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Land-Use Changes in the Upper Lam Phra Phloeng Watershed, Northeastern Thailand: Characteristics and Driving Forces

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Abstract
For a typical smallholder agricultural area in northeast Thailand, this paper describes the land-use changes, their main driving forces and their consequences over the last forty years - from the conversion of the original forest to the present agricultural land use.

The area has a relatively short agricultural history. From the 1960s onward, people started to settle in the area and began to clear-cut the forest to grow subsistence crops, such as upland rice and castor beans. After a relatively short period dominated by subsistence crops, the land use rapidly developed into maize-based cash-crop systems. Maize is still the main crop. Since the beginning of agriculture in the area, the farmers practiced continuous cropping. Shifting cultivation was never practiced. Initially, the soil was not tilled, and dibbling of seeds was exclusively practiced. All soil and crop husbandry practices were carried out manually. Due to the influx of more people, the agricultural land area expanded rapidly. Most of the land remains government property. Only recently, limited land-use rights for the farmers are being issued. With the change of the land-use systems over time, i.e., from upland rice to maize, and from subsistence to more market-oriented farming, the agronomic practices also changed adapting to the requirements of the new crops. The application of inorganic fertilizers, herbicides and pesticides became standard practice. The use of these inputs led to a significant increase in land productivity. However, most farmers do not have sufficient capital to purchase all required inputs fore cultivation and they largely depend on private money lenders and middlemen for input supply at extremely high interest rates.

There is a general perception amongst farmers of a considerable soil-fertility decline and that more and more fertilizer needs to be applied to maintain the current yield levels. To realize more sustainable agriculture, land-use technologies need to be adopted at the farm level that increase the efficiency of nutrient and organic matter cycling and reduce soil-degradation risks. Simultaneously, an enabling environment needs to be developed based on appropriate extension services and adequate credit facilities for the farmers.

Keywords: cropping systems, forest clearing, land productivity, land-use change, Thailand

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1 Introduction

The conversion of land from natural vegetation -forest in many cases- to agricultural land uses is often perceived as environmentally degrading, especially in terms of rapidly declining soil quality. Claims are being made that intensively used agricultural areas cannot buffer the adverse effects of agriculture on the environment (ISLAM and WEIL, 2000). However, the need to secure and increase land productivity in order to survive is crucial for many people in rural areas, especially in the developing world, who therefore need to expand -and subsequently develop- agricultural areas in order to secure their livelihood (BROOKFIELD, 2001). Pressure on the land inevitably leads to changes in land use, basically triggered by the need to achieve higher agricultural production (NIELSEN and ZOEBISCH, 2001; ZOEBISCH and DE PAUW, 2002). Land-use changes are typically characterized in terms of changes of crops, land-husbandry practices and inputs used, such as capital, labour, fertilizers and pesticides. (PULLEMAN *et al.*, 2000).

This paper addresses the issues of land-use changes in three typical villages in the rainfed farming areas of northeast Thailand. It aims to provide an overview of the land-use changes in the area in the context of the conditions, the driving forces and the consequences on the management of the land.

It has commonly been observed that clearing and cultivation of forestland leads to a deterioration of the physical, chemical and biological properties of soils and that reforestation measures gradually restore soil quality (ISLAM and WEIL, 2000)(Islam and Weil, 2000). However, with appropriate land-use technologies that are suited to the location-specific needs of an area, even under continued permanent agricultural land use, soil quality can be maintained and improved (KOTTO-SAME *et al.*, 1997). In northeastern Thailand for instance, the intercropping of maize with legumes, such as spineless mimosa (*Mimosa invisa*) or pigeon pea (*Cajanus cajan*) resulted in higher grain yields than the conventional continuous monocropping of maize and led to a better protection of the soil against erosion and an overall improvement of the soil quality (SUWANARIT *et al.*, 1999). Similar positive effects on soil quality have been found with sequential cropping systems, contour tillage, and contour-strip and hedgerow cultivation methods (POUDEL *et al.*, 2000; THAPA *et al.*, 2001).

