breed.

Generally, the determinants of improved pig adoption are dependency ratio, informal credit, paddy area, the frequency of appointments with staff from companies, the district center, commune center and the opinion of households about extension workers regarding information about innovations. Informal credit, paddy area and the opinion of the household regarding extension workers, particularly strongly affects the adoption of the improved pig breed.

5.0 IMPACT OF INNOVATIONS

5.1 Perceptions of Farmers

During the household survey, the farmers were asked how they evaluate the impacts of the adopted innovations on the environment and on household income. In terms of the environment, the question referred to impacts on soil quality, but for raising goats and the improved pig breed farmers were asked about impacts on water quality. For income, the question referred to impacts on household income and consumption. Five grades were developed to quantify the answers, as described in the section on research methods. During the survey, the quantified grades were explained to the farmers. When answering the questions, farmers selected one of the five grades which they thought corresponded to the real situation. The results of farmers' perceptions are presented in Figure 7 and Figure 8.

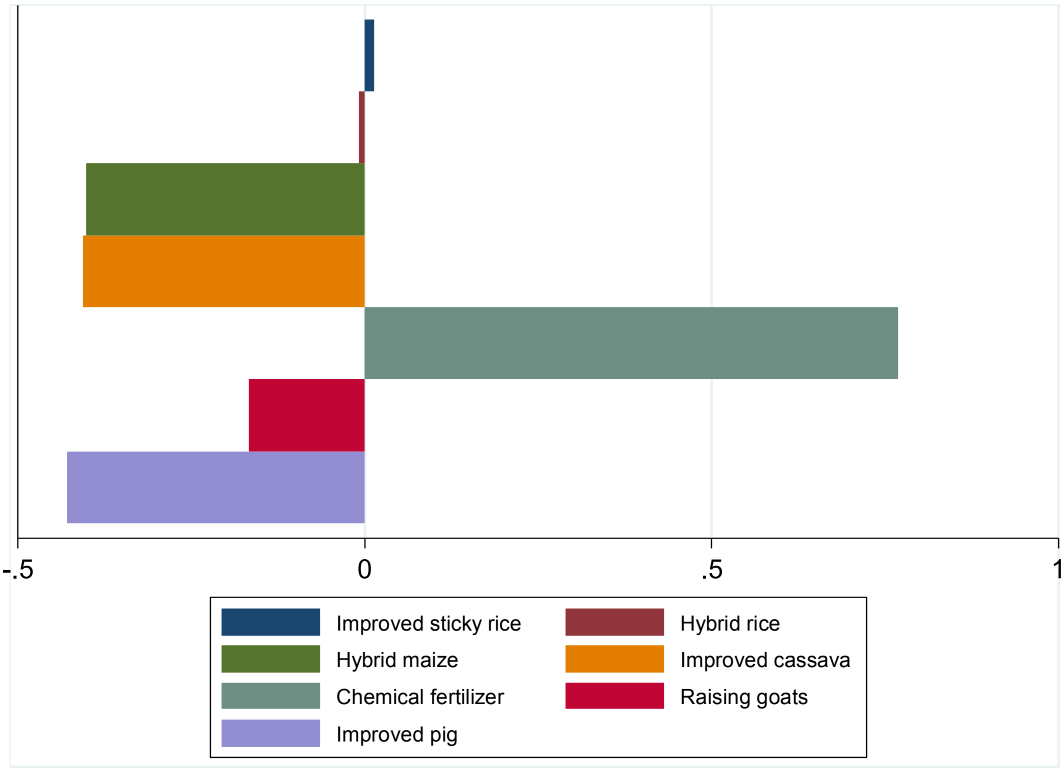


Figure 7. Impact of innovations on soil and water quality

As depicted in Figure 8 and Figure 9, the perceptions of farmers about improved sticky rice and hybrid rice almost have no impact on the environment but they do have a positive impact on household consumption in terms of food security.

In general, the adopted innovations which have negatively affected the environment are hybrid maize, improved cassava, raising goats and the improved pig breed. The hybrid maize and improved cassava negatively affect the soil quality while raising goats and improved pigs can pollute the water. The improved pigs have a bigger negative effect compared to that of raising goats (Figure 7). Only chemical fertilizers have a positive impact on the soil quality because, according to the farmers, using chemical fertilizers on sloping land makes the soil more fertile.

Figure 8 shows all the positive effects of selected innovations on household income and consumption. The use of chemical fertilizers on sloping land has the strongest positive impact, with hybrid maize coming second. Improved cassava, hybrid rice and improved sticky rice have the same effect on household income and consumption. Generally, these five adopted innovations have affected household incomes and consumption levels in a positive way. In the case of livestock, raising goats and improved pigs has positively affected household income and consumption at a lower level. In particular, raising improved pigs just slightly impacted on household income and consumption (Figure 8).

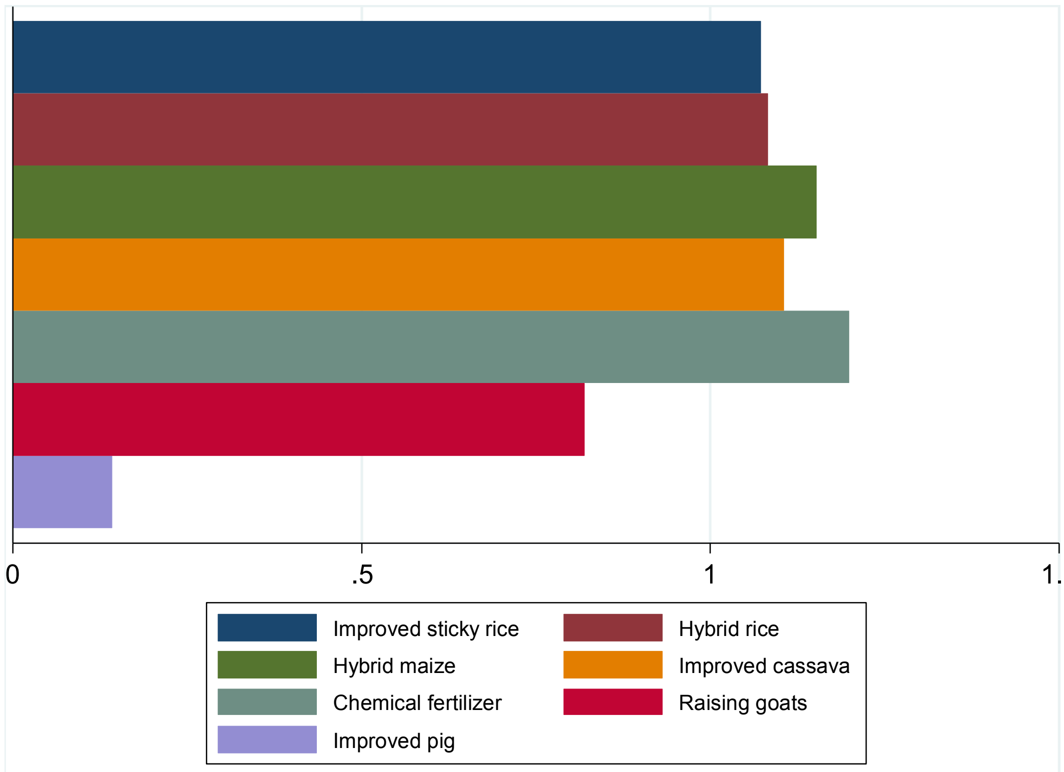


Figure 8. Impact of innovations on household income and consumption

In conclusion, the perceptions of the farmers are that the improved sticky rice and hybrid rice have had no impact on environment and they have positively affected household income and consumption at a good level in terms of food security. The hybrid maize and improved cassava have had negative effects on soil quality but make a good contribution to household income and consumption. Using chemical fertilizers on sloping land has positively affected both soil quality and household income and consumption. In the case of raising animals, keeping improved pigs has had a bigger negative effect on the environment compared to raising goats and slightly positive impacts on household income and consumption.

5.2 Perceptions of Researchers

I used the agent-based model called MP-MAS to integrate a social-economic model with bio-physical models. The social-economic models were estimated from survey data whilst the bio-physical models were developed from data provided by other sub-projects in the Uplands Program, as mentioned in the section on research methods.

After the MP-MAS was developed, it was validated until the output data was as close as possible to the survey data. This was the baseline scenario. Other scenarios were used to analyze the impacts of hybrid maize, improved cassava, the use of chemical fertilizers on sloping land, and raising goats and improved pigs (Table 14). The improved sticky rice and hybrid rice were not selected for scenario analysis because they had almost no impact on the environment as far as farmers' perceptions were concerned. On the other hand, paddy rice cannot be excluded from the sub-catchment due to food security.

Table 14. Scenarios developed for impact evaluation

Prefix	Scenarios	Description
S1	Baseline scenario	This scenario included all the above-mentioned innovations except the improved pig breed because the use rate and adoption rate are very low. This scenario assumed that there are no improved pigs in the sub-catchment. In reality farmers mainly raise local pigs.
S2	Scenario 2 Excluded hybrid maize	This scenario was developed based on the assumption that in order to conserve the environment the government imposes a policy that farmers are not allowed to grow hybrid maize.
S3	Scenario 3 Excluded improved cassava	Similar to S2, in S3 the farmers are not allowed to grow improved cassava.
S4	Scenario 4 Included improved pigs	S4 was developed based on the assumption that improved pigs are well disseminated throughout the sub-catchment. All farm households know how to keep the improved pig breed and each farm-household is raising a maximum of two improved pigs per year.
S5	Scenario 5 Excluded chemical fertilizers	Similar to S2 and S3, the farmers are not allowed to use chemical fertilizers.
S6	Scenario 6 Excluded raising goats	Currently, the government of the sub-catchment has a policy of eliminating raising goats because, in their opinion, goats destroy the crops. In this scenario farmers are not allowed to raise goats.

Compared to the baseline scenario, the results of scenarios 2 to 6 are used to assess the impacts of innovations on the environment and income per capita.

5.2.1 Baseline scenario

After a MP-MAS of Chieng Khoi was structured, the baseline scenario was set up based on the social-economic survey and experiment data. The social-economic component was developed by survey data while the bio-physic component was constructed by TSPC as described in the section on research methods. The outputs of the baseline were compared with survey data to validate the model (Figure 9).

