Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Northeastern Thailand

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Abstract

Lands of northeastern Thailand are sloping and fragile. A large proportion of these soils are degraded due to soil erosion. Degraded soils are one of the major constraints for agricultural production in this region. ICRISAT in collaboration with the Department of Agriculture, Land Development Department, and Khon Kaen University, Thailand started a project in 1999 with the financial support from the Asian Development Bank to improve the management of natural resources for sustainable rainfed agriculture through integrated watershed approach. This paper summarizes all the research work carried out for three years during the project period. This includes selection of benchmark site in the ecoregion, baseline surveys, establishment of monitoring devices and various interventions in cropping systems, land and water management and fertility management areas, and human resource development. The initial results of research indicate a reduction in soil erosion and improvement of crop yields due to various interventions. There is sufficient scope to scale up this work in the ecoregion. The details of various activities undertaken and the outputs are presented in the paper.

Agricultural production in northeast (NE) Thailand compared to other regions is diverse but mainly dependent on rainfed production and constrained due to moderate to low seasonal rainfall, lack of water during the dry season, undulating terrain, and poor soils. In NE Thailand only 8% area is irrigated and remaining 92% is either rainfed or partially irrigated with the water harvested from higher slopes. Besides, in most part of the northeastern region the underground water is mostly saline because of the underlying rock salt geological formations.

Soils are mostly degraded primarily due to the predominance of fragile shallow and eroded soils. The common land use practices are mainly in the form of shifting cultivation; however, farmers draw a distinction between shifting cultivation and the more common practice of “land rotation farming”. Under such a practice, land is fallowed for 3–5 years for soil fertility regeneration. With increasing population landholdings are becoming smaller and smaller resulting in intensifying crop production to fulfill the demands of food. Alongside, however, the soil erosion has also increased and serious soil degradation is taking place. Due to frequent plowing of land, bush regrowth gets reduced so that there is little vegetative cover to protect the land. Therefore, land degradation by soil erosion has lately increased, mainly due to the adoption of inappropriate new production technologies.

Significantly, more than 95% lowland paddy in NE Thailand is also grown under rainfed agriculture. The cropping systems in rainfed agriculture include maize as a cash crop on the high slopes and upland rice on the lower slopes; tree crops and fruit trees are usually

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grown close to supplementary water resources on the lower slopes. Sometimes, legumes and cereals are rotated with upland rice and maize, according to soil fertility and economic returns. Cassava is another major crop.

The Environment and Natural Resource Degradation

The basic constraints of rainfed agriculture impact several soil degradation processes individually or interactively at different levels of land use hierarchy. At the highest level of toposequential hierarchy, soil erosion from steep slopes is extremely severe because the land preparation is done along the slope by tractors. This practice substantially increases soil erosion. Forest fires, particularly during the extended dry periods, and unavailability of water during dry periods constrain establishing plantations on steep slopes. In the mid-slopes, the second level of toposequential hierarchy, some soil conservation practices can be applied to reduce soil erosion by flexible land preparation, introduction of smaller plots (<1 ha), which shorten slope lengths, and growing alternative crops. For the relatively flat undulating area, the third level of toposequential hierarchy, soil erosion is low due to the presence of trees and more care taken by farmers to conserve lands. Therefore, classification of land types is needed for matching appropriate technology options to combat soil erosion. Moreover, where the soil erosion is not severe, nutrient depletion may well be the cause of decline in productivity in low input intensified systems (Table 1). In the intensified production systems, soil acidification is taking place either in the subsoil or in the topsoil or in both. All these problems have resulted in decline in crop productivity, and have eventually restricted introduction of alternative crops. Some off-site effects are unabated soil erosion, which has led to public health problems of poor quality water, siltation of reservoirs resulting in a decline of water and fish resources, and related environmental issues. Other off-site effects of land degradation include further encroachment and clearing of forest for new fertile land by the farmers thus setting in motion a continuous cycle of decline in reserve forest resources. This is a vicious problem for sustaining natural resources in the rainfed agricultural areas.

To reduce the negative effects of conventional farming practices on the degradation of land, Thai institutions and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), with the assistance from the Asian Development Bank (ADB), had initiated a pilot rainfed agriculture project in 1999 in NE Thailand. The objectives of the project are to:

- Evaluate the degree and potential of land degradation in NE Thailand.
- Screen and identify appropriate existing technologies to control soil degradation.
- Evaluate improved conservation-effective land and water management technologies to rehabilitate degraded soils.
- Field test new technologies to sustain productivity and minimize land degradation.

