# Community Watershed Management for Sustainable Intensification in Northeast Thailand

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# Community Watershed Management for Sustainable Intensification in Northeast Thailand

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# Foreword

Some eighty per cent of the world's agricultural area is rainfed. This area is also the most vulnerable to the impacts of climate change and remains the hot-spot of poverty, water scarcity, and malnutrition. In order to reduce poverty through increased productivity while minimizing land degradation, ICRISAT has developed and pilot tested an integrated watershed management approach which is farmer-centric, participatory and holistic. This was tested at Kothapally, Andhra Pradesh, India, and has been scaled-up in Thailand, Vietnam, China and India with support from the Asian Development Bank. Twenty-five benchmark watershed sites were established in different agro-ecoregions in India, Thailand, Vietnam and China in two phases from 1999 to 2006 under the ADB-ICRISAT collaborative project.

Through RETA 5812 entitled "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" and RETA 6067 entitled "Participatory Watershed Management for Reducing Poverty and Land Degradation in the SAT Asia", this approach was introduced in Northeast Thailand with its sloping lands and higher rainfall. Various interventions for productivity enhancement have resulted in increased water use efficiency and crop diversification in the areas covered. They also minimized land degradation through soil conservation, prevented nutrient depletion and enhanced water availability in the region.

I am pleased to note that the work under the ADB-ICRISAT collaborative projects has been documented in this publication. The learning and insights from the experiences in these particular projects will be of great help not only to the farmers but also to the policy makers in the region to address the issues of sustainability, poverty reduction, food security and improving livelihoods to small and marginal farmers.

**William D Dar**
Director General, ICRISAT

# Preface

Globally rainfed agriculture covers 80% of arable land and plays an important role not only in achieving food security but also for providing the livelihoods for 60-90% of population in rural areas of Asia and Africa. Agriculture is the main occupation in Thailand and is important in the economic development as well as for achieving food security in the country. The Northeast part of Thailand occupies 33% of the whole country and is the hot-spot of poverty, food insecurity, water scarcity and also prone to severe land degradation due to its topographical features and high rainfall in the region. To address these issues ICRISAT in partnership with Department of Agriculture, Department of Land Development and Khon Kaen University developed a consortium and established two benchmark watershed sites for establishing "a proof of concept" that rainfed agriculture potential can be harnessed through sustainable management of natural resources by adopting watershed management approach. This publication is based on the participatory research for development undertaken at two benchmark watershed sites in Northeast Thailand during 1999-2006. The results from large number of on-farm trials are synthesized and presented in this book.

This book will be a valuable source of information in the area of sustainable management of natural resources not only for the development workers but also for the natural resources scientists, policy makers and also the farmers.

*Suhas P Wani, P Pathak and KL Sahrawat*

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# 1. Baseline Characterization of Tad Fa Watershed, Khon Kaen Province, Northeast Thailand

***Somchai Tongpoonpol, Arun Pongkanchana, Pranee Seehaban, Suhas P Wani and TJ Rego***

## Introduction

Agriculture is the main occupation in Thailand and it plays an important role in the economic development of the country. Thailand is located in the tropical monsoon climate region where the amount of rainfall is high but shortage of water occurs even in rainy season. Only 20% of total agricultural area is under irrigation, with rest constituting rainfed area, which has relatively lower crop yields. High soil erosion and reduced soil productivity are some of the problems in the rainfed area.

The northeastern part of Thailand occupies one-third of the whole country. The climate of the region is drier than that of other regions. Most of the soils in Northeast Thailand are infertile at present and liable to be further degraded. The empirical evidence shows that crop yields decreased over the years after the conversion of the area as agricultural land by deforestation. The soils have become infertile due to improper soil management. The soils are low in fertility and have low water-holding capacity (WHC), and soil erosion is a serious problem. The interventions by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) project aim to address these problems in the rainfed areas of Northeast Thailand. The watershed area in Phu Pa Man district in Khon Kaen province has been selected as benchmark site to address the above problems and increase agricultural productivity through a sustainable manner by adopting integrated soil, water and nutrient management (SWNM) and integrated crop management options.