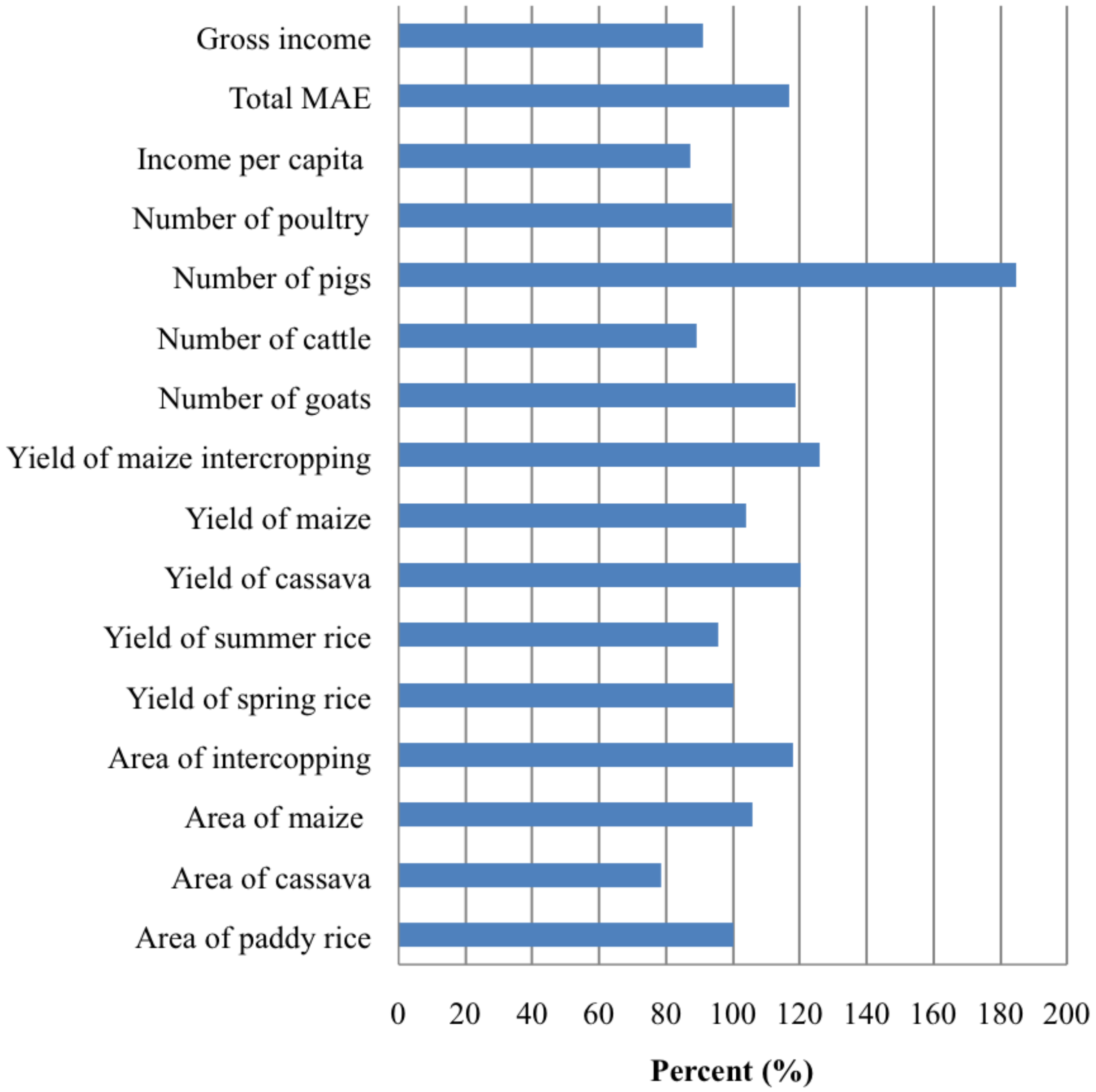


Figure 9. Rate of model data versus surveyed data

Figure 9 shows the ratio between the model and the surveyed data when considering the surveyed data as 100%. As depicted in this figure, the area and the yield of crops almost reaches the surveyed value. The numbers of pigs and goats were overestimated. Finally, the income per capita and gross income (the total income from both farm and off-farm activities of all households) of the model equals 90% of the value calculated from the surveyed data. Generally, on average, the data estimated by model equals 102% of observed data from the 2008 survey (Figure 10).

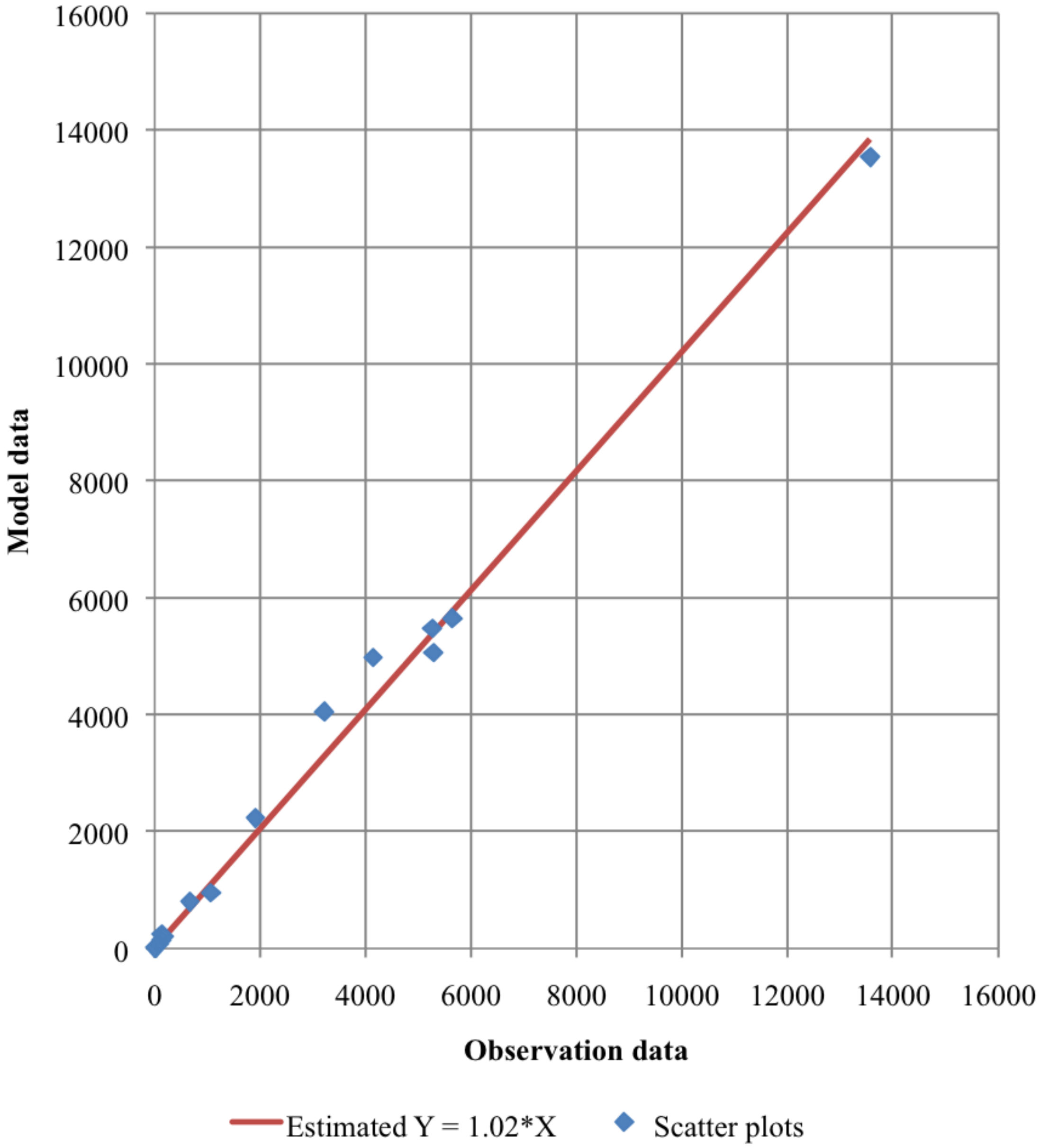


Figure 10. Validation graph

5.2.2 Impact of innovations on soil nutrients

In MP-MAS the main soil nutrients are nitrogen, phosphorus and potassium. These substances are major indicators of soil fertility. The amounts of these substances vary between different types of soils and they exist in different forms. However, an indicator used to calculate the overall content of these substances is available and can be abbreviated to NAV, PAV and KAV standing for available value of nitrogen, phosphorus and potassium respectively (Schreinemachers 2006). This indicator has been used to present the quality of the soils for impact assessment.

The calculation methods of NAV, PAV and KAV are referred to in Schreinemachers' dissertation of 2006. The available nitrogen is calculated by a function of four variables, including the atmospheric deposition of nitrogen, nitrogen mineralized from soil organic matter, manure, residues and nitrogen from mineral fertilizers. The available phosphorus is the function of decomposition of soil organic matter, mineral fertilizer, manure, and the carry-over effect of phosphorus from previous periods. The available potassium is calculated by total potassium in the soil, mineral fertilizer in the current year and manure from previous years (Schreinemachers 2006). In this report, the NAV, PAV and KAV are calculated as an average value of all soil types over 15 periods (years) for impact assessment as depicted in Figure 11.

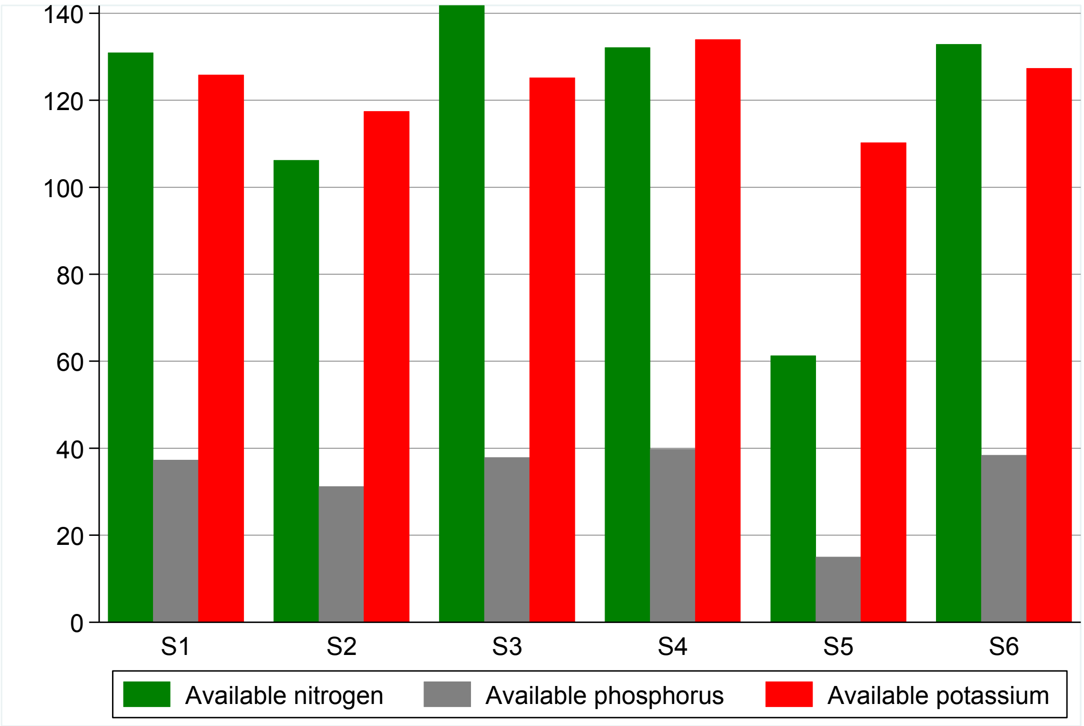


Figure 11. Available nutrients on average by scenario

Figure 11 shows the average value of available nitrogen, phosphorus and potassium over six scenarios. Compared to nitrogen and potassium, the amount of phosphorus is much lower and the value is almost 40 kg per ha in the baseline scenario. The amount of available potassium and nitrogen is relatively high in scenarios 1, 2, 3, 4 and 6. Only in scenario 5 is the value of available nitrogen much lower than that of others. The available phosphorus and potassium in the soil in scenario 5 are also lower than that of other scenarios. The main reason for this is that chemical fertilizers were not allowed in this simulation.

Regarding the impact of innovations, chemical fertilizers considerably affected soil nutrients, especially the amount of available nitrogen. On average, the NAV of scenario 5, without chemical fertilizers, is about 60 kg per ha less than that of the baseline scenario, while the PAV and KAV were about 15–20 kg per ha less than the baseline (Figure 11).

The other scenarios slightly impacted on soil nutrients. In the simulation of scenario 2, without hybrid maize, and scenario 3, without improved cassava, the amount of available potassium was a little lower than the baseline while the content of available phosphorus did not differ. The amount of available nitrogen is a little lower when farmers do not use hybrid maize and slightly higher when farmers do not use improved cassava. Animal rearing (goats and improved pigs) in scenarios 4 and 6 had absolutely no effect on soil nutrients.

5.2.3 Impact of innovations on nutrient balance

The simulation was run for 15 periods. In each period, the available nutrients were calculated to estimate crop productivity. At the end of each period the nutrient balance was evaluated for an estimate of the available nutrients in the next period. The equations to evaluate the nutrient balance are mentioned on page 83 of Schreinemachers' dissertation (Schreinemachers 2006).

For the purposes of impact assessment, the values of the nutrient balance of nitrogen, phosphorus and potassium were estimated according to average soil types and time periods. The average balance value of nitrogen, phosphorus and potassium are presented in Figures 12 and 14 for paddy and sloping land respectively. Figure 12 shows that except for chemical fertilizers other innovations have no impact on the paddy nutrient balance. Without using chemical fertilizers, the paddy nutrient balance has negative value.