Selection of Benchmark Watershed Site

In March 1999, a team of scientists from the Department of Agriculture (DOA), Land Development Department (LDD), and Khon Kaen University (KKU) in Thailand and ICRISAT identified Tad Fa watershed for on-farm benchmark research and development. The site is situated about

Table 1. Nutrient loss (t yr^{-1}) in different regions of Thailand.

Region	Nitrogen	Phosphorus	Potassium
Northern	38,288	4,467	75,588
Northeastern	18,896	1,212	91,644
Eastern	17,890	1,074	30,860
Southern	17,310	453	13,254

Source: Land Development Department.

150 km northwest of Khon Kaen. It is at a junction of three big watersheds namely Mae Khong in the northeast, Chi in the east, and Pasak in the southwest (Fig. 1). Tad Fa watershed represents the "ecoregion" covered by these three watersheds which cover 47,000, 49,480, and 15,780 km^2 respectively. Tad Fa watershed has 2,500 ha land, which is a part of "Nam Chern" sub-watershed (2,920 km^2) in the Chi watershed. The Tad Fa watershed falls in two provinces. The eastern part of river Tad Fa is in Khon Kaen Province which has nearly 700 ha while the western side is in Petchabun Province. All the research and development work was carried out in the eastern part of Tad Fa watershed called Huay Lad covering 200 ha cultivated land spread in two villages, Ban Tad Fa and Ban Dong Sakran.

Research and Development

The following research and development activities were undertaken:

- Collection and analysis of ecoregional database to identify constraints in the ecoregion and yield gap analysis to find out the scope for yield improvement in the ecoregion.
- Participatory rural appraisal (PRA) of Tad Fa (eastern part) watershed to identify and prioritize the constraints for enhanced crop production on sustainable basis while conserving the natural resources.
- Strategic research to overcome nutrient constraints as well as to quantify land degradation.
- On-farm development and evaluation of various technologies through farmer participatory approach.
- Continuous monitoring and evaluation of improved options.
- Human resource development of the national agricultural research system (NARS) researchers and farmers through various training programs, workshops, and field days.

Ecoregional Database Analysis

The report contains information on the agroecology of three main watersheds (Mae Khong, Chi, and Pasak) surrounding Tad Fa. Biophysical and

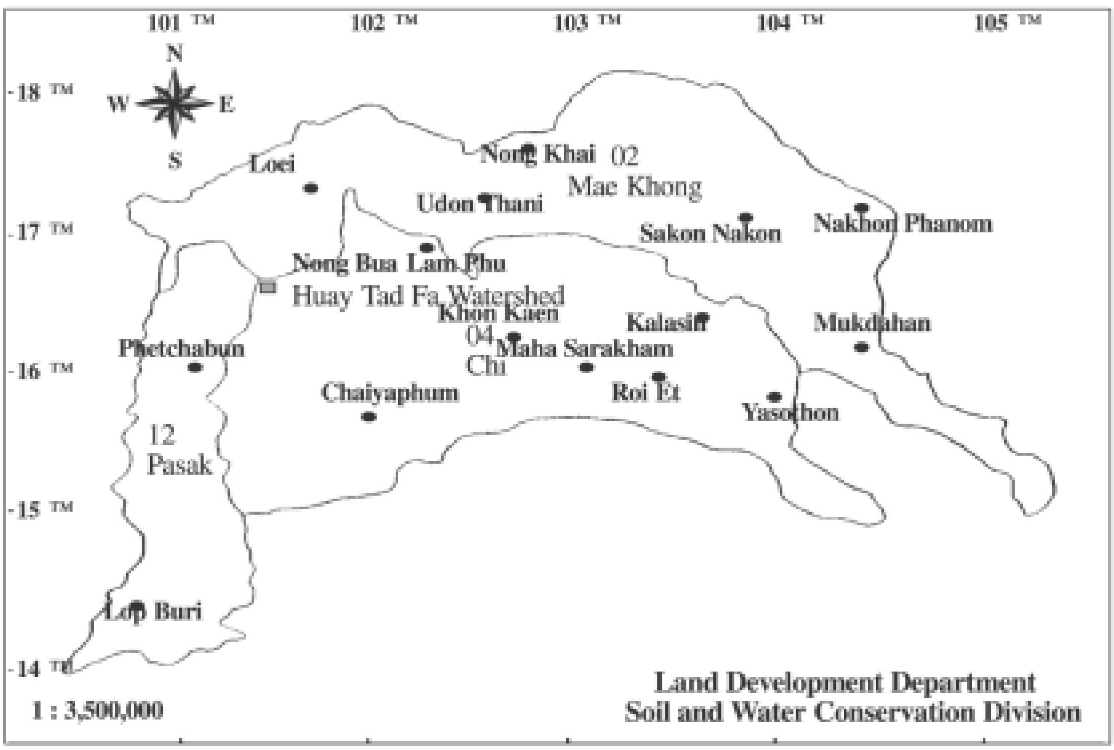

Figure 1. Tad Fa wataershed in NE Thailand.