With increasing pressure on the land, changes in land use that lead to higher land productivity appear to be unavoidable. The rainfed farming areas of northeastern Thailand are typical examples of rapid land-use changes prompted by the rapid increases in productivity needs and expectations of the land users. In order to identify land-use technologies that match productivity expectations with environmental concerns and secure the maintenance of soil quality, it is important to understand the conditions and driving forces that lead to changes in land use.

2 Methodology

2.1 Study area

This paper is based on a case study carried out in three typical villages in the rainfed farming areas of northeast Thailand. The villages (*Ban Pong Chanuan, Ban Takien*

Ngam, and *Ban Thep Nimitr*) are located in the western upper reaches of the *Lam Phra Phloeng* watershed, Nakhon Ratchasima Province, bordering the *Khao Yai National Park*. The area is characterized by a generally hilly topography, with undulating slopes and few flat areas. Elevations range from 200 m.a.s.l. in the northeastern parts to about 1,150 m.a.s.l. in the southwestern parts of the watershed. The climate is influenced by both the northeast and southwest monsoons, leading to a bimodal rainfall pattern with an average annual rainfall of around 1,000 mm. The northeast-monsoon rains occur from November to February, and the southwest-monsoon rains from May to September. The mean monthly maximum temperature ranges between 37° C (April) and 27° C (December), and the mean monthly minimum temperature ranges between 24° C (June) and 14° C (December). The soils in the area are dominantly Ultisols (*Korat* Series) with low inherent fertility (LDD, 2002). Soil textures vary from loamy to clayey sands. Originally, the area was under evergreen forest, which, these days, can only be found in the adjacent *Khao Yai National Park*.

The administrative territory of the three villages has about 48 % agricultural land and 52% forest (incl. dry evergreen forest, secondary natural re-growth, and reforested areas). All of this forest belongs to the national park and cannot be used for farming. Of the agricultural area, 72% are cultivated for field crops and about 18% is covered by orchards. Irrigated vegetables and marigold flowers are important crops, but their areas are small, mainly because of limited irrigation-water availability. Maize is the dominant crop, but significant areas are also planted to mungbean. The main fruit grown is mango, but there are also plantations of custard apple, tamarind, papaya, and jackfruit. The main vegetables grown are eggplant, yellow chili, Chinese kale, and cabbage. The average farm size in the three villages studied is 8.2 ha, ranging from 0.8 ha to 32 ha, with only a few farms with more than 15 ha.

In the lower reaches of the watershed, agriculture has been practiced for a long time and the forests have completely disappeared. The upper reaches of the watershed still have some forest cover, especially in the areas bordering the national park. Since 1980, in this part, considerable areas used for agriculture have been declared 'protected buffer zone' for the national park (i.e., watershed protection areas). Most of this buffer zone has been left for natural forest re-growth, but some areas have been re-afforested recently.

2.2 Data collection

The study is based on individual and group discussions with farmers. For general information on farming systems and practices structured questionnaires were used. The interviews on the land-use changes were of the discussion-type and open-ended. Because of the special interest in the land-use history, only the older farmers, who have witnessed and took part in the initial forest clearing and cultivation of the area -and who have observed the land-use changes since then- have been included in the study. Thirty-eight individual interviews were conducted. During each interview a visit was made to the farmer's fields. In each village, two group discussions were organized with 5 - 6 participants. During the group discussions, typical different land-use successions that took place in the villages were identified and described.

3 From Forest to Cropland: Land-Use Dynamics

The settlement and land-use histories of the three neighboring villages studied are typical for the recent agricultural settlements in the former forested areas of northeastern Thailand. Although the villages followed different pathways there were common general trends of land clearing and land use in the area that led to the current maize-dominated cropping pattern.

Driven first by the subsistence needs of relatively small numbers of settlers, the increased influx of more people and the need to grow cash crops to satisfy cash-income requirements accelerated the forest clearing. After only about three decades the forest cover in the area had disappeared almost completely to make room for agriculture. The villages are located in the buffer zone of the national park and the present forest cover has largely been preserved and re-established due to the land-use restrictions within and in the vicinity of the national park.