In Figure 13 the negative value of potassium and nitrogen in all of the scenarios shows the reduction of nutrients on sloping land over the years. However, this reduction is not identical across all the scenarios. In scenario 2, without hybrid maize, and in scenario 5, without chemical fertilizers, the impact on available nitrogen is considerably different compared to the baseline. These scenarios show that without chemical fertilizers the available nitrogen will reduce a further 30 kg per ha compared to the baseline scenario, while this value increases 30 kg per ha less than baseline when farmers do not grow hybrid maize. This implies that the chemical fertilizers compensate 30 kg NAV per ha per year on average, while hybrid maize uptake is 30 kg NAV per ha per year. Similar to cassava, it slightly compensates available nitrogen as presented in scenario 3, Figure 13. The two other scenarios, raising goats and improved pigs, can slightly improve the soil nutrient balance on sloping land compared to the negative circumstances of the baseline scenario. However, this improvement is only a few kg of nitrogen per ha.

Regarding the balance of phosphorus, there is a little impact on available phosphorus in the case of raising goats and improved pigs. Available phosphorus is slightly compensated when farmers use chemical fertilizers or grow cassava. Inversely, on average the available phosphorus is slightly reduced when farmers grow hybrid maize (Figure 13).

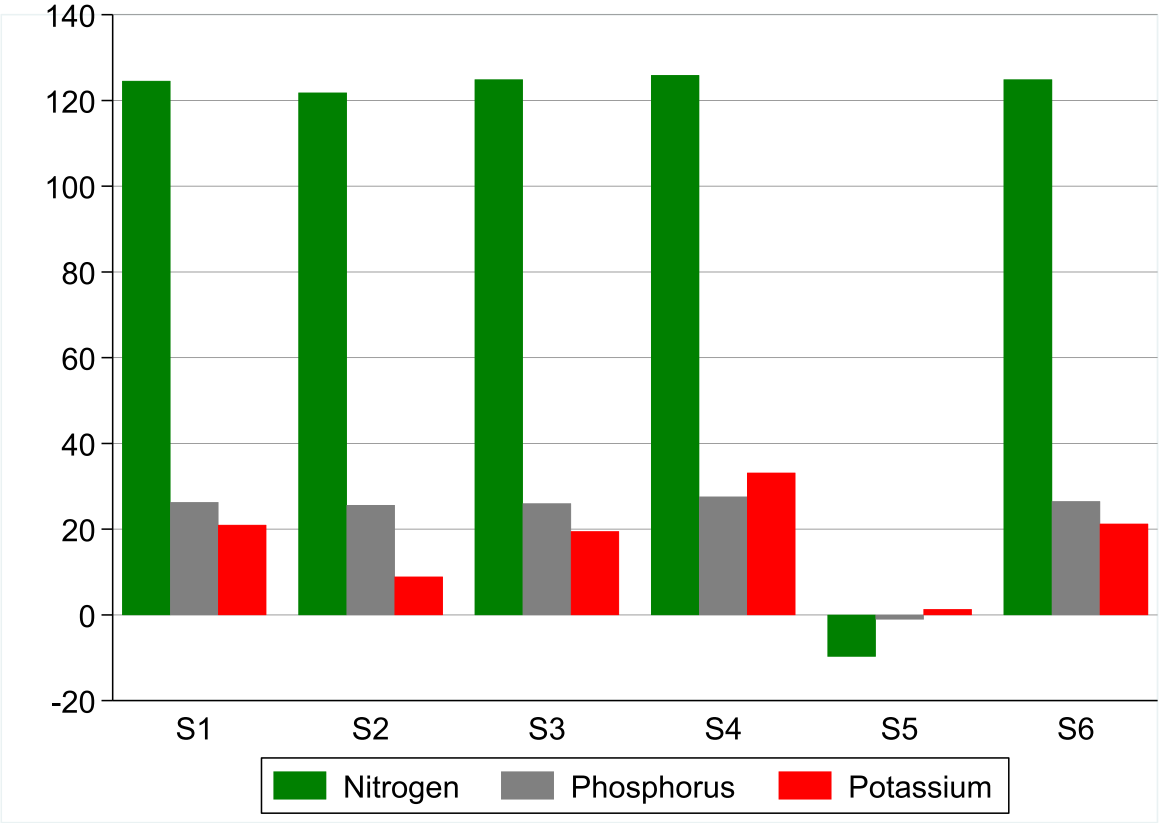


Figure 12. Paddy soil nutrient balance

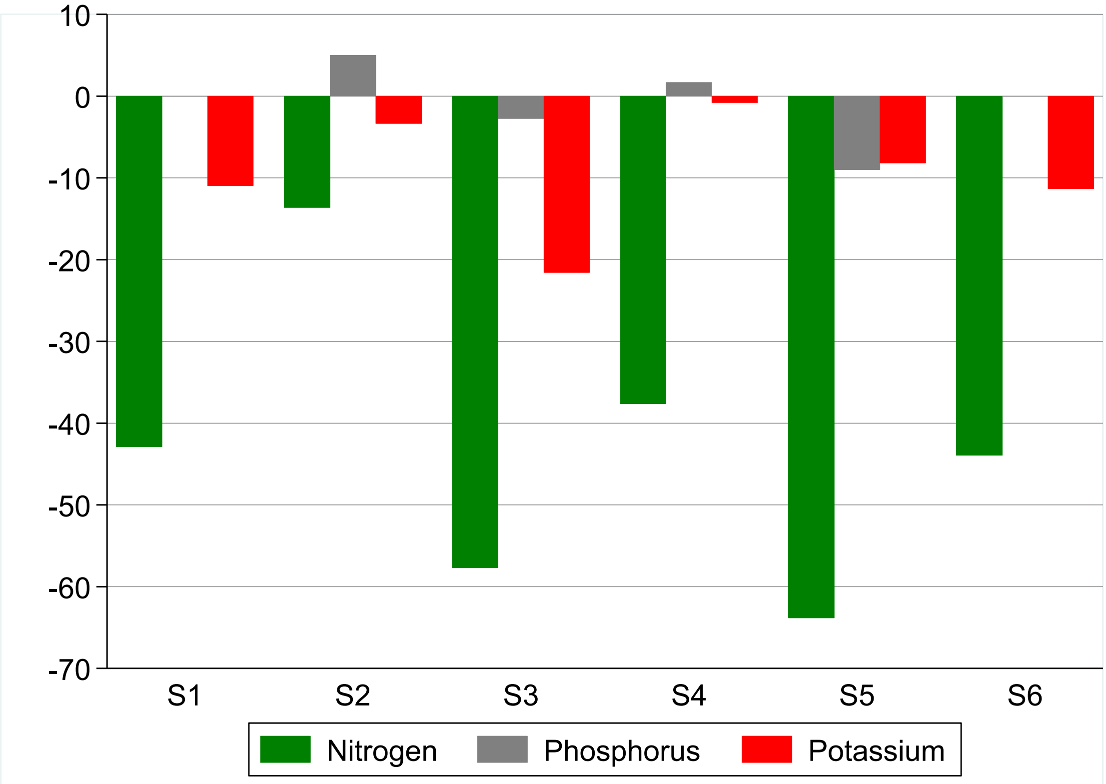


Figure 13. Sloping land soil nutrient balance

5.2.4 Impact of innovations on soil erosion versus income per capita

The main reason for soil erosion is that annual crops are grown on sloping land without appropriate soil conservation. Annually in Chieng Khoi 600 ha of crops cause about 9,000 tons of soil loss. This is mainly due to the cropping practices of farm households on slopping land and the cropping patterns of the region. The cropping practices are an agricultural innovation, while the cropping pattern is actually a land use pattern. When agricultural innovation changed the land use changed correspondingly[4]. Thus, the agricultural innovation should be taken account in the impact assessment on soil erosion in order to select appropriate agricultural practices in the context of soil conservation. However, the adoption of agricultural innovations causes a loss in the farmer's welfare in terms of money. The income per capita, therefore, is selected to indicate household welfare while the impact assessment of agricultural innovation for soil conservation is being done. Figure 14 shows the impact of agricultural innovation on soil erosion and income per capita.

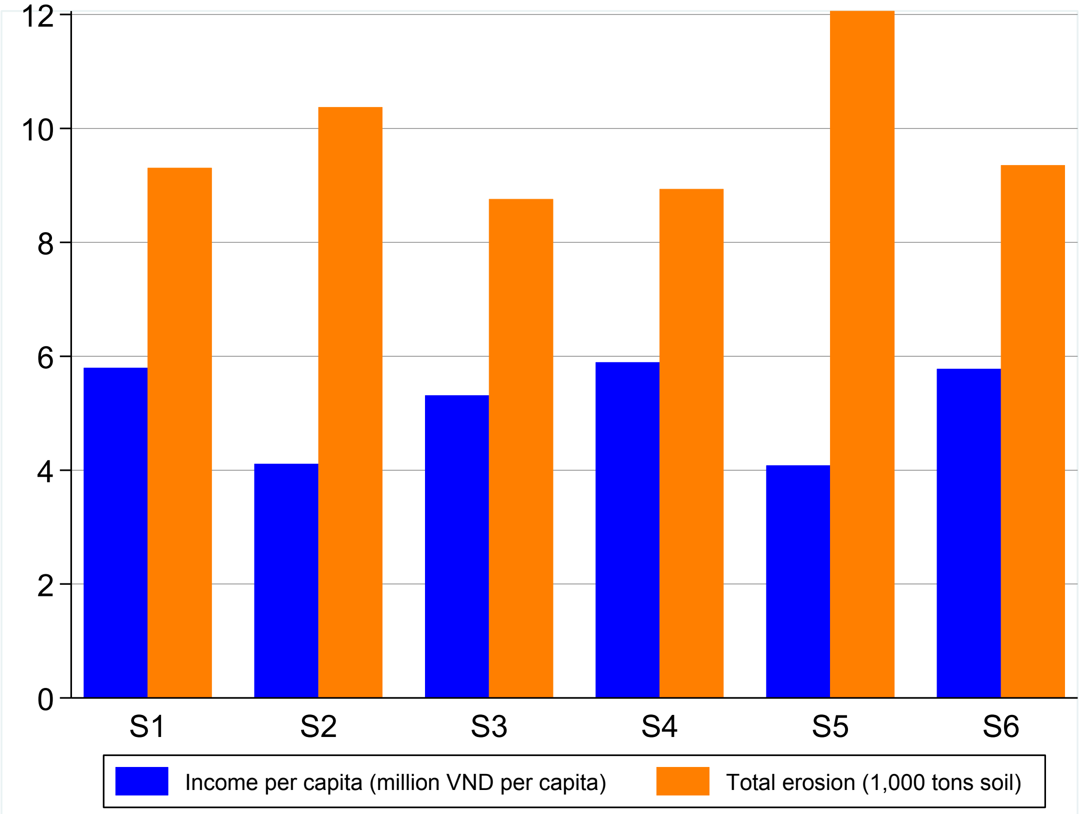


Figure 14. Soil erosion versus income per capita

As depicted in Figure 14, hybrid maize and improved cassava considerably impact on soil erosion in comparison to other innovations. In scenario 2, without hybrid maize, the total soil erosion is more than 10,000 tons, while in scenario 3, without improved cassava, the amount of soil loss is slightly lower than the baseline. The difference

[4] The land use change simulation of each scenario is available on request.

between scenarios 2 and 3 and the baseline is 1 and 0.6 thousand tons respectively. This explains that improved cassava causes more soil erosion in comparison with hybrid maize. Scenario 5 shows that without using chemical fertilizers the quantity of soil lost tends to be higher than that of the baseline scenario. It implies that chemical fertilizers contribute positively to the problem of soil erosion.

Scenario 4, improved pigs, and scenario 6, without raising goats, in general have little effect on soil erosion. The main reason is that these two innovations do not considerably affect land use cover.

In terms of income impact assessment, scenarios 2 and 5 show that growing hybrid maize and the use of chemical fertilizers considerably improves the income of farmers. Without neither growing hybrid maize nor using chemical fertilizer income per capita would reduce from 5.7 to 4.1 million VND per capita (Appendix 3). Improved cassava also promotes the income of local people but less than that of hybrid maize and chemical fertilizers. Improved pigs have little effect on income per capita while it is likely that raising goats has no impact on income per capita (Figure 14).

In conclusion, it is recommended that to support sustainability, defined by adequate levels of soil nutrients and an end to soil erosion, the area of both hybrid maize and improved cassava grown should be reduced. Instead of these crops, income generation activities should be encouraged because the reduction in farming area of improved maize and cassava would partially negatively affect the income of farm households.