socioeconomic data were collected from secondary sources. Tad Fa watershed is tropical (26–28ºC). The annual rainfall is 1200–1400 mm and evaporation is 1900–2000 mm. Topographically it has sloping-upland complexes; soils are mostly Ustults and the land use is mostly comprised of forestry, agroforestry, horticulture, and field crops.

Physical constraints

No rainfall in the dry season (November to March) is a major constraint. A less important constraint is the high relative humidity in the wet season (June to October) which encourages pests and diseases in dryland crops like maize.

Relief is a major constraint in hilly and mountainous terrain. The steep and uneven slopes make cultivation difficult and result in rapid runoff of rainfall, accompanied by sheet and gully erosion. Flooding of lowland is also a major constraint resulting in low yields during intensive rains.

Low soil fertility affects large areas in highlands and strongly leached soils on slightly higher terrain in lowlands. Shallow soil depth and lateritic gravel aggravate the fertility problem. Loss of applied nutrients occurs during the wet season, especially on steep slopes. Shallow soils have reduced water-holding capacity in the soil profile, limit rooting depth, and increase erosion hazard.

Technological constraints

A large number of technological innovations are available to overcome physical constraints like irrigation, drainage, flood control, systems of highland agriculture and forest conservation, application of fertilizers and pesticides, weed control, and seed supply. But these technologies should be modified as per the characteristics of the location and problem.

Institutional constraints

Since Thailand has a well developed research, training, extension, and agricultural credit system there are minor institutional constraints. However, farmers' groups or cooperatives to manage natural resources are not prevalent.

Socioeconomic constraints

Farmers are economically poor and education in the family in this region is quite low. Thai farmers are quite hard working and adaptable. Since 1975 even population growth has been checked which may result in stopping further fragmentation of land. The government has provided infrastructural support and even guarantees minimum farm-gate price for certain crops.

Yield Gap Analysis

Five major crops (rice, maize, soybean, groundnut, and sunflower) of NE Thailand were chosen for the study. Experiment station yields, representative country yields, and regional yields have been compared with the crop yields harvested by farmers in NE Thailand. The average yield of rice in NE Thailand is 1.8 t ha^{-1} compared to experiment station yield of 3.4 t ha^{-1} (Table 2). The yield gap is 1.7 t ha^{-1}; however, it is only 0.2 t ha^{-1} when compared with the country's average yield. The average yield of maize in NE Thailand is 2.5 t ha^{-1} while experimental station yield is 4.7 t ha^{-1}, and the country's average yield is

Table 2. Average crop productivity of five crops in different regions of Thailand in 1998.

	Yield (t ha^{-1})				
Region	Rice	Maize	Soybean	Groundnut	Sunflower
Northeastern	1.8	2.5	1.2	1.3	1.5
Northern	2.8	2.9	1.2	1.5	1.5
Central Plain	2.9	3.1	1.2	1.5	1.5
Southern	2.1	2.6	1.3	1.1	–
Country	2.0	2.8	2.8	1.4	1.5

2.8 t ha^{-1}. The NE region is further subdivided into highland, upland, and lowland areas. Maize yield is 1.5 t ha^{-1} in highlands, 2.4 t ha^{-1} in uplands, and 3.5 t ha^{-1} in lowlands. Even though water may not be limiting for the rainy season maize, it clearly indicates the degradation of soil in the highlands and uplands.

Participatory Rural Appraisal of Tad Fa Watershed

A PRA was conducted in 1999 in the eastern part of Tad Fa watershed, which was further divided into three parts based on three streams namely Samtada, Lad, and Wang Deun Ha. In addition to these three agricultural areas, two additonal forest watersheds were identified, one in the north and another in the south of these agricultural watershed areas. The PRA on socioeconomic aspects was conducted in all the three agricultural watershed areas. The objectives of this survey were:

- To understand the existing socioeconomic situations in Tad Fa watershed in order to plan a research program for sustaining agricultural production.
- To select a catchment which is representative of the agroecology where research and development work will be carried out.