## Physical Resources

### Location and Extent

Northeast Thailand is situated between 14$^{o}$ to 19$^{o}$ N latitude and 101$^{o}$ to 106$^{o}$ E longitude. The area is about 17 million ha or one-third of the whole country and is spread over 19 provinces: Kalasin, Khon Kaen, Chaiyaphum, Ysothon, Nakhon Phanom, Nakhon Ratchasima, Burirum, Maha Sarakham, Roi Et, Loei, Sri Sa Ket, Sakon Nakon, Surin, Nong Khai, Udon Thani, Ubon Ratchathani, Mukdaharn, Nong Bua Lam Phu and Amnat Charoen. Location of the benchmark Tad Fa watershed is shown in Figure 1.

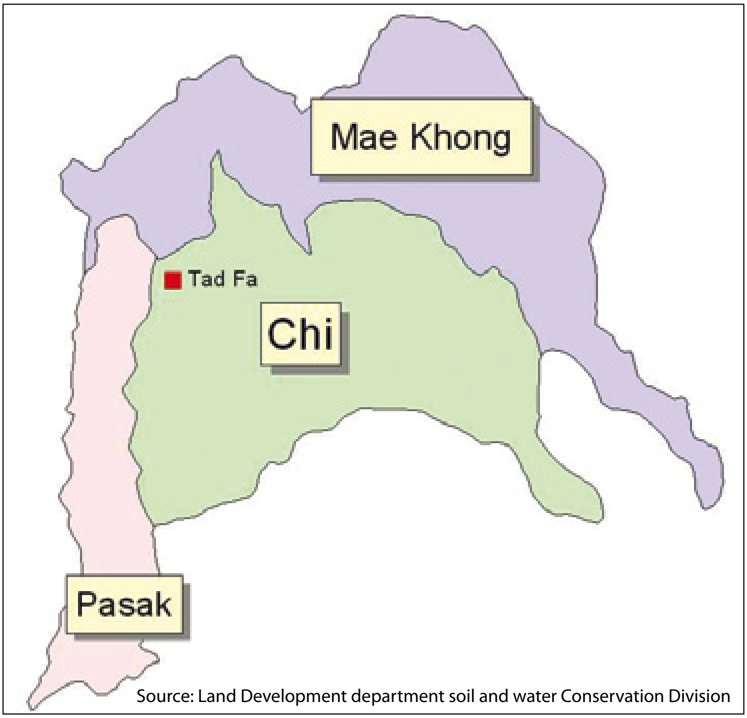



*Figure 1. Location of Tad Fa watershed.*

The topography of Northeast Thailand is generally characterized by high plateau with the ranges of Phetchabun and Dong Phayayen on the west, Phaya Dong Rak bordering Thailand with Cambodia on the South and Southeast, and Mae Khong river bordering with the Democratic Republic of Laos (LAOSPPR) on the north. On the middle, the range of Phu Pan divides the watershed area into two basins: Sakon Nakon basin on the upper part and Mun watershed on the lower part.

Despite similar amount of rainfall as in North and Central Thailand, Northeast Thailand is drier because of the shorter rainy season. Farming is the main occupation, with only 20% of total agricultural area under irrigation. Low crop productivity, soil salinity and soil erosion are some of the problems faced by the farmers.

## Topography

Northeast Thailand, or the “Khorat Plateau”, is characterized by shallow basin (saucer-shaped basin). The plateau consists of flat-topped mountains and dissected peneplain surface with undulating features. The elevation varies from 200 m to 1000 m above mean sea level (amsl). Geologically, the region can be divided into six parts.

### Western Highland

This area is distinct by hilly to mountainous topography, except the area close to northeastern part which is undulating to rolling topography. It covers the province of Loei and some part of Udon Thani, Khon Kaen, Chaiyaphum and Nakhon Ratchasima.

### Northern Highland

This area is formed as thin strip on the northernmost region. The topography is rolling to hilly underlaid by lower and middle Khorat group. It covers some part of Nong Khai province and Nakhon Phanom province.