Since the 1960s, the land-use in the area has changed remarkably. Initially, the area was dense natural forest. Due to the increasing population, more land was needed to grow crops. From 1960 to 1970, small groups of people settled in the area. They clear-cut patches of forest to cultivate upland rice, cotton, peas, beans, and vegetables for home consumption. The development of agriculture in the area was very slow at that time. Communication and transportation were difficult because there were no roads in the area. In 1960, the boundaries between the *Khao Yai National Park* and the villages were officially established. The Forest Industries Organization (FIO) had forest concessions and the farmers used to fell big timber trees for the FIO. This way, the forest gradually deteriorated. To exploit the timber, a simple road network was developed. The road network also enabled the people to reach the neighboring villages and the district town more easily. This opened market opportunities and encouraged the farmers to produce crops for sale on the cleared land and enabled them to buy other products. Because growing upland rice -used for home consumption- was labor demanding and it could easily be bought at the market it was increasingly being replaced with maize, which could be sold to feed mills, and oil-extraction and starch factories. This was a growing market.

Shifting cultivation was never practiced in the area. After forest clearing, most of the land was directly used for continuous cropping of maize (2 crops per year). This practice continued for about 30 years without regular fallowing. A number of farmers then began to plant mungbean after each maize harvest replacing the second crop of maize within the same year. However, most farmers still continue to plant two crops of maize within a year.
Around 1970, most of the forest had disappeared and maize had become the overwhelmingly dominant crop in the area. The livelihood of the farmers depended almost exclusively on maize. Cotton growing that had also been taken on in the area was stopped due to increasing pest problems, further increasing the area under maize. Around 1971, due to attractive producer prices for mangoes, a considerable number of farmers started to grow mangoes which used to be intercropped with maize for the first three years

after the establishment of the plantations. But already twenty years later, i.e., around 1990, the productivity of the fruit trees had declined considerably. For several years, the trees did not bear any fruits. This was because most of the farmers did not have the skills and experience for adequate tree management, and they did not have the equipment to apply pesticides to the trees. There was no extension service which could provide advice. Therefore many farmers uprooted their mango trees and changed again to growing maize, to vegetables, or both. Thus, the dependency on maize was again increasing. Generally, the farmers now realize that they have to apply more inputs these days to maintain the yields at current levels.

The land the farmers had cleared from the forest remained government property. Some farmers received rights of use for agriculture that could be handed over to their children, but the land could not be sold. However, without full land ownership, the farmers could not get loans from the agricultural or cooperative banks. Small farmers still face significant difficulty to obtain the required investment capital to buy the needed inputs (e.g., machinery hire, seeds, fertilizers, pesticides) for their crops. Most farmers have to borrow money from private sources, especially from the middlemen. The interest rate is around 5 percent per month (i.e., 60% per year). Hence, many farmers depend totally on the middlemen to grow their crops. Because of the high input costs and high interest rates, the farmers cannot build up sufficient savings after harvest to finance the following cropping season, and they feel that they do not have any alternatives to this situation.

4 Land-Use Successions: Driving Forces of Land-Use Change

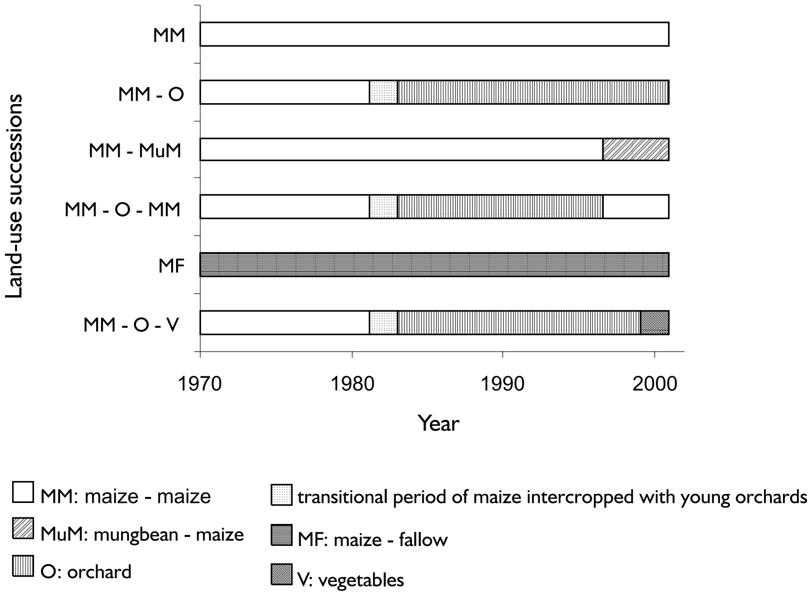
Six typical land-use successions have been identified in the area (Figure 1). All of these successions indicate the clear orientation of the farmers towards cash crops. Maize remains the dominant crop, as maize-maize (i.e., two maize crops per year), maize-mungbean, and maize-fallow rotation. Orchards are increasingly phased out, due to a declining productivity of the trees.