The survey indicated that there are three regions, based on soil quality, in the watershed. The middle portion is the most fertile while the regions to the north as well as to the south are less fertile. The soil depth ranges from 0.5 m to 2 m. The soil is sandy loam at the surface and is clayey loam to loam at subsurface. There are nearly 80 farm ponds in eastern Tad Fa, of which only 4 store water throughout the dry season, while others dry in summer because of very porous subsoil and high seepage losses. Farmers have planted fruit trees only around their houses and not on steep slopes as desired (and recommended) by the government.

In Tad Fa watershed upland rice is mainly grown for home consumption. Maize is the main cash crop. Ginger has been tried since two years by few farmers but is very risky due to disease problems and price fluctuations. Soybean is not grown because of high vegetative growth and very poor grain yields. Rice (local variety) is grown only in poor soils or less fertile patches since more vegetative growth has been observed in the fertile lands. A very small amount of urea is mixed with the rice seeds at sowing. Only maize and ginger crops are fertilized. Rice is planted in June and harvested in October. About 2.5 to 3.0 t ha^{-1} grain yield is obtained. Often, maize is grown twice a year depending on the onset of monsoon. The first crop is grown during March to July and second crop during July to November. Farmers apply about 150 kg ha^{-1} of NPK (15:15:15) fertilizer and harvest 3 to 3.5 t ha^{-1} of grain yield. Ginger is grown in March/April to December. A heavy dose of NPK fertilizer at 600 kg ha^{-1} is applied.

Farmers have identified the following constraints: land tenure, lack of capital, lack of water resources, costly agricultural inputs, price fluctuation, lack of government support, lack of transport facilities, soil erosion, forest fires, and labor shortage. Since these are displaced farmers, they do not have much capital to invest. But highest priority is given to children education. There is only one primary school in the village and children have to go to other villages for high school education. Second priority is given for housing. As most of the farmers have poor temporary houses, they wish to build new houses.

Farmers give third priority for agriculture. Fortunately, the land is reasonably fertile. Rice is grown as a subsistence crop without much fertilizer application. Maize, which is grown as a cash crop is fertilized. However, farmers have to invest a sizeable capital on labor because household labor is scarce; all operations like land preparation, seeding, weeding, and harvesting are given on contract to service providers. Few farmers have tried the risky ginger crop with huge investment and most of them have suffered heavy losses.

Overcoming Nutrient Constraint

Most of the farmers apply chemical fertilizers to their cash crops to harvest good yields. Chemical fertilizers are one of the costliest inputs and there was a need to search other alternatives or supplement sources to overcome nutrient constraints. There is not much scope to use farmyard manure as farm animals have been replaced by farm machines for draft purposes. The use of legumes in the cropping system would certainly help to reduce the amount of chemical nitrogen (N) fertilizer. Legumes were evaluated to quantify N_2 fixation and the benefits of legumes using ^{15}N abundance method and ^{15}N isotope dilution method on farmers' fields at Ban Koke Mon located near Ban Tad Fa.

Based on the N difference method N_2 fixation varied from 20 to 104 kg N ha^{-1} and net N benefit to the succeeding crop was estimated at 2 to 51 kg ha^{-1}. Following legumes, a maize crop was grown with 40 kg N ha^{-1} along with the organic matter from the legume residues. Grain yield of succeeding maize crop was significantly ($P \leq 0.05$) higher by 27 to 34% in treatments following black gram, rice bean, and sunnhemp over the yield of maize crop (Table 3). Although N_2 fixation was highest in sword bean (104 kg N ha^{-1}) the benefits were not translated in terms of increased maize yields. These results demonstrated that it is not only the quantity of N_2 fixed that determines the benefit to the succeeding crop but also the quality of organic matter and N release pattern from the legume residue. However, in the long term, sword bean could play an important role for sustaining land productivity.

Growing black gram, rice bean, and sunnheamp in the system would help in reducing N requirement for the succeeding maize crop. The actual realized benefits from legumes in terms of increased N uptake by the succeeding maize crop varied from 5.3 to 19.3 kg N ha^{-1} whereas the expected benefits from legumes through biological nitrogen fixation (BNF) and soil N sparing effect over a maize crop varied from 15 to 64 kg N ha^{-1} (Table 4). These results revealed that for quick benefits for succeeding maize crop farmers would be benefited by growing legumes such as rice bean, sunnhemp, and black gram.

Table 3. Dry matter (kg ha^{-1}) of maize grown after five different crops at Ban Koke Mon in the rainy season 2000.