### Sakon Nakon Basin

This basin is in the north of the region in which Sakon Nakon province is located in the middle. The basin covers the provinces of Nakhon Phanom, Sakon Nakon, Udon Thani, and Nong Khai. The topography is flat to undulating underneath by evaparite-bearing salt formation. The area is approximately 43,000 $km^2$ and the streams mainly flow to Nong Han, the biggest lagoon in Thailand with 170 $km^2$ size and then flow to Mae Khong river via Num Karn stream. Moreover, Songkram river, which originates in the north, joins with Mae hong river flowing through the northeastern part of the plateau.

### Central Highland

This area is characterized by rolling to hilly topography. The range of Phu Pan is situated in southeastern part. It lies below the lower and middle Khorat group. Phu Pan range is extended to Mae Khong river.

### Khorat Basin

The basin is located in the south of the region where Roi Et province and the north of Nakhon Ratchasima province are in the middle. It also covers the provinces of Surin, Sri Saket, Nakhon Ratchasima, Ubon Ratchathani, Roi Et, Burirum, Maha Sarakham, Chaiyaphum, Yasothon, Khon Kaen and Kalasin. The topography is flat or almost flat or undulating. The area is about 137,000 $km^2$. The basin receives the water from Mun river which originates in the southeastern mountain and flows from east to the south. The watershed area is about 82,000 $km^2$. Chi river originates in the rim of the western part of the plateau, flows to the middle of the basin and joins with Mun river in Ubon Ratchathani province. The Chi river then flows to Mae Khong on the southeastern part of the plateau. Chi watershed is approximately 55,000 $km^2$.

### Southern Lowland

This area is situated on the southernmost part of the region, where Phanom Dong Rak range is formed as a strip on the southernmost part. The topography is sloped northward towards Mun river and is characterized by flat to undulating land with some hilly topography in many areas especially the provinces of Surin, Burirum and the southeast of Nakhon Ratchasima. Basalt rock in tertiary area lies underneath. From the above characterization Northeast Thailand thus can be described in three areas: highland, upland and lowland.

## Climate

The northeastern part of Thailand is located in the low latitude and is influenced by tropical low rainfall climate and wet-dry monsoonal or tropical Savannah climate. During November to February, the area is influenced by the northeast monsoon from the Eurasian continent resulting in a cooler and dry weather covering the whole region. The southwest monsoon lasting from May to September brings warm and moist weather from Indian Ocean to the area.

### Seasons

The year can be divided into three seasons. Based on the climatic data for 10 years from 1988 to 1997 of many stations in Northeast Thailand, the climatological parameters are summarized.

**Rainy season:** The rainy season starts from May or the beginning of June to the beginning of October due to the effect of the southwest monsoon. Because the ranges of Phetchabun on the northeast and Dong Phayayen on the west, and the ranges of San Khampaeng and Phanom Dong Rak on the south are barriers, the rainfall due to the southwest monsoon is lower compared with the rainfall due the depression from the South China sea.

**Winter season:** The season starts from mid October to mid February caused by the northeast monsoon from China and brings a cool and dry climatic mass without vapor to the area. Thus the weather is very cool in the north while on the south it is warmer.

**Hot season:** The season starts from February to the end of May caused by the northeast monsoon from the South China sea and Gulf of Thailand. Because the northeast region is located far away from the Gulf of Thailand, the climate is hot and very dry.

## Rainfall

The annual rainfall in Northeast Thailand is about 1,375 mm. In the west and the middle of the region including the provinces Chaiyaphum, Nakhon Ratchasima, Loei, Khon Kaen and Roi Et, the rainfall is lower than in the east and the north and is about 1,000–1,400 mm, occurring on 108 rainy days. In the east and north including the provinces Nakhon Phanom, Sakon Nakon, Nong Khai, Ubon Ratchathani, Udon Thani and Mukdahan, the annual rainfall is about 1,500–2,300 mm. Rainfall is highest in the Nakhon Phanom province (Table 1) and the number of rainy days is about 123 (Fig. 2).