6.0 THE TRADE-OFF BETWEEN WELFARE AND SOIL CONSERVATION

As described in the previous section, hybrid maize and improved cassava cause a large quantity of soil loss due to erosion from sloping land. This generates negative externalities because soil erosion not only negatively impacts local farmers but also has further off-site affects. According to the polluter pays principle, local farmers should cover the costs of damage caused by soil erosion. It is assumed that in order to conserve the soil that is not currently eroded, the government should levy an eco-tax on the areas where farmers grow annual crops on sloping land without soil conservation measures. The cost of the damage caused by soil erosion could be implicit in the tax form. However the question is, how much would it cost to reduce the soil loss and how would this impact on the welfare of farmers? Using scenario analysis, in addition to the baseline scenario, five others were set up with different tax levels as described in Table 15. More specifically, the agents have to pay tax when growing maize, cassava or intercropping on sloping land. Agents do not have to pay tax when they let the land lie fallow or grow perennial trees. In the model, this cost is not used for paddy.

Table 15. Simulation scenarios with different levels of land tax

Prefix	Scenarios	Land tax level (million VND/ha)
S1	Baseline scenario	0
S2	Scenario 2	6
S3	Scenario 3	8
S4	Scenario 4	10
S5	Scenario 5	11
S6	Scenario 6	12

The land tax increases farm costs. Increasing the tax level affects the decisions of farmers regarding farming activities. A higher tax level for maize and cassava grown on sloping land would lower the benefits from these activities if the market price does not increase. Alternatively, farmers would select other activities to compensate for the loss or else the household income would reduce considerably. If this was the case then the land use pattern would be considerably affected[5].

6.1 The Impact of Land Taxation on Soil Nutrients

Similar to the previous section, the available nutrients were used to assess the impacts of a tax on soil fertility. Figure 15 shows the available nitrogen, phosphorus and potassium on sloping land in different simulated scenarios in which scenario 1 is the baseline, with zero tax. The tax levels increase from scenario 2 to scenario 6. As depicted in this figure, the available phosphorus and nitrogen, on average, slightly reduces while the available potassium was observed to rise when an additional tax was implemented. Generally, the tax had little effect on soil fertility in terms of available soil nutrients.

[5] The land use change simulation of each scenario is available on request.

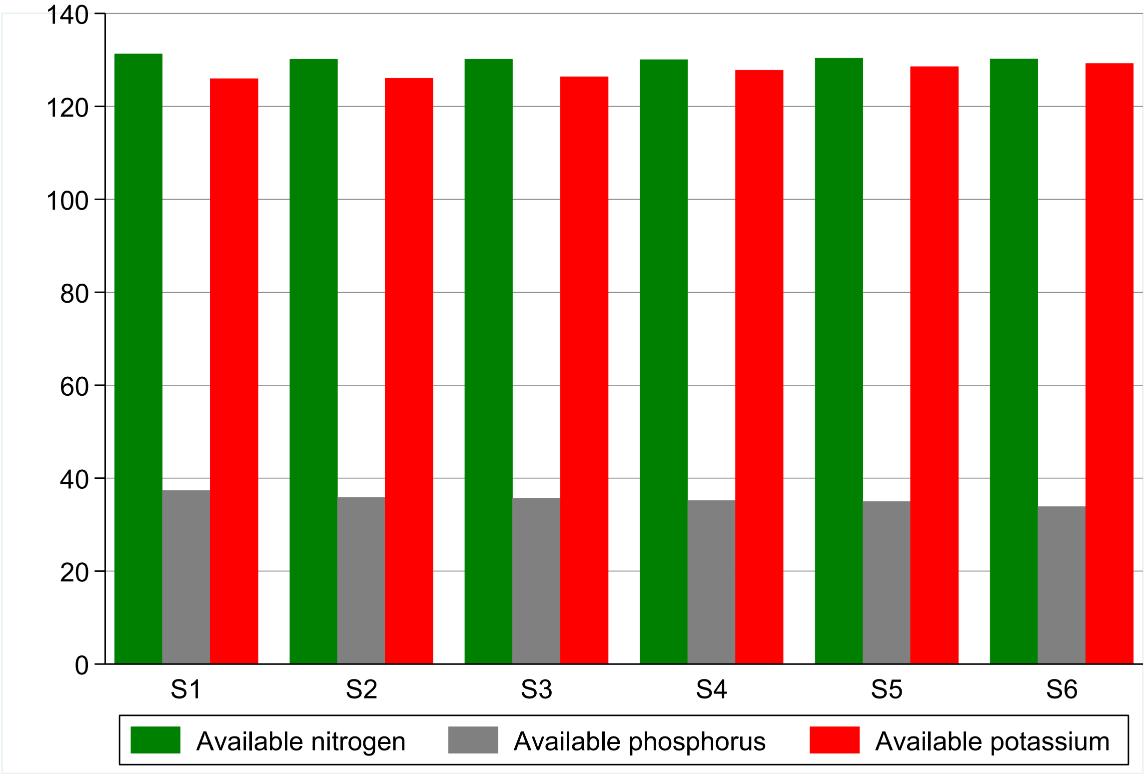


Figure 15. Available soil nutrients on sloping land according to increasing tax level

6.2 The Impact of Land Taxation on Soil Erosion and Income per Capita

The land use pattern demonstrates that the cropping area would be significantly reduced if the tax level of 11 and 12 million VND per ha in scenarios 5 and 6 respectively were applied. From scenarios 1 to 4, the agents would shift to cultivate fewer annual crops on sloping land and grow more perennials[5] to compensate for a reduction in income. The income per capita, therefore, constantly declines, as illustrated in Figure 16, or in other words, the increasing tax levels affect the farmers' incomes.

Moreover, the reduction in the maize and cassava cropping area directly affects the cash derived from these activities. As represented in Figure 16, the revenue from maize and cassava at the tax level of 12 million VND/ha dropped to 3.74 million VND per household, equal to 38.9% of that in the baseline scenario. Similarly, the quantity of soil loss apparently declined when the land tax increased (Figure 16).

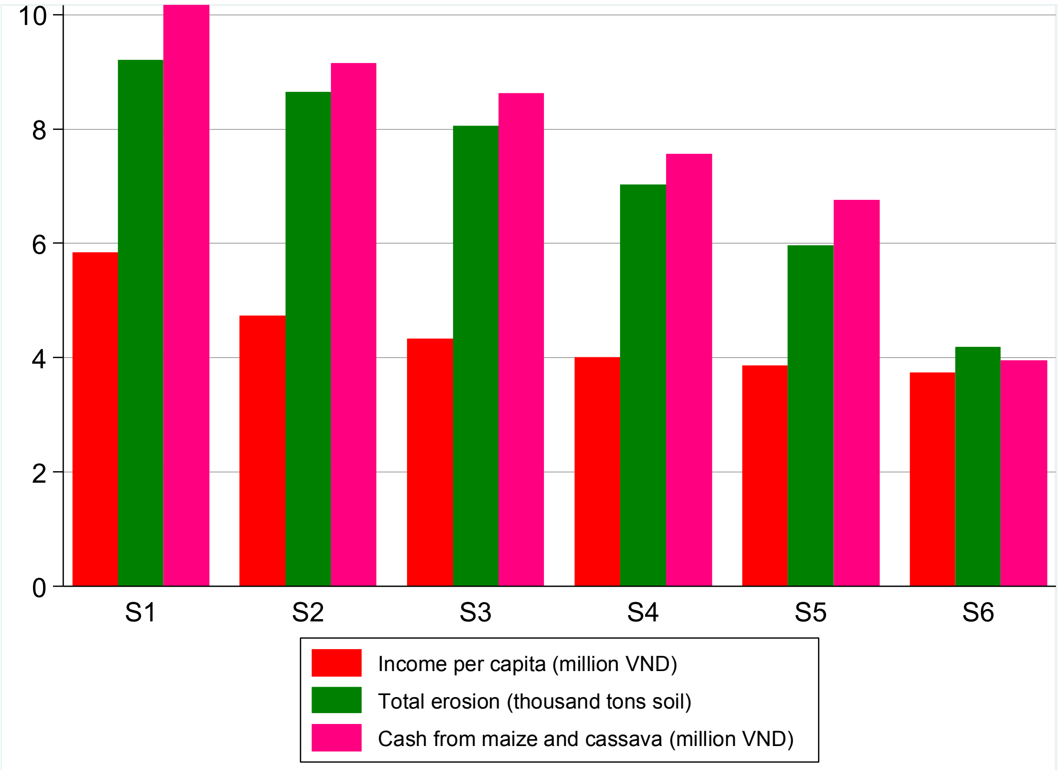


Figure 16. Erosion and income according to increasing tax level

6.3 The Trade-off between Household Soil Conservation and Economic Welfare

The production of maize and cassava contributes a large proportion of farmers' income. Each activity contributes 20.5% and 15.5% respectively (Figure 17). A cut in production would directly affect the income of farm households if they do not have access to an alternative income stream. Therefore, revenue received from growing maize and cassava on sloping land is used to represent household economic welfare. Reduction of soil loss has been used to indicate soil conservation. The results of six scenario simulations are shown in Figure18.

Figure 17 illustrates soil conservation, showing the percentage reduction in soil loss as a green line, of which scenario 1, without land tax, shows no reduction in soil loss. The red line, which describes the index of revenue received from growing maize and cassava in percentage terms, represents household welfare. In general, Figure 17 demonstrates that if the government applied a strict soil conservation policy via the imposition of a tax, the quantity of soil loss would reduce considerably and household welfare would be strongly affected. Increasing the tax level positively affects the reduction of soil conservation and inversely negatively impacts household welfare. Figure 17 illustrates the trade-off between soil conservation and household economic welfare. In Figure 17, the intersection point is at a tax level of 11.65 million VND/ha. At this trade-off point, the quantity of soil loss reduces by 48% while the revenue received from maize and cassava would cut 52% of the income in the baseline scenario. For minority people, this would have a strong impact on their livelihoods. It can be concluded that without alternatives the high tax level would negatively affect the livelihoods of local farmers while possibly reducing less than half of the soil erosion.

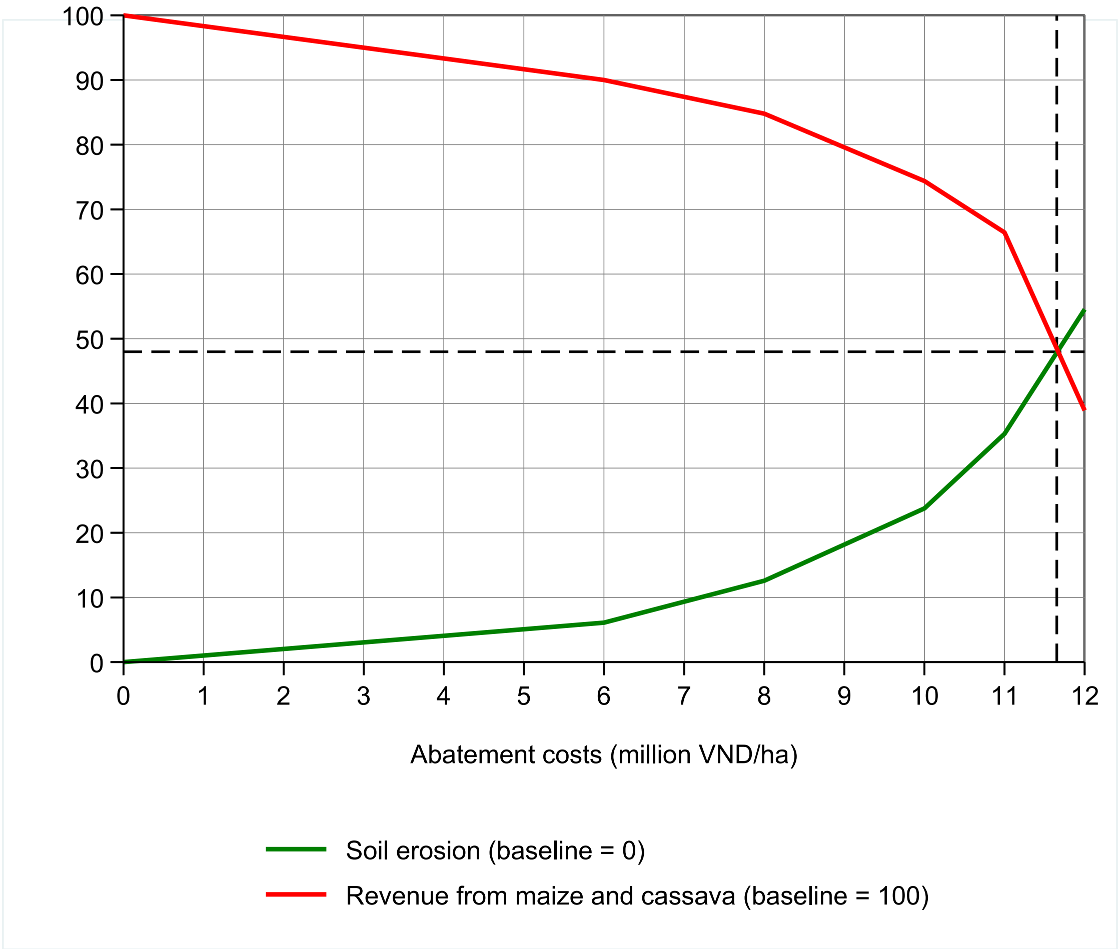


Figure 17. Loss in revenue from reduced maize and cassava production versus increased soil conservation

7.0 RELEVANT POLICY FOR SOIL CONSERVATION

As far as sustainable development is concerned, the environment should be protected and soil should be preserved so that it is of better quality and suffers less erosion. Using MP-MAS, an agent-based simulation approach, the scenario analysis of impact assessment recommends that the area of maize and cassava farmed should be reduced. To offset this reduction, animal husbandry should be encouraged (i.e. raising goats) in order to maintain local people's income.