Treatment	Stover	Cob	Seed[1]	Total
Rice bean	7069	816	4541 a	12425
Sunnhemp	6634	786	4720 a	12141
Sword bean	6689	659	3642 b	10991
Black gram	6786	875	4488 a	12149
Maize[2]	5560	697	3525 b	9781
F test	NS[3]	NS	*	NS
CV (%)	14.57	14.41	13.36	13.13

1. Figures followed by the same letter do not differ significantly at $P \leq 0.05$; * = Significant at $P < 0.05$.
2. The maize crop received nitrogen (N) from legume crop residue plus 40 kg N ha^{-1} in the form of chemical fertilizer.
3. NS = Not significant.

Table 4. Nitrogen benefit realized from legumes in maize-based systems.

Crop	N fixed by legume (kg ha^{-1})	Net N benefit expected[1] (kg ha^{-1})	Total N uptake by succeeding maize (kg ha^{-1})	N benefit realized from legume over maize[2] (kg ha^{-1})	Expected benefit from BNF + N saving benefit (kg ha^{-1})
Rice bean	20	2	75.9	19.1	15
Sunnhemp	90	31	76.1	19.3	44
Sword bean	104	51	62.1	5.3	64
Black gram	27	8	68.9	12.1	21
Maize	-	–13	56.8	-	-

1. N_2 fixed – Seed N.
2. Total N uptake by succeeding maize – Total N uptake by maize grown after maize.

Table 5. Maize grain yield (t ha^{-1}) across topo-sequence in NE Thailand during 1999 to 2001[1].

Toposequence	1999	2000	2001
Steep (>15%)	3.1 (3)	4.5 (4)	2.1
Moderate (5–15%)	3.6 (6)	4.8 (5)	2.9
Mild (2–5%)	4.1 (2)	5.3 (4)	3.4

1. Figures in parentheses refer to the number of farmer fields at each slope.

Quantification of Land Degradation

In NE Thailand, types of land degradation (e.g., biological and chemical) are not fully studied. To study the effect of land degradation on crop productivity, sites in the toposequence were identified and crop yields were monitored during 1999, 2000, and 2001 (Table 5). Soil samples at these spots up to 110 cm depth were collected and analyzed for physical, chemical, and biological properties (Table 6). The maize grain yield data clearly indicated the loss of productivity on steep slopes and on moderate slopes when compared to mild slopes. The clay and organic matter content at these spots indicated that precious clay and organic matter have been eroded from the steep slopes. Most of these changes have occurred in the topsoil layers which are very important for crop production. A new methodology to quantify land degradation called Soil Fingerprint method is being used.

Fingerprint technique (FPT) is an approach for monitoring land degradation as it impacts soil quality. FPT primarily utilizes characteristics of landform and some soil physical properties as a basic guideline for comparable paired sites. Usually the comparison is based on pairing of the virtually similar location with different land use system, namely forest as control (less disturbed) site and agriculture plot as degraded site. Thereafter, further soil chemical analysis is done to identify soil profile similarities and depths of undisturbed horizon using both general soil chemical properties and soil charge fingerprinting characteristics of each horizon. Once the profiles are considered comparable, the discrepancies in soil depth and physical properties of comparable profiles were considered as soil loss through erosion and soil physical degradation, respectively. FPT-based information could be used as a good first approximation to estimate loss of soil organic matter, clay, mineral bases, and soil fertility under different land uses. These soil parameters are important for the evaluation of soil and land degradation, which is a major constraint to the sustainability of agriculture in the tropics.

The watershed was surveyed to identify suitable sites for soil degradation study using FPT. From the landscape layout, it was found that at least 7 sites were considered physically suitable. Land use history was further investigated using a rapid rural appraisal (RRA) technique. From the 7 sites, only 5 transects were found suitable. These transects were used as the final study sites. Soil physical analysis was completed for all samples. In general, the charge fingerprints indicated that soils under 30 cm depth have similar charge fingerprinting.

On-farm Development and Evaluation of Various Technologies through Farmer Participatory Approach

Out of 700 ha of land in the eastern part of Tad Fa, we selected the middle portion of the watershed called Huay Lad, which had about 200 ha of land under cultivation; also the two villages, Ban Tad Fa and Ban Dong Sakran, were located in this area. Most of the farmers from Ban Tad Fa village had land in the northern Huay Samtada.