The reasons and driving forces behind the changes in land-use and management are basically based on changing market opportunities and declining productivity (i.e., yields) of crops. Specifically, the driving forces that triggered the change from one crop to another can be characterized as follows:

Forest ⟶ upland rice, cotton, beans, and vegetables
Landless people from other rural areas started to settle in the forest along the streams. Because their livelihood was based on subsistence there was a need for agricultural land. There were no alternative income-generation opportunities. After they clear-cut patches of forest they immediately practiced continuous cultivation which they had already been practiced in their places of origin. They never practiced shifting cultivation typical for indigenous forest dwellers. The first main crops grown were upland rice and vegetables.

Upland rice ⟶ maize-maize (2 crops per year) rotation
After road construction, farmers could easily access the cash-crop market. Rice -the main staple food- was available on the market at relatively low cost, and because of the

Figure 1: Typical land-use successions in the study area after forest clearing.



high time and labor requirement its cultivation was given up. Maize for the market was planted instead because of its attractive producer prices. Moreover, upland rice could only be grown once a year and the land lay fallow until the next main growing season. With maize, two crops per year were possible, increasing cash-earning opportunities.

Maize-maize ⟶ maize-fallow (1 crop per year) rotation
Some of the larger farmers wanted to avoid the risk of drought stress frequently causing failure of the second maize crop due to erratic rainfall and leading to a loss of inputs (e.g., time, labor, fertilizer). Therefore only one crop of maize per year (August- December/January) was planted, followed by a short fallow period until the next year's growing season.

Maize-maize (2 crops per year) rotation ⟶ orchard
Because of attractive prices for mangoes in the early 1970s and a perceived low labor demand, mango-tree plantations were established. Local and regional market opportunities were good. Orchards are still being established, but mainly of custard apples. In the first 3 years after establishment, i.e., before fruit bearing, the plantations can be intercropped with maize. This provides some cash income for the farmer from the plot.

Orchard ⟶ maize-maize (2 crops per year) rotation
Since many farmers converted part of their maize growing areas to mango orchards the prices of the fruits decreased. Some farmers did not have adequate sprayers to apply pesticides to the trees, and the hire of the additionally required labor to maintain the orchards was very costly. In 15 to 20 years old trees, the quality of the fruit also

deteriorated (especially the size of the fruits) and the overall tree productivity declined. There were some years without any fruit on some trees. Therefore, many farmers uprooted their orchards and began to grow maize again. The uprooted trees were made into charcoal for home consumption.

Maize-maize (2 crops per year) ⟶ mungbean-maize rotation
To reduce the risk of drought damage during the flowering stage (September, October), mungbean was promoted by the agricultural extension service as a replacement for the second maize crop in the year. Some farmers changed their maize-maize system to mungbean-maize rotation. Mungbean as a short-life-cycle legume crop fits well into the annual rainfall pattern, and it can reduce the risk of drought damage that exists with the second maize crop.

Orchard ⟶ vegetables
Where irrigation water is available, some farmers changed to horticultural cash crops, such as vegetables (chili, aubergine, mustard, cabbage, Chinese cabbage, kale, etc). Vegetables have good local and regional market opportunities and can earn fast cash income.

5 Changes in Land-Use Technologies

The land and crop-husbandry practices have changed along with the changes in crops and the general availability of inputs and the need for their application, especially fertilizers and pesticides. An overview of the changes in crop and land-husbandry practices by the farmers in continuous maize-maize, maize-orchard, and continuous maize to mungbean-maize land-use successions are given in Tables 1, 2, and 3, respectively. The tables show a general trend to increased use of external inputs and mechanization.