A relevant policy option to reduce the area of maize and cassava farmed would be to levy a tax level on the area of maize and cassava grown on sloping land. This policy would reduce the soil loss and therefore aid soil conservation. Inversely, this new tax level would affect household revenue by diminishing cash income. The result of the simulation model shows a 48% reduction in soil loss is exchanged for a 52% loss in cash received from farming sloping land areas. At this point, the tax level is 11.65 million VND per ha.

The high land taxation without soil conservation measure implies that in addition to an imposed policy of soil conservation, an incentive policy of stimulating animal husbandry and soil conservation measures to maintain the income of farm households is essential. The appropriate methods of animal or soil conservation practices should be considered and disseminated throughout the region where soil conservation policy is applied.

8.0 CONCLUSIONS

Using the MP-MAS approach, the impacts of past agricultural innovations on household welfare and the environment were evaluated. Household welfare was indicated by income per capita and revenue, and the environment was represented by the soil nutrient content and degree of soil erosion. The simulation results showed that except for the case of chemical fertilizers, a specific agricultural innovation could not separately have a negative effect on farmers' income in the context of multiple alternatives for income earning. However, as far as the environment is concerned, the impacts of agricultural innovations on soil nutrients are different between crops and animals. Hybrid maize and improved cassava negatively affected the quality of soil nutrients as well as soil erosion while improved pigs and raising goats had no impact on soil quality.

In general, the findings of the MP-MAS simulations were relatively close to the qualitative observations of farmers that growing improved maize and cassava negatively affects soil nutrients while chemical fertilizers improve the fertility of the soil. Compared to other studies, this study only discusses the impacts of innovations in terms of soil nutrients and soil erosion. The impacts of other aspects of agricultural innovations, e.g. the emission of nitrogen due to chemical fertilizers or run-off water that is polluted due to chemical fertilizers, were not discussed.

The MP-MAS was also used to *ex ante* evaluate the impacts of future policy options on soil conservation. Using MP-MAS, a simulation of the impact of land taxation on both the environment and household economic was done at different levels. This resulted in a trade-off between revenue and soil conservation. Consequently, the land tax policy could satisfy conservationists but have negative impacts on the income of natural resource users. Specifically, a taxation level of 11.65 million VND per ha would reduce 48% of the soil loss and decrease revenue from regulated activities by 52% as income per capita would reduce due to the increased tax level and the changed crop area.

In addition to simulation, this study also identifies the determinants of the adoption of agricultural innovations. It would be useful for extension workers to be able to identify early adopters. In order to disseminate an agricultural innovation, extension workers should consider household characteristics such as gender and the occupation of the head of the household, the dependency ratio, access to informal credit and land area. Early adopters tend to consist of a household with a male head, engaged mainly in farming, with a low dependency ratio, able to get credit from traders, and having a large area of land. Households who are currently indebted to informal credit sources do not take on the early adoption of innovations in husbandry. Social relations of farm households are also an important indicator in the adoption of agricultural innovations. Households who have more frequent contact with extension workers, the village head man, the district center or those who watch VTV2 more often, tend to adopt new agricultural practices before others.

REFERENCES

Batz, F.J.; K.J. Peters; and W. Janssen. 1999. The Influence of the technology characteristics on the rate and speed of adoption. Agricultural Economics 21. 121-130.

Batz, F.J.; W. Janssen; and K.J. Peters. 2003. Predicting Technology adoption to improve research priority – setting. Agricultural Economics 28. 151-164.

Becu, N.; A. Neef; P. Schreinemachers; and C. Sangkapitux. 2007. Participatory Modeling to Support Collective Decision-Making: Potential and Limits of Stakeholder Involvement. Land Use Policy, accepted for publication.

Berger, T. 2001. Agent-based models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. Agricultural Economics. 25. (2/3). 245-260.

Berger, T. and P. Schreinemachers. 2006. Creating agents and landscapes for multi-agent systems from random samples. Ecology and Society. 11. (2). Art.19. Available online at: http://www.ecologyandsociety.org/viewissue.php?sf=25

Berger, T.; P. Schreinemachers; and T. Arnold. 2007. Mathematical Programming-based Multi-Agent Systems to Simulate Sustainable Resource Use in Agriculture and Forestry. Software manual. The University of Hohenheim, Stuttgart, Germany.

Cartographic Publishing House of Vietnam, 1996. National Atlas of Vietnam. 163 p.

Herdt, R.W. and C. Capule. 1983. Adoption, spread production impact of modern rice varieties in Asia. International Rice Research Institute, Manila, Philippines.

Janssen, M.A. 2002. Complexity and ecosystem management: The theory and practice of multi-agent systems. Cheltenham, U.K. and Northampton, Mass.: Edward Elgar Publishers.

Janssen, S.; and M.K. van Ittersum. 2007. Assessing farm innovations and responses to policies: A review of bio-economic farm models. Agricultural Systems. 94(3). 622-636.

Le, Q.B. 2005. Multi-agent system for simulation of land-use and land cover change: A theoretical framework and its first implementation for an upland watershed in the Central Coast of Vietnam. Ecological and Development Series. No.29. Cuvillier Verlag, Gottingen, Germany.

MARD (Ministry of Agricultural and Rural Development), 2005. Viet Nam Forest Sector Indicators and 2005 Baseline Data Report. Electronic reports in website: http://www.vietnamforestry.org.vn/list_news.aspx?ncid=105

Minot, N. and B. Baulch. 2002. The Spatial Distribution of Poverty in Vietnam and the Potential for Targeting, Policy Research Working Paper 2829, the World Bank and International Food Policy Research Institute, Washington DC. USA.

Parker, D.C.; S.M. Manson; M.A. Janssen; M.J. Hoffmann; and P. Deadman. 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Annals of the Association of American Geographers. 93 (2). 314-337.

Phuong, N.T. and E. Foerster. 2003. Bao Cao Dieu Tra Ho Gia Dinh Yen Chau 2003. (The Report of Housheold Survey in Yen Chau 2003). The Social Forestry Development Project Song Da, Vietnam.

Quang, D.V. and T.N. Anh. 2006. Commercial collection of NTFPs and households living in or near the forests: Case study in Que, Con Cuong and Ma, Tuong Duong, Nghe An, Vietnam. Ecological Economics. Vol. 60. 65-74.

Railsback, S.; S. Lytinen; and S. Jackson. 2006. Agent-based simulation platforms: review and development recommendations. Simulation. 82 (9). 609-623.

Rogers, E.M. 1995. Diffusion of Innovations, Fourth Edition, New York: Free press.

Schreinemachers, P. 2006. The (Ir)relevance of the Crop Yield Gap Concept to Food Security in Developing Countries with an Application of Multi-Agent Modeling to Farming System in Uganda. PhD dissertation, The University of Bonn.

Schreinemachers, P. and T. Berger. 2006. Land-use decisions in developing countries and their representation in multi-agent systems. Journal of Land Use Science. 1 (1). 29-44.

Schreinemachers, P. and T. Berger. 2006. Assessing innovation and sustainability strategies with Multi Agent Systems. International Symposium: Towards Sustainable Livelihoods and Ecosystem in Mountainous Regions, 7-9 March 2006, Chiang Mai, Thailand.

Schreinemachers, P.; T. Berger; and J.B. Aune. 2007. Simulating soil fertility and poverty dynamics in Uganda: A bio-economic multi-agent systems approach. Ecological Economics. 64, 387-401.

Schuler, J. and C. Sattler. 2008. The estimation of agricultural policy effects on soil erosion – An application for the bio-economic model MODAM. Land use policy. Doi: 10.1016/j.landusepol.2008.05.001

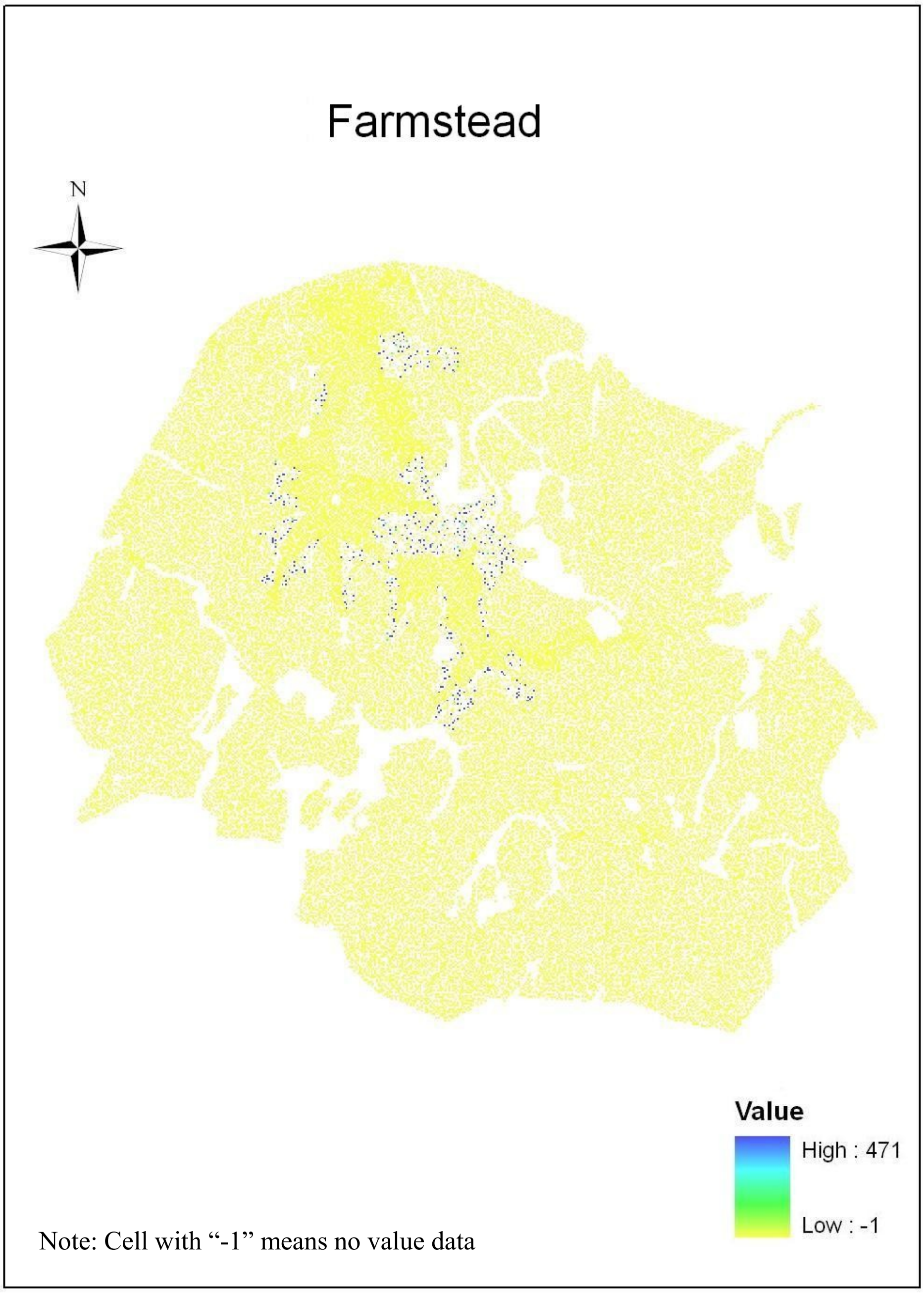
Sunderlin W. D.; D. Müller; and M. Epprecht. 2006. Nguoi Ngheo o Dau? Cay coi o dau? Đat muc tieu xoa doi giam ngheo va bao ton rung tai Vietnam. (Where are the poor? Where are the trees? Target to poverty reduction and forest conservation in Vietnam. Center for International Forestry Research (CIFOR). Jakarta, Indonesia.