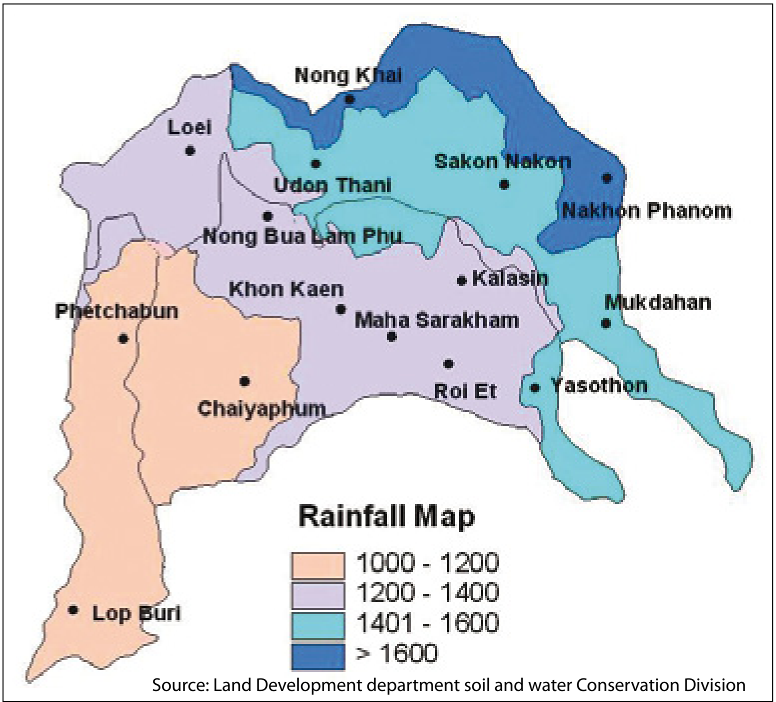


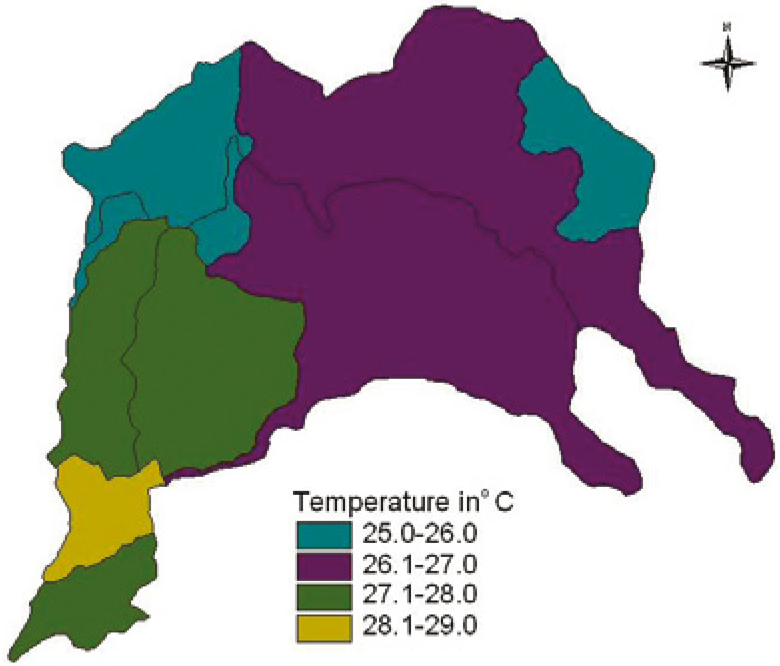

*Figure 2. Rainfall distribution in different watersheds of Northeast Thailand.*

**Table 1. Mean annual rainfall (mm) in Northeast Thailand during 1988 to 1997.**

| Province | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mukdahan | 1206 | 1537 | 1762 | 1515 | 1438 | 1324 | 1490 | 1370 | 1751 | 1423 | 1482 |
| Sakon Nakon | 1623 | 1569 | 2078 | 1563 | 1513 | 1369 | 1686 | 1321 | 1614 | 1588 | 1593 |
| Nong Khai | 1878 | 1822 | 1566 | 1932 | 1626 | 1723 | 1992 | 1591 | 1372 | 1749 | 1755 |
| Loei | 1490 | 1131 | 1357 | 1252 | 1098 | 862 | 1318 | 1420 | 1289 | 969 | 1219 |
| Udon Thani | 1516 | 1399 | 1674 | 1281 | 1208 | 983 | 1932 | 1355 | 1845 | 1429 | 1462 |
| Ubon Ratchathani | 1270 | 1382 | 1734 | 1490 | 1597 | 1029 | 1956 | 1266 | 1470 | 1555 | 1475 |
| Nong Bua Lam Phu | - | 952 | 1041 | 457 | - | 865 | 1196 | 1344 | 1310 | 911 | 1009 |
| Amnateharoen | 1329 | 1595 | 1808 | 1724 | 1561 | 1167 | 1210 | 1038 | 1361 | 1306 | 1410 |
| Chaiyaphum | 1260 | 905 | 1193 | 1135 | 987 | 1026 | 1191 | 1147 | 1442 | 760 | 1104 |
| Kalasin | 1302 | 1022 | 1299 | 1361 | 1109 | 1087 | 1174 | 1023 | 889 | 1044 | 1131 |
| Maha Sarakham | 988 | 1011 | 1207 | 1381 | 1122 | - | - | 1374 | 1590 | - | 1382 |
| Yasothon | 1482 | 1253 | 1313 | 1345 | 1236 | 1152 | 1155 | 1203 | 1132 | 1195 | 1247 |
| Nakhon Ratchasima | 1446 | 974 | 914 | 8732 | 1039 | 1232 | 774 | 1292 | 1174 | 624 | 1034 |
| Sri Sa Ket | 1435 | 1135 | 1877 | 1387 | 1419 | 1187 | 1547 | 1448 | 1647 | 1489 | 1457 |
| Khon Kaen | 1255 | 1280 | 1449 | 1333 | 912 | 873 | 1252 | 1479 | 1293 | 898 | 1202 |
| Roi Et | 1477 | 1251 | 1351 | 1309 | 1257 | 957 | 1004 | 1194 | 1110 | 1197 | 1211 |
| Nakhon Phanom | 1977 | 2060 | 2975 | 2158 | 1920 | 2355 | 2326 | 1193 | 2371 | 2660 | 2324 |
| Burirum | 1360 | 1213 | 1314 | 1395 | - | 1260 | - | 2442 | 1269 | - | 1244 |