The main observed changes in land-use technologies in the area can be characterized as follows:

Land preparation
Since around 1980, because of the need to cultivate larger areas to secure the increasing requirements for higher farm returns, the farmers have changed from hand hoeing and animal powered tillage to tractor drawn land-preparation. This led to more intensive soil mixing and deeper tillage. Also, due to the nature and capacity of large machinery, the direction of tillage is often across the contour, thus encouraging soil erosion. The equipment is almost exclusively hired from contractors because the farmers cannot afford to purchase and maintain expensive machinery.

Crop varieties
Almost all farmers have abandoned the local varieties and are using hybrids that were introduced by the agricultural extension service and the seed companies through the middlemen who provide the inputs to the farmers. The main reason for the adoption of hybrid varieties was the higher yields. But these varieties also require high fertilizer input. Several different hybrid varieties are available and the farmers usually use the varieties provided by the middlemen.

Table 1: Overview of the changes in land and crop-husbandry practices: continuous maize - maize land-use succession (2 crops per year)

Activity	Period			
	1961-1970	1971-1980	1981-1990	1991-2001
Variety selection	- Local (Kaen Daeng)	- Local Kaen Daeng)	- Local - Suwan (started around 1986)	- Suwan*(about 1986-1993) - 888 (about 1994-1995) - Pioneer (1996-1997) - Cargil** (After 1997)
Land preparation				
- Ploughing	- Manual	- Tractor	- Tractor	- Tractor
- Ridging	- Manual	- Cattle/Buffalo	- Tractor	- Tractor
- Seeding	- Manual	- Manual	- Tractor	- Tractor
Planting method	Dibbling	Broadcasting	Sowing machine	Sowing machine
Weed control	- Hand weeding	- Hand weeding - Buffalo ploughing between rows	- Hand weeding - Buffalo ploughing between rows	- Introducing herbicides Grammoxone (2.5-3 l ha^{-1}) Atrazine (3-3.5 l ha^{-1}) About 25 d.a.p. ***
Fertilizer application	- No fertilizer used	- No fertilizer used	- No fertilizer with local variety	
First application Amount (kg ha^{-1}) Type			- With land preparation - 60 to 70 kg ha^{-1} - 16-20-0 or 20-20-0 or 15-15-15	- With land preparation - 135 to 140 kg ha^{-1} - 16-20-0 or 20-20-0 or 15-15-15
Second application Amount (kg ha^{-1}) Type (and or not)			- 45 d.a.p*** - 70 to 80 kg ha^{-1} - 16-20-0 or 20-20-0 or 15-15-15	- 45 d.a.p*** - 155 to 160 kg ha^{-1} - 16-20-0 or 20-20-0 or 15-15-15
Second application Amount (kg ha^{-1}) Type			- 45 d.a.p*** - 80 to 90 kg ha^{-1} - Urea	- 45 d.a.p*** - 180 to 185 kg ha^{-1} - Urea
Harvesting	- Picking cobs by hand	- Picking cobs by hand	- Picking cobs by hand	- Picking cobs by hand
Threshing	- Manual	- Manual	- By middlemen or cooperative	- By middlemen or local cooperative
Residue and fallow management	- Residue burned after harvest; land left bare for about 2 months until next crop	- Residue burned after harvest; land left bare for about 2 months until next crop	- Residue burned after harvest; land left bare for about 2 months until next crop	- Residue bent down and left in the field until the next land preparation (practice started 1997)

Notes: * Suwan series (1 or 2 or 3 or 5) ** Cargil varieties (919 or 929 or 939 or 949 or 979 or 717 or 747)

*** dap = days after planting

Table 2: Overview of the changes in land and crop husbandry practices: Maize to orchard land-use succession