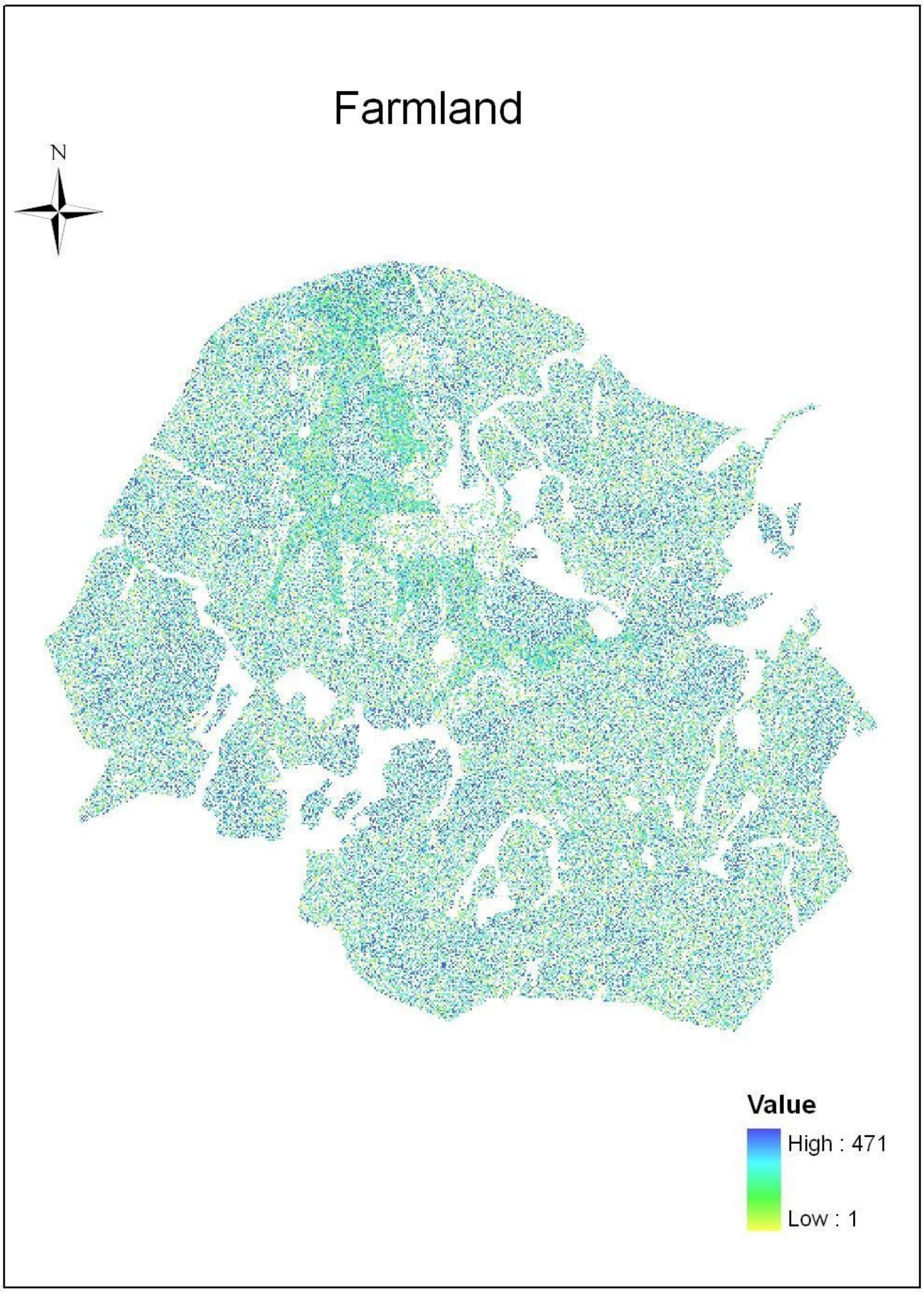
Truong Manh Tien. 2003. Bao ve moi truong voi phat trien cong dong dan cu vung dan toc mien nui. (Environment protection and community development in the habitat of ethnic minorities). Cong San. Vol. 12. 47-50.

Young, A. 1990. Agro-forestry soil conservation. International Council for Research in Agroforestry (ICRAF). BPCC Wheatons Ltd., UK.

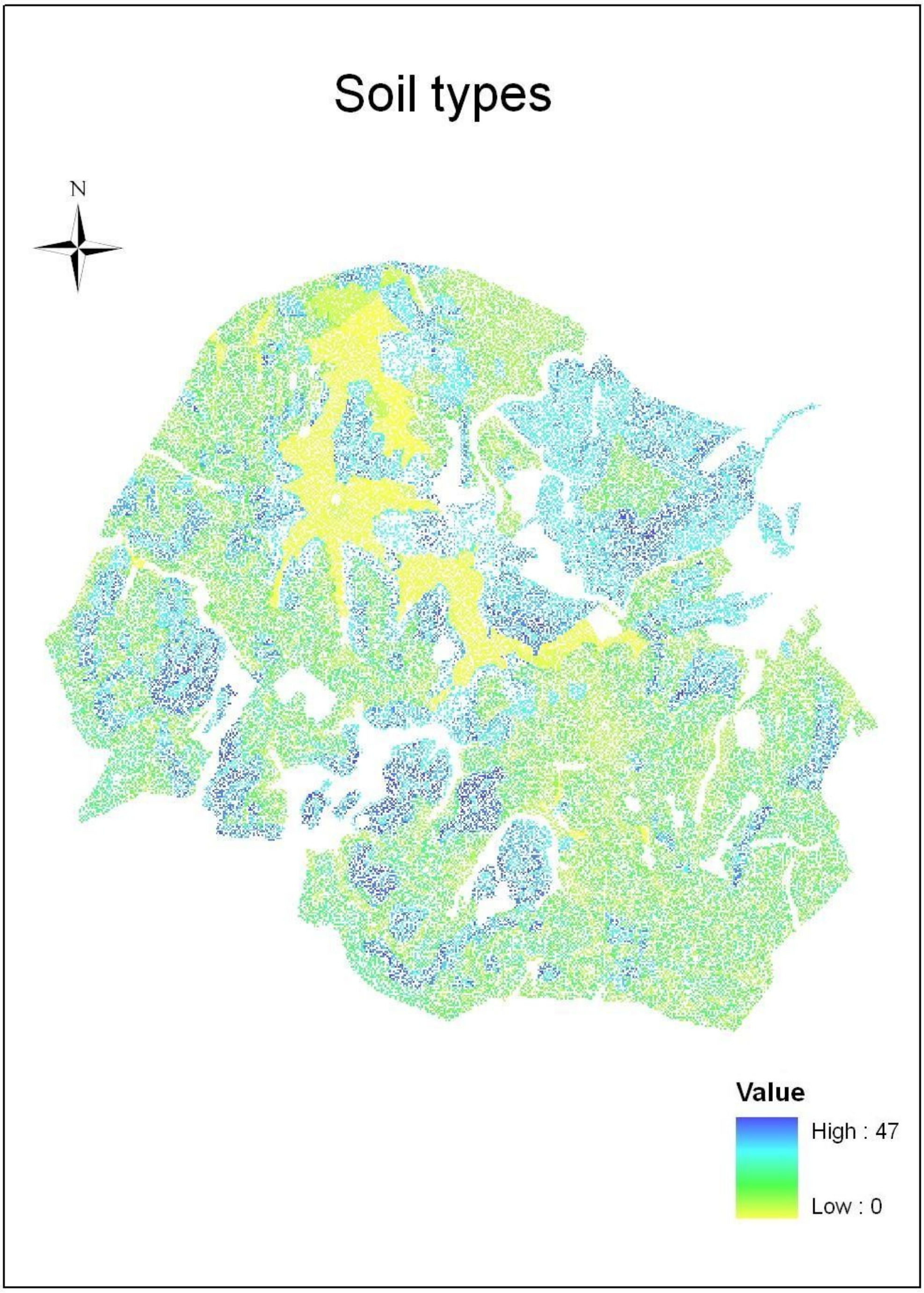
APPENDICES

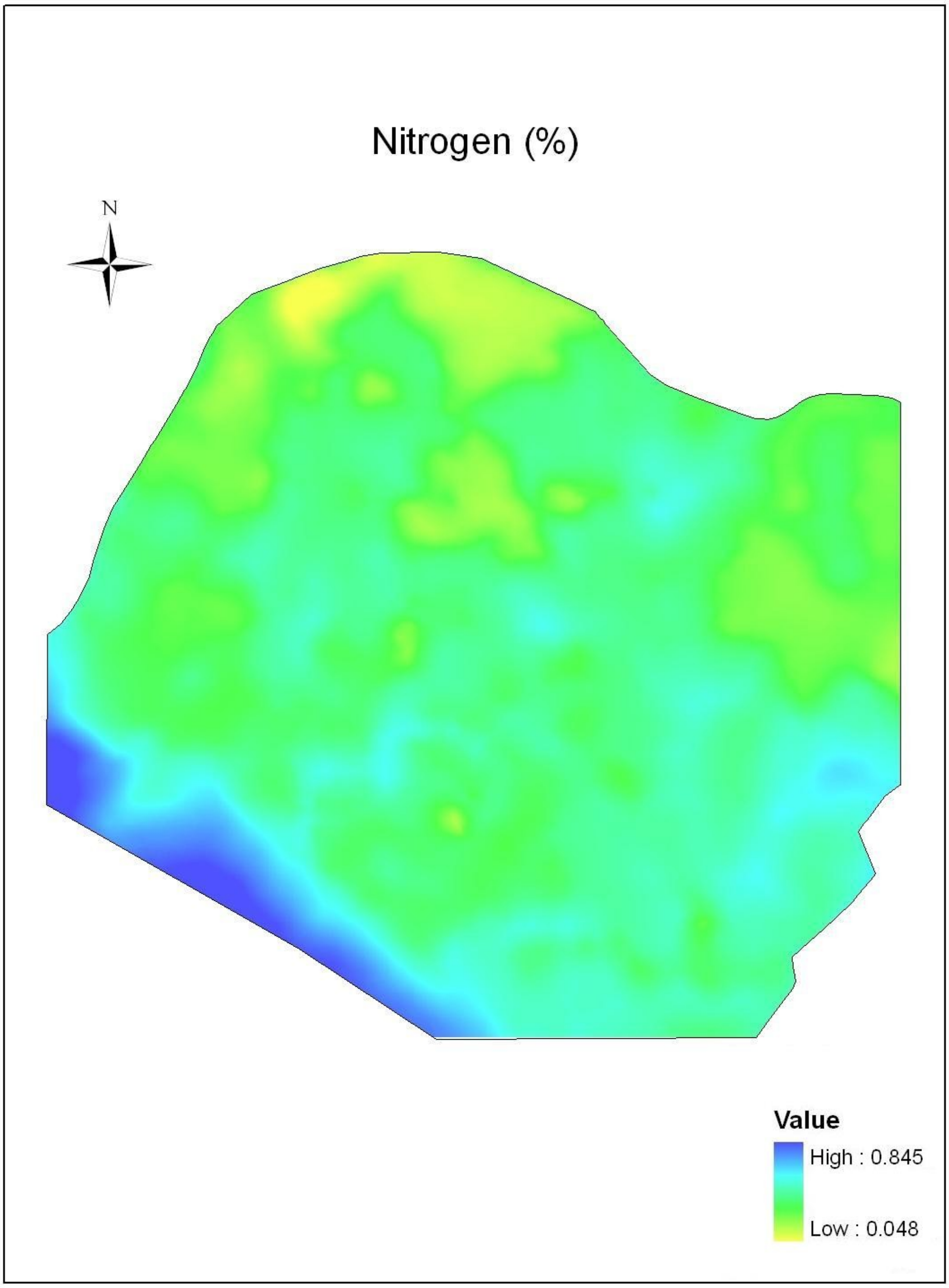
Appendix 1: Spatial maps used in MP-MAS model