| Surin | 1422 | 1343 | 1567 | 1411 | 1041 | 1107 | 1439 | 895 | 1711 | 1480 | 1379 |

### Temperature

The mean temperature during the 10-year period from 1988 to 1997 in Northeast Thailand was about 26.7°C. Maximum temperature is about 27.4°C in Nakhon Ratchasima province, while it is about 25.7°C in Sakon Nakon (Fig. 3).




Source: Land Development department soil and water Conservation Division

*Figure 3. Temperature distribution in the watersheds of Northeast Thailand.*

## Irrigated area and water resources

The water resource in the northeast is surface water. The area consists of two basins: Khorat basin and Sakon Nakon basin. The Phu Pan range is the barrier between these basins.

### Water Resources in Sakon Nakon Basin

The basin composes of Nong Khai, Sakon Nakon and Nakhon Phanom provinces. Their streams flow to the north and then to the east, finally joining the Mae Khong river. The important river is Song Khram, which originates in Phu Pan range. It flows through the province of Sakon Nakon and Nong Khai and joins the Mae Khong in Nakhon Phanom province. The other river is Huai

Luang. It joins the Song Khram river in Nakhon Phanom province and then flows into the Mae Khong. There are many other streams such as Num Pung that flow into the Nong Han in Sakon Nakon province.

### Water Resources in Khorat Basin

The basin is located in the south of Phu Pan range and in the north of the provinces of Khon Kaen, Kalasin, Nakhon Ratchasima, Maha Sarakham, Roi Et, Yasothon and Ubon Ratchathani. The important rivers are Chi and Mun. The Mun river originates in the ranges on the southeast of the region. It flows eastwards through the provinces of Nakhon Ratchasima, Burirum, Surin, Sri Sa Ket to the Mae Khong in Ubon Ratchathani province. It has several tributaries including Lum Ta Khong, Lum Pra Pleong, Lum Plai Mat, Lum Dom Yai and Lum Dom Noi.