We concentrated in the Huay Lad area (Dong Sakran village) for research and development work. There were 49 farm ponds in the Huay Lad. We identified two micro-watersheds for our research. One micro-watershed was "traditional", which had moderate slope and nearly 70% land had fruit trees and in the remaining area other annual crops like maize and upland rice were grown. The other micro-watershed had moderate as well as steep lands and mostly annual crops like maize and upland rice were grown. All the interventions were carried out in this micro-watershed. In almost 80% of this micro-watershed, "hillside ditches" were dug for soil conservation on contour. Vetiver and maize were planted along the side of "hillside ditches". It was suggested that all farmers should plant crops like maize along the contour instead of usual up and down the slope. One automatic runoff and sediment sampling system was installed at the lowest point of each micro-watershed to

Table 6. Biological and chemical properties of soil samples from toposequence in Ban Tad Fa watershed in NE Thailand.

Topsequence	0–10[1]	10–20	20–30	30–50	50–70	70–90	90–110
Organic C (g kg^{-1} soil)							
Top	28	27	26	14	13	9	7
Middle	31	29	26	18	12	10	10
Lower	40	34	29	20	35	20	19
LSD = 1.15							
Total N (mg kg^{-1} soil)							
Top	2073	2085	1956	1755	1324	1249	1092
Middle	1967	1771	1785	1376	1178	1352	1012
Lower	2336	2287	1971	1563	2345	1630	1462
LSD = 621.2							
Net "N" mineralization (mg kg^{-1} soil 10d^{-1})							
Top	11.89	10.03	6.80	5.52	2.30	1.97	1.47
Middle	14.22	11.16	8.93	6.07	3.84	3.75	3.04
Lower	15.11	14.49	12.72	9.04	5.73	4.53	4.70
LSD = 6.034							
Biomass C (mg kg^{-1} soil)							
Top	366	304	275	258	178	149	133
Middle	362	300	240	206	173	124	100
Lower	384	328	276	213	128	145	112
LSD = 86.3							
Clay content (g kg^{-1} soil)							
Top	330	350	380	330	330	0	0
Middle	390	380	430	420	370	230	0
Lower	450	450	450	490	550	550	590
LSD = 2.4							
Fine sand (g kg^{-1} soil)							
Top	90	70	70	180	140	0	0
Middle	80	80	80	130	120	160	0
Lower	60	60	60	70	60	60	40
LSD = 1.6							
Gravel (g kg^{-1} soil)							
Top	190	150	130	100	140	0	0
Middle	130	120	100	80	250	150	0
Lower	140	140	130	110	120	100	90
LSD = 1.9							

1. Soil depth in cm.

monitor runoff and soil loss. The area of the traditional micro-watershed was 17.8 ha with 4 farmers while that of the improved micro-watershed was 12 ha with 5 farmers. Two farmers had land in both micro-watersheds. An automatic weather station was installed near the research area to monitor rainfall, temperature, sunshine, humidity, wind velocity, and soil temperature on a continuous basis at fixed intervals of time.

Soil survey of the entire Huay Lad agricultural land was done and detailed soil map and land use map was prepared. Majority of the soil was silty clay loam with a very small fraction of clay loam. Almost all the clay loam had 2–5 and 5–12% slope while a small proportion of silty clay loam had 2–5% slope and the rest had 5–12, 12–20, and even 20–35% slope. There were 13 distinct soil series and their variants in Huay Lad.

Detailed baseline survey of all the 10 households involved in the micro-watershed was done. This will be used to measure the impact of interventions. The survey covered size of family, age, education, source of income, size of landholding, land use, crops grown, agricultural implements, animals reared, and financial status of farmers. Even though all farmers recognized soil erosion as a cause for land degradation none of them have seriously followed any measures to check soil erosion. Since the history of cultivation of these lands is only about 80 years, the soils are still rich in organic matter and support reasonable crop production. But farmers apply chemical fertilizer to their maize crop, which is a major cash crop and is grown on moderate and steep slopes. Upland rice is mostly grown on mild slopes without much fertilizers since these soils are not eroded. Even though planting of fruit trees and other trees on steep slopes is recommended, farmers have planted fruit trees on mild slopes where they have some water sources to irrigate these trees during dry periods of establishment. The results of on-farm research are given below:

- Comparison of groundnut yields grown in the two rainy seasons:
  Early season (first crop) gave higher yield of fresh pods (3.7 t ha^{-1}) when compared to second season yield of 2.5 t ha^{-1}. These low yields in both the seasons may be due to phosphorus (P) deficiency in the soil.
- Evaluation of the performance of soybean in the benchmark watershed area:
  Five soybean varieties were grown. The grain yields were low ranging from 510 to 875 kg ha^{-1}. In Thailand yields less than 1.2 t ha^{-1} are considered uneconomic. The experimental fields had less than 5 ppm of P as against the threshold level of 15 ppm. Thus the performance of soybean was poor perhaps due to acute P deficiency. Weed competition was also severe, as farmers do not adequately weed the crop. At present soybean crop does not hold promise in Tad Fa watershed.
- Productivity of upland rice at two toposequential slopes:
  Rice is a popular crop among all farmers and is grown in the lower part of the toposequence. Often farmers grow only traditional varieties and mainly for home consumption on 0.5 to 1.0 ha of land. Nearly 75% of farmers grow “Lao Taek”. Mild slope (2–5%) and very mild slope (<2%) did not affect the rice yield significantly; the mild slope produced 3.5 t ha^{-1} when compared to 3.4 t ha^{-1} in very mild slope area.
- Evaluation of the productivity of relay cropped rice bean at different sites in the toposequence:
  Rice bean is a popular legume crop grown in sloping land ecologies of NE Thailand. In about 40% of the maize growing area rice bean is relay planted. It is sown in the standing crop of maize at the flowering time. Since it is sown without any land preparation (unlike sequential planting) relay planting is a soil conservation efficient system. In steeper slope (>15%), the yield (970 kg ha^{-1}) is 25–30% less compared to moderate slope (5–15%) (1270 kg ha^{-1}) or mild slope (2–5%) (1360 kg ha^{-1}). Poor soil as well as less amount of soil moisture may be responsible for low yields at steep slopes. This system has to be popularized with most of the maize farmers who sometimes try a second crop of maize, which suffers due to terminal drought or sometimes they are not able to plant the second crop due to late onset of monsoon and late planting of first maize crop.
- Response of maize to fertilizer at upper and lower slope of toposequence:
  Most farmers apply fertilizers at 150 kg ha^{-1} of NPK (16-20-0). To see the maize performance without fertilizers at the upper and lower portion of toposequence, a small trial was carried out in different farmers’ fields. At the upper site maize produced 2.6 t ha^{-1} and at the lower site it produced 4.1 t ha^{-1} of grain without application of any fertilizer while the yields were 4.1 and 6.7 t ha^{-1} respectively with fertilizer. This again reveals the degradation of soil at the upper end of toposequence and indicates that in terms of economic losses land degradation has resulted equivalent to 2 t of maize grains ha^{-1} yr^{-1}. Such differences are variable in some years.
- Minimum tillage and contour cultivation:
  In order to reduce tillage on steep slopes which may trigger enhanced soil erosion, hand dibbling was tried on steep slopes and tractor planting on contour on moderate and mild slopes. Minimum tillage was

as effective as tractor planting. Grain yield of maize was 4.1 t ha^{-1} on steep slope, 4.5 kg ha^{-1} on moderate slope, and 4.9 kg ha^{-1} on mild slope.

- Maize relay cropping with legumes:
  Rice bean was relay cropped with maize on two slopes. On moderate slope, yield was 980 kg ha^{-1} while on mild slopes 1060 kg ha^{-1} was recorded. This small increase on mild slopes may be due to higher moisture retention at lower ends. In another trial a new legume crop, black gram, was grown as relay crop with maize. Compared to rice bean it produced only 290 kg ha^{-1} while the former gave 810 kg ha^{-1}. Black gram was shaded by maize and also was severely suppressed by weeds. Many pests attacked the foliage as well as the pods. Black gram may not be suitable as relay crop with maize.
- Fruit tree planting and intercropping:
  Our continued efforts resulted in planting of 625 fruit tree seedlings of longan, litchi, and mango in 4 ha in the watershed. Few farmers grew maize as an intercrop between the fruit trees providing shade for trees as well as helped in suppressing fast-growing *Mimosa* weeds. Farmers harvested maize grains providing direct income until the trees started producing fruits. In this process farmers need not suffer for a few years till the trees start bearing fruits. But some technologies should be improved to reduce competition to fruit trees by maize and *Mimosa*.
- Community-based banana dryer:
  The farmers of Tad Fa get very low returns for their banana crop. The scientists of DOA analyzed this problem and came up with a practical solution of value addition to their product and also to increase the shelf life by drying the ripe banana and then selling. This is possible in summer months. In rainy season they cannot do it efficiently and the product may get spoiled. To overcome this problem, with the help of KKU engineers they developed solar dryers as there is no electricity in the village. On a trial basis DOA plans to install community-based solar dryers with a very nominal charge for maintenance. If this intervention succeeds, then the farmers will not only get additional income but also the funds generated for the community will help to buy additional dryers.
- Minimum tillage cultivation for maize:
  As mentioned earlier, farmers plow the land deep with hired tractors. Due to our persuasion a few farmers followed minimum cultivation. The grain yield of maize cultivar CD-DK 888 was 4020 kg ha^{-1} while that of Suwan 1 was 2100 kg ha^{-1}. These yields are fairly good. Also, the cost of cultivation was less and minimum tillage prevents soil erosion from the sloping lands.
- Sequential cropping of groundnut:
  Groundnut was planted in July as a sequential crop after maize. The variety Khon Kaen 5 produced 4980 kg ha^{-1} fresh pods while Native (red seed) produced 4540 kg ha^{-1} fresh pods.