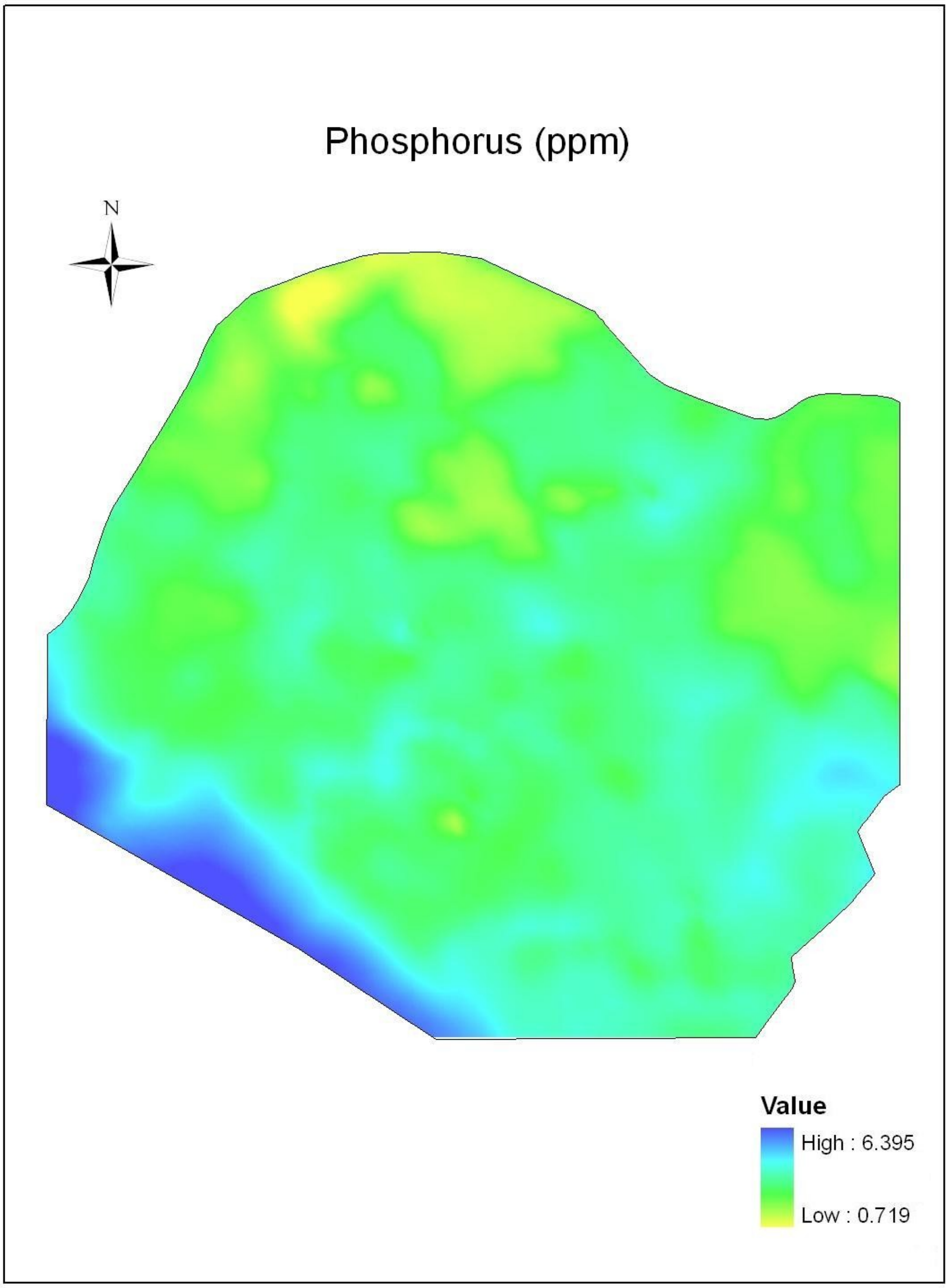


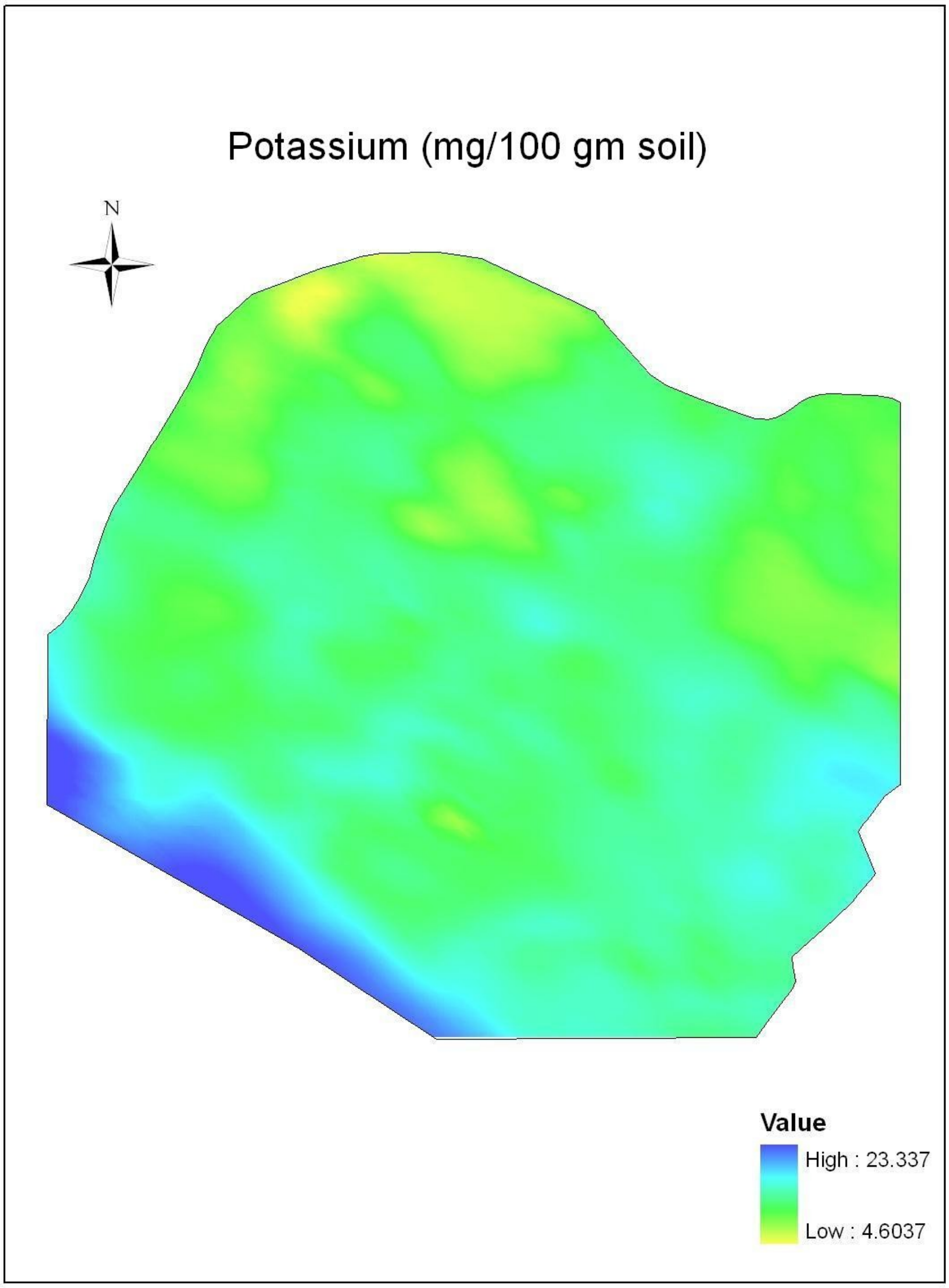


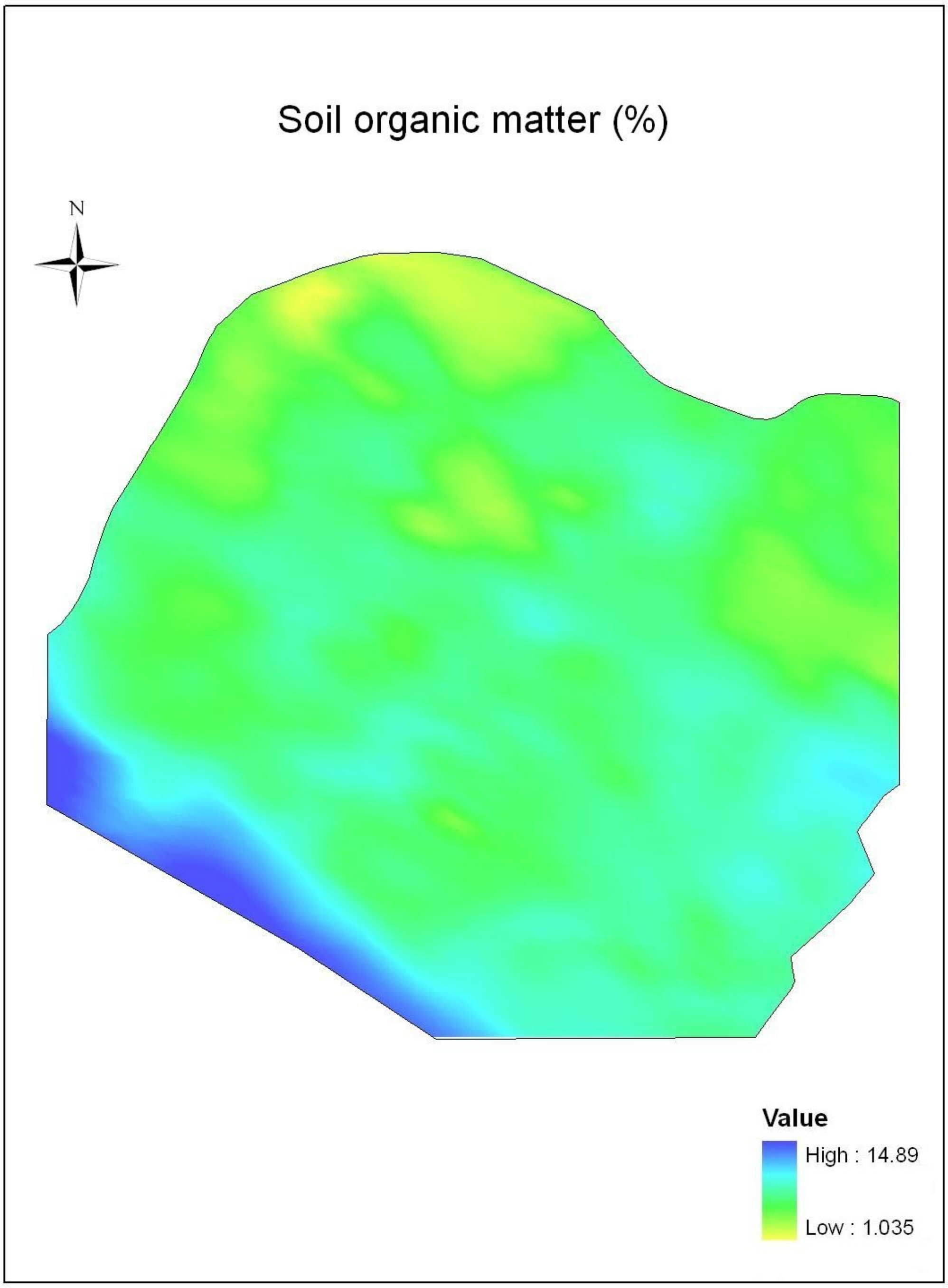
Farmland
N
Value
High : 471
Low : 1

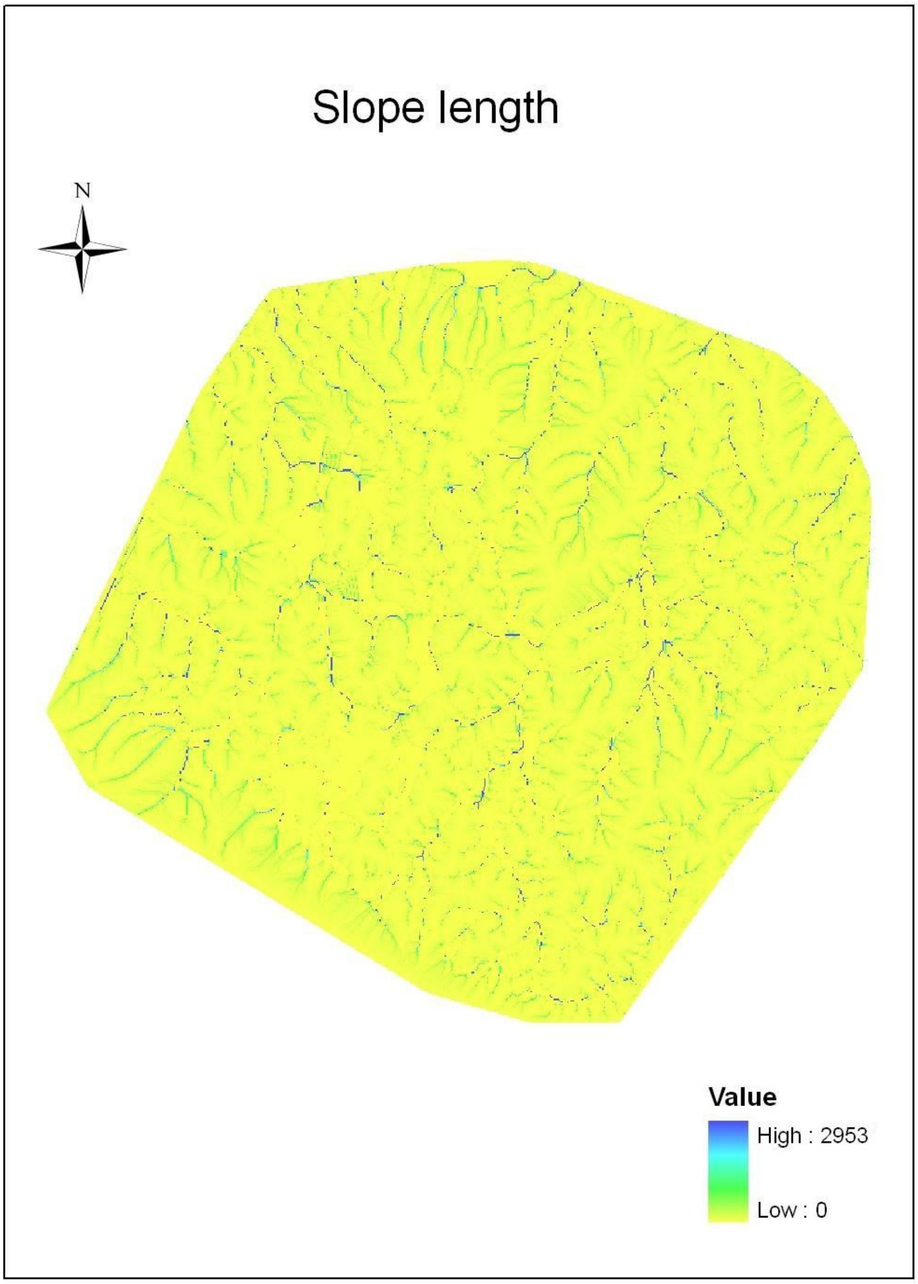

Soil types
N
Value
High : 47
Low : 0


Nitrogen (%)
N
Value
High : 0.845
Low : 0.048

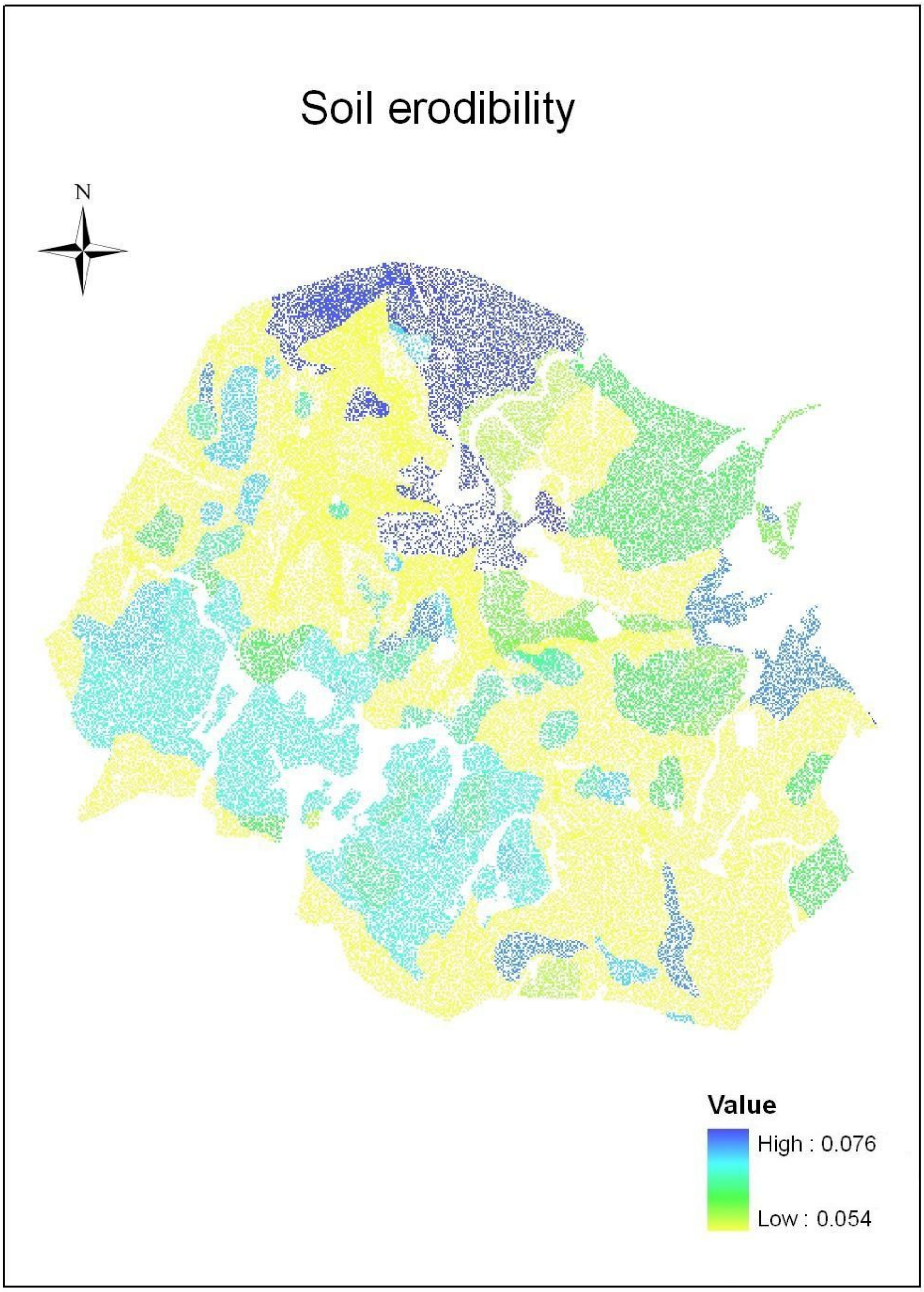

Phosphorus (ppm)
N
Value
High : 6.395
Low : 0.719


Potassium (mg/100 gm soil)
N
Value
High : 23.337
Low : 4.6037


Soil organic matter (%)
N
Value
High : 14.89
Low : 1.035



Slope length
N
Value
High : 2953
Low : 0


Soil erodibility
N
Value
High : 0.076
Low : 0.054

Appendix 2: Minimum, maximum and median value of the clusters

Maximum value of resource endowment

Cluster	Female child (person)	Female adult (person)	Male child (person)	Male adult (person)	Liquidity (000 VND)	Male cattle (head)	Female cattle (head)	Female goats (head)	Male goats (head)
1	0	2	1	2	32,247	1	0	0	0
2	2	1	2	1	28,132	1	2	8	0
3	3	5	2	3	48,586	2	4	4	8
4	2	4	2	6	57,499	2	3	3	0
5	2	4	2	4	370,182	2	4	5	4
6	2	5	2	6	59,049	2	3	4	1
7	3	5	3	3	86,576	2	2	2	2
8	1	4	1	3	92,026	1	2	3	0
9	0	1	2	1	7,334	1	0	2	0

Source: 2008 survey data

Minimum value of resource endowment

Cluster	Female child (person)	Female adult (person)	Male child (person)	Male adult (person)	Liquidity (000 VND)	Male cattle (head)	Female cattle (head)	Female goats (head)	Male goats (head)
1	0	2	1	2	32,247	1	0	0	0
2	0	1	0	1	3,280	0	0	0	0
3	0	1	0	1	5,676	0	0	0	0
4	0	1	0	1	4,966	0	0	0	0
5	0	1	0	1	8,381	0	0	0	0
6	0	1	0	0	9,960	0	0	0	0
7	0	1	0	1	28,077	0	0	0	0
8	0	1	0	2	12,942	0	1	0	0
9	0	1	2	1	7,334	1	0	2	0

Source: 2008 survey data

Median value of resource endowment

Cluster	Female child (person)	Female adult (person)	Male child (person)	Male adult (person)	Liquidity (000 VND)	Male cattle (head)	Female cattle (head)	Female goats (head)	Male goats (head)