The Chi river originates in the ranges of the provinces of Loei, Chaiyaphum and Khon Kaen. There are three main tributaries which join the Chi river: Num Pang which originates in Loei province, Num Proom which originates in Chaiyaphum province and Num Pao or Lum Pao which originated in Kalasin. These rivers join the Chi river at Koengnai and Warinchumrap district in Ubon Ratchathani province, which then flows into the Mae Khong in the east. The Chi river has many tributaries such as Lum Se, Huai Se Bok and Lum Num young. The streams in the northeast normally have water only during some periods of the year and there is water shortage during the dry season, even in the main river like Chi, Mun and Song Khram. Water resources development is being promoted in approximately 4.64 million ha or about 20% of the agricultural land.

## Soil

The Survey Division (1996) reported that the northeastern Thailand soils consist of nine sub-orders: Usterts, Aquepts, Tropepts, Ustolis, Aqualfs, Ustalfs, Aquults, Ustults and Udults (Fig. 4). The soil is characterized by sandy or sandy loam to sandy clay loam texture with low to medium fertility. Ustults area is the largest and mainly used for field crops; Aquults area is less than that of Ustults and is flat and mainly used for paddy rice (Fig. 4).

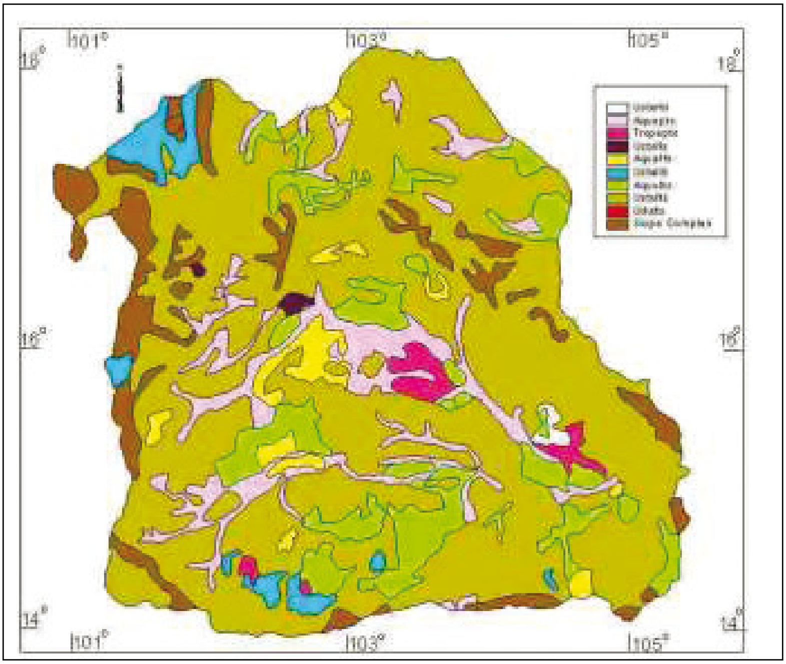



*Figure 4. Soil distribution in northeastern Thailand.*

## Landuse

There are three kinds of forests as described below.

### Dry Dipterocarp Forest

Dry dipterocarp forests exist in this region both in the flat plain and in highland. These forests are in the elevated area but below 1,000 m amsl. The area is characterized by sandy or lateritic soil, and is dry with low soil productivity.

### Mixed Deciduous Forest

The mixed deciduous forest is composed of medium-size trees. These forests are found more in the provinces of Khon Kaen, Nong Khai and Nakhon Phanom.

### Tropical Rain Forest

Large trees with high rainfall characterize these forests. Most of the area has been deforested with a greater proportion of the remaining area being present in the provinces of Loei and Nakhon Ratchanima.

## Physical Characteristics of the Watershed

The Tad Fa Watershed is located within the three main watersheds namely, sub-system of Mae Khong watershed in the Northeast, Chi watershed in the East and Pasak watershed in the Southwest. In order to study the ecology of the watershed, the biophysical and socioeconomic data have been collected and analyzed. The related parameters of ecoregional database comprise the rainfall, evaporation, temperature, elevation, soil and land use.