Particular	1961-1970	1971-1980	1981-1990	1991-2001
Land preparation - Ploughing - Rowing - Seeding	 - Manual - Manual - Manual	 - Tractor - Cattle/Buffalo - Manual	 - Orchard plantation (fruit trees)	 - Orchard plantation
Variety selection - Local (Kaen Daeng) - Suwan	 - Local - Local - Local	 - Local - Local - Local	 - Local - Suwan - Orchard;Local*	 - Orchard; Local and improved**
Planting method	- Dibbling	- Dibbling - Broadcast, some who have cattle or buffalo	- Sowing machine - Spacing (Inter-crop planted maize with orchard)	- After 4-5 years intercropping, stopped maize planting in the orchard. Grafting with improved variety during rainy season when the trees are 8-9 years old.
Weeding	- Hand weeding	- Hand weeding or buffalo ploughing	- Hand weeding or buffalo ploughing	- Hand weeding or buffalo ploughing - Cutting grass by knife (2 times per year) or ploughing with small tractor between rows of trees
Fertilizer application - Time - Amount - Type - Method	- No fertilizer used	- No fertilizer used	- No fertilizer used	- Started to apply about 5 years ago - After pruning - 0.5 to 1 kg per tree - 16-20-0 or 15-15-15 - Basal placement
Pruning				- 1 time per year after harvest - Some farmers: 1 time every 2-4 years - Some farmers: never prune
Harvesting - Yields - Fruits (buying)	- Manual (maize)	- Manual (maize) - Local: (3500 - 3600 kg ha^{-1} - Suwan: 4300 - 4400 kg ha^{-1}	- Manual (orchard) - 60 kg per tree - By middlemen	- Manual (orchard) - 60 kg per tree reduced to → 0-20 kg per tree - By middlemen
Residue management	- Burned after harvest	- Burned after harvest	- Piling of the pruned branches at the base of the trees	- Piling of the pruned branches at the base of the trees and - Some make charcoal by clear-cut of mango trees for home consumption
Land management	- About 2 months bare land between successive crops	- About 2 months bare land between successive crops	- About 2 months bare land between successive crops	- Cattle grazing in the orchard field; some leave as it is, and some clear-cut (18-20 yrs old fruit trees) and change to maize and/ or vegetable cultivation

Notes: *Kaew ** Nam dok mai, Fa lan, Keuw Sawey, Thong dam, Oak rong, Nong saeng, Pim sean

Table 3: Overview of the changes in land and crop husbandry practices: Maize - maize to mungbean - maize rotation land-use succession

Particular	**1961-1970**	**1971-1980**	**1981-1990**	**1991-2001**
Land preparation - Ploughing - Ridging - Seeding	 - Manual - Manual - Manual	 - Tractor - Cattle/Buffalo - Manual	 - Tractor - Tractor - Tractor	 - Tractor - Tractor - Tractor
Variety selection	(maize) - Local (Kaen Daeng)	(maize)	(maize) - Local - Suwan (started about 1986)	(maize, mungbean) - Suwan - 888 - Pioneer - Cargil - local variety for mungbean
Planting method	- Dibbling	- Dibbling or broadcast	- Sowing machine	- Sowing machine
Herbicide application - Time - Amount (kg/ha) and type	- Hand weeding	- Hand weeding or buffalo ploughing	- Hand weeding or buffalo ploughing	- Start to use - 25 d.a.p. - 2.5 to 3 l/ha, Gramoxone - 3 to 3.5 l/ha, Atrazine
Fertilizer application (for maize) - Time (first) - Amount (kg/ha) - Type - Time (second) - Amount (kg/ha) - Type (and /or/not) - Time (second) - Amount (kg/ha) - Type	- No fertilizer used	- No fertilizer used	- Not used for maize, local variety	 - With land preparation - 60 to 70 increased to 135-140 - 16-20-0 or 20-20-0 or 15-15-15 - 45 d.a.p. - 70 to 80 increased to 155-160 - 16-20-0 or 20-20-0 or 15-15-15 - 45 d.a.p. - 80 to 90 increased to 180-185 - urea
(for mungbean) - Time - Amount (kg/ha) - Type - Hormone				- With land preparation - 89 - 16-20-0 or 15-15-15 (only new farmers use) - Gibberellin + mixed nutrients (1l/ha); spray 45 d.a.p (almost all farmers use)
Yields (kg ha^{-1})	- Local: 3500-3600	- Local: 3500-3600	- Suwan: 4300-4400 - 888: 4400-4500 - Cargil: 5100-5200	- mungbean: 600-650
Residue management	- Burned after harvest	- Burned after harvest	Burned after harvest	Bent down and leave in the field until next land preparation
Fallow period	2 months bare land	2 months bare land	2 months bare land	2 months fallow after mungbean & 2 months fallow after maize

Use of fertilizers
Fertilizers have only been used widely for the past 5 years, and only for the hybrid varieties. While all farmers use fertilizers for maize, only a few apply fertilizer to mungbean. The rates of application have doubled since fertilizer was first used, from around 210 kg ha^{-1} five years or longer ago to about 470 kg ha^{-1} at present.