Human Resources Development

The following activities were undertaken during the project period to develop human resources of partner NARS:

- A training course on database management system for sustainable rainfed agriculture was held at ICRISAT, Patancheru, India from 15 November to 3 December 1999. One Thai researcher attended the training.
- A traveling workshop was organized from 27 August to 12 September 2000. Two Thai researchers participated and traveled to all the project sites in India, Thailand, and Vietnam.
- A training workshop on “Impacts of Variability of Natural Resources on the Performance of Community Scale Watershed” was held from 16 to 29 November 2000 at ICRISAT and two Thai researchers participated.
- A training workshop on “On-farm Participatory Research Methodology” was held at Khon Kaen from 26 to 31 July 2001. Two scientists, each from DOA and LDD, attended this workshop.
- A training program on “Farmer Participatory Research” was conducted by the faculty of KKU for the staff of DOA and LDD involved in the Tad Fa watershed. This training was held in two sessions. The first one was held at Nam Nao from 10 to 12 May 2001 and a total of 18 staff from DOA and LDD attended. The second one was held from 18 to 20 October 2001 at ChumPhe and 22 members attended.

Lessons Learned and Future Strategy

- Land degradation in general and soil erosion in particular has been perceived as a major constraint for sustainable agricultural production in the study area not only by the agricultural scientists but also by the farmers.
- Since the cultivation history is only about 80 years, the soils are reasonably productive at present but poor productivity has been noticed both on steep and moderate slopes of the toposequence. Farmers apply fertilizers to cash crops on these sites.
- Land degradation in the watershed on a toposequense is evident and clearly demonstrated by the varying yields of maize from 300 to 3000 kg ha^{-1} during different cropping seasons depending on rainfall. Farmers recognize these effects and are ready to work along with scientists to develop measures for soil and water conservation.
- Farmers have recognized water conservation as an important aspect and are willing to contribute resources (cash and in kind) for undertaking rainwater harvesting structures.
- Due to lack of capital as well as the fear of evacuation as they do not have permanent tenure, farmers had not taken up major soil and water conservation and management practices.
- Since the government has recognized the settlement as villages in 1998 the farmers are optimistic of ownership of their lands and started heeding the advice of scientists and policy makers to plant more fruit trees in the agricultural land. Looking at the response of the farmers since two years we are hopeful that fruit tree planting will cover a large area in the near future, which not only will reduce soil erosion but also will improve the economic status of the farmers in a sustainable way.
- Since the underground parent material is very porous, almost all the dug tanks do not hold water for summer. We may have to look either for improvement of these structures or for possibilities of using groundwater and sharing the same for the drier months by the community.
- There is a need to evaluate the soil conservation practices like hillside ditches, vetiver planting, and contour planting of crops.
- The annual cash crops are very much influenced by markets. Crops like ginger and pineapple have disappeared from this area. Maize crop was being cultivated as a cash crop for a long-time on steep and moderate slopes. Since one year the prices of maize are falling down. Many farmers have started growing vegetables as cash crops. We believe fruit trees will stabilize the situation in the future.
- Finally, this watershed approach with more focus on soil conservation and rainwater harvest should be extended to other areas in the ecoregion with emphasis on both community as well as individual farmers.

Acknowledgments

We sincerely thank Dr Montien Somabhi and Mr Panya Ekmahachai of DOA, Dr Manu Srikhajon and Mr Rungroj Puengpan of LDD, and Dr S M Virmani (formerly at ICRISAT) who were involved in the initial planning and execution (under the leadership of Dr Narongsak Senanarong of DOA and country coordinator). We also thank Dr S P Wani, Project Coordinator and Mr P Pathak and other staff of ICRISAT whose active support helped to run this project successfully and to achieve the planned outputs.