1	0	2	1	2	32,247	1	0	0	0
2	1	1	1	1	14,044	0	0	0	0
3	1	1	0	2	20,065	0	1	0	0
4	1	1	0	2	21,642	0	1	0	0
5	1	2	0	2	26,866	0	1	0	0
6	0	2	0	2	28,018	1	1	0	0
7	0	3	1	2	44,389	1	1	0	0
8	0	2.5	0.5	2	46,100	1	1	1	0
9	0	1	2	1	7,334	1	0	2	0

Source: 2008 survey data

The average value of resource endowment

Cluster	Female child (person)	Female adult (person)	Male child (person)	Male adult (person)	Liquidity (000 VND)	Male cattle (head)	Female cattle (head)	Female goats (head)	Male goats (head)
1	0.00	2.00	1.00	2.00	32,247	1.00	0.00	0.00	0.00
2	0.82	1.00	0.91	1.00	14,663	0.18	0.55	1.18	0.00
3	0.76	1.43	0.48	1.62	22,015	0.43	1.10	0.43	0.57
4	0.58	1.70	0.33	1.73	23,814	0.61	1.06	0.45	0.00
5	0.62	1.86	0.64	1.94	39,601	0.54	1.22	0.76	0.26
6	0.63	2.33	0.52	2.04	30,631	0.67	1.37	0.78	0.04
7	0.67	2.89	1.00	2.11	47,627	1.22	1.22	0.44	0.22
8	0.33	2.50	0.50	2.33	45,429	0.67	1.17	1.17	0.00
9	0.00	1.00	2.00	1.00	7,334	1.00	0.00	2.00	0.00

Source: 2008 survey data

Appendix 3: Soil nutrients, income per capita and soil erosion by level of land tax

Scenario	**Available nitrogen (kg/ha)**	**Available phosphorus (kg/ha)**	**Available Potassium (kg/ha)**	**Revenue from maize and cassava (million VND)**	**Income per capital (million VND/per person)**	**Total erosion (thousand tons)**	**Index of revenue from maize and cassava (%)**	**Index of income per capita (%)**	**Reduction of erosion (%)**	**Level of land tax (million VND/ha)**
S1	121.20	37.34	122.45	10.16	5.84	9.21	100	100	0	0
S2	119.83	36.59	123.02	9.15	4.73	8.64	90	81	6	6
S3	118.99	36.29	123.57	8.62	4.33	8.05	85	74	13	8
S4	116.97	35.41	126.04	7.56	4.01	7.02	74	69	24	10
S5	115.88	34.97	127.62	6.75	3.86	5.96	66	66	35	11
S6	106.73	31.75	129.04	3.95	3.74	4.18	39	64	55	12