Use of herbicides and pesticides
When crop cultivation began in the area, farmers practiced hand-weeding, using bush knives to cut the weeds (i.e., mainly grasses). With the introduction of draught animals (i.e., buffaloes) ploughs were used to control the weeds. With increasing agricultural mechanization, weed and pest control with herbicides and pesticides has eventually replaced mechanical weed control.

Pruning of fruit trees
Many farmers do not prune their trees regularly. However, they do apply some fertilizer. Around 1985, the fruit yields of mango trees were about 60 kg per tree and year. Current yields have dropped to about 20 kg per tree and year. Some of the 18-20 year old trees have stopped producing fruit. This has been the reason for increased uprooting of the trees.

Harvesting and threshing
Initially, both harvesting and threshing were done manually. Cob harvesting is still done exclusively by hand, but since about 1990, threshing is only done by machinery at the agricultural cooperative.

6 Technology-Development Needs and Options

The changes in land use also brought along changes in crop and land husbandry practices. More intensive cultivation of larger areas led to a higher degree in mechanization, especially soil tillage. Expectations for higher crop productivity led to the introduction of hybrid maize varieties together with chemical fertilizers and pesticides. This again increased the level of inputs needed to produce a crop. Thus investment costs increased beyond the capacity of most farmers and there was a need for credit.

The farmers have no control over the sale of their maize crop, because they are bound to deliver their harvest to the creditors to pay back their loans 'in kind'. This creates a permanent dependency on the money lenders and the farmers effectively become contract workers for the creditors, with no or very little profit and virtually no room for long-term investment into the development of their farms. The farmers are aware that, in the long term, the fertility of their soils will decrease because of a lack of soil-fertility maintenance measures and inappropriate soil-tillage practices that enhance soil degradation and erosion. With the present system, the sustainability of farming in the area is at risk.

There is little hope in the short term for effective changes of the general economic and institutional frameworks within which the farmers operate. The farmers realize the need for improvements (change) but they are not in a position to make investments beyond the required level to produce the next crop. At the farm level, financial constraints limit larger investments. The choice of options is therefore limited to measures that economize inputs and changes in practices that do not require additional investments (neither labor nor cash). There is, therefore, a need to develop an array of simple and low-cost adaptations to the present land and crop husbandry practices that could have a positive impact in the long-term.

To prevent a further degradation of the resources, soil-fertility improvement measures are needed that have long-term effects. Maize is the overall dominant crop in the area, reinforcing the dependency of the farmers on a single commodity. To reduce this dependency -and its obvious risks- diversification of agricultural production into other marketable products is desirable. Niches need to be identified that provide improved opportunities for income generation with low initial investment requirements that reduce the current dependency on the middlemen. The diversification of horticultural crops -including fruit trees-, the introduction of small livestock and the introduction of 'organic farming' products could tap growing markets in the cities.

No single technology improvement will lead to a sustainable improvement of soil fertility and yield levels. Because of their close inter-linkages, the soil (land) and crop management systems and practices need to be addressed as a whole. The study identified the following technology-development needs that are assumed key factors for the overall improvement of land productivity in the study area. However, there is no single method that can improve land productivity.

6.1 Land-husbandry options

Water conservation
Options for soil-moisture conservation and water harvesting should be explored to bridge the temporal and erratic soil-moisture shortages that occur during the dryer periods of the year, i.e., between October and February.

Appropriate mechanization
Tractors have replaced animal power to cultivate larger areas and reduce seasonal labor shortages. Some larger farmers have their own machines. Those who do not have machines hire them from others at high cost. There is a need to develop farm machinery and farm-machinery networks that are appropriate and affordable for the resource-poor farmers in the area.

Improved soil management and tillage
Contour tillage should be promoted. The type and intensity of the tillage presently practiced also destroy soil structure, and therefore have a negative effect on soil-moisture storage and nutrient-uptake efficiency. The tillage systems need to be more conservation-oriented. They need to be adapted (modified) to reduce runoff formation and improve soil structure through the incorporation of organic matter (e.g., residues, mulches, manure). This would contribute to a gradual improvement of soil fertility and stabilization of yields on a more sustainable level (Cannell and Hawes, 1994; Papendick and Parr, 1997; Reeves, 1997).

Residue management
Burning of the crop residue immediately after harvest is common. Most farmers do not know the beneficial effects of good crop-residue management on the soil quality. They need to be advised of the values of crop residue to protect the soil from erosion (i.e., as a mulch) and to improve the soil quality, and hence productivity of their fields.

6.2 Crop-husbandry options

Crop and variety diversification
Crop diversification will reduce the overall risks of production (climatic and economic) and contribute to a more ecologically balanced and sustainable use of the limited natural resources in the area. The local varieties (especially of maize) have been entirely replaced by hybrid varieties. Because farmers cannot use the seeds from their harvest of hybrid varieties for the following season, they are forced to buy new seed material each year. Local varieties, although lower in potential yield, also require lower input levels, and thus the overall net farm return may be improved. Farm-level research is needed to adapt the maize-based cropping systems to a lower input level.

Legume-based crop rotation
Legumes could contribute substantial levels of nitrogen to the succeeding crop. According to RERKASEM and RERKASEM (1994) who conducted research in northern Thailand, growing legumes, such as *Mimosa invisa* or special manure species, such as *Sesbania rostrata* during the fallow periods could easily provide 100-200 kg N ha^{-1}. These plants would also provide protective ground cover during the fallow periods, reduce runoff and soil erosion, and increase soil moisture retention (LIN, 1997). For the northeastern region of Thailand, POLTHANEE *et al.* (2002) found that mungbean residue incorporated into the soil increased pH and soil organic matter and the availability of P and K. Hence, legume-based cropping systems have potential to improve soil productivity in the area.

Optimizing the use of fertilizers
The farmers apply as much inorganic fertilizers as they can afford to increase crop yields. They do not know the required optimum application rates. Advice from the agricultural extension agencies is not readily available to the farmers.

Pest management
Farmers are increasingly facing insect and disease problems, especially in vegetables and fruit trees. They do apply pesticides, but according to the principle '*a-lot-helps-a-lot*'. They get their information from their neighbors or the companies that sell the products. The instructions on the packages do not seem to be followed. The excessive application of chemicals will have negative effects on health and the environment.
Awareness and training on the hazards of pesticide application and the proper dosages should be made a priority in agricultural extension.

Improved fruit-tree husbandry
Presently, mango trees that are between 15 and 20 years old have a very low or no production at all, although they have a high potential for production in the area, and there is a market for quality fruits. Instead, clear-cutting of the trees is common in

order to make space for other crops, such as maize and mungbean. There is a need to introduce appropriate tree-husbandry practices that enhance tree productivity.

Crop - livestock integration
Livestock raising is practiced by a few farmers only, and mainly for household consumption. Maize and other farm produce and crop residues could be used as livestock feed for a more commercially-oriented livestock enterprise that would generate additional income for the farmers. Livestock integration would also contribute to the long-term improvement of soil quality and hence productivity.

6.3 Support-services options

Effective extension service
The farmers practice agriculture by experience and they learn from their neighbors. The agricultural extension should provide services that address the real needs of the farmers in a more participatory (bottom-up) and less prescribed (top-down) way, as is currently done.

Adequate credit facilities
The smallholders are entangled in a debt cycle. In case of crop failure due to inadequate rainfall, they may even lose their assets. Options that address the capital needs of the farmers should include the setting up of saving funds and a smallholder credit scheme, facilitated by the government that minimizes the dependency on middlemen.

7 Conclusions

The land-use dynamics in the area and their driving forces are complex. The study has shown that changes in land use do not happen randomly. They are largely rooted in the economic circumstances of the time, the dependency of the land users on their limited land and capital resources and an increase in productivity needs and expectations. The different technology options outlined are apparent. However, they only address individual aspects of the land-use system and the land-management practices. Without an appropriate institutional framework that sets the foundations for investment in land and offers choices for the farmers, substantial productivity improvements that also ensure the conservation and enhancement of the land resources will most likely not materialize.

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