The existing data concerning the biophysical and sociological data have been analyzed to present the important data in terms of watershed name, watershed code, location, latitude, longitude, area, length of main river, highest elevation, geomorphology, dam/reservoir, annual rainfall, runoff, population, province and land use. These data are the main characteristics of the whole watershed as shown in Tables 2-4.

**Table 2. Basic data of Mae Khong sub-watershed.**

| Description |
|---|
| Name: Mae Khong River; Watershed code: 02 |
| Location: Northeastern region |
| Latitude: 16$^{O}$ 08' 55 – 18$^{O}$ 28' 00 N |
| Longitude: 100$^{O}$ 54' 10 – 106$^{O}$ 04' 00 E |
| Area: 47,002 km$^2$; Length of main river: 3927 km |
| Head watershed: Nammailoei |
| Lower watershed: South China Sea |
| Geomorphology: Granite and Granodiolite, Kaeng Krachan Formation, Kanchanaburi Formation, Mafic and Ultramaific, Phu Pan and Phra Wihan Formation, Ratburi Formation, Mae Moh and Li Formation, Phu Kradung Formation, Alluvium, Marine Formation, Granite, Basalts and its equivalents, Phu Pan and Whian Formation salt and Khok Kruat Formation. |
| Important Dam/Reservoir: Nam Un dam 477 m.cu.m (constructed in 1974), Hui Luang Dam 108 m.cu.m (constructed in 1973) |
| Mean annual rainfall: 1,871 mm (1952-1996) at station 03023301 Amphur Mung, Sakon Nakon province |
| Runoff: 36.82 cu.m/sec (1984–1997) at Ban Ta Hui Lua, Ban Muang district, Sake Nakhon province |
| Population: 5,763,690 (1997) |
| Provinces involved: Loei, Nong Khai, Udon Thani, Sakon Nakon, Nakhon Phanom, Mudahan, Amnat Charoen, Ubon Ratchathani |
| Land use: Forest 2.7%; paddy 38.6%; upland crop 23.5%; fruit crops and perennial crops 5.1%; urban area 1.4%; and water area 2.8% |

*Cont...*

*Continued*

**Area of watershed**

| Watershed name | Area (km²) | Watershed name | Area (km²) |
|---|---|---|---|
| Second part of Nam Khong | 508 | Upper Part of Songkhram river | 3299 |
| Third part of Nam Khong | 674 | Lower part of Songkhram river | 3030 |
| Nam Un | 622 | Hui Klong | 693 |
| Nam Sai | 876 | Hui he | 715 |
| Fourth part of Nam Khong | 808 | Nam Yam | 1733 |
| Nam Puan | 658 | Hui Nam Un | 3469 |
| Lower Loei river | 2902 | Hui Tuay | 788 |
| Fifth part of Nam Khong | 1823 | Eighth part of Nam Khong | 1186 |
| Nam Sano | 1056 | Nam Phung | 971 |
| Nam Mong | 2718 | Nam Kam | 2537 |
| Sixth part of Nam Khong | 540 | Ninth part of Nam Khong | 6444 |
| Nam sui | 1310 | Hui Bangsai | 1366 |
| Hui Luang | 3425 | Hui Muk | 552 |
| Hui Dan | 681 | Hui Bung Ae | 1590 |
| Seventh part of Nam Khong | 2704 | Lower part of Nam Khong | 3387 |

**Table 3. Basic data of Chi watershed.**

Description

Name: Chi River; Watershed code: 04

Location: Northeastern region

Latitude: 15° 30' 00 – 17° 30' 00 N

Longitude: 101° 30' 00 –104° 30' 00 E

Area: 49,476 km², Length of main river: 3015 km

**Geomorphology:** Kanchanaburi Formation, Phu Pan and Pha Wihan Formation, Ratburi Formation, Phu Kradung Formation, alluvium, salt and Krat formation.

**Area of watershed**

| Watershed name | Area (km²) | Watershed name | Area (km²) |
|---|---|---|---|
| Upper Chi | 2489 | Nam Prom | 2320 |
| Lam Sapung | 758 | Nam Chern Chirn | 2922 |
| Kamkrajan | 886 | Lowerpart of Nam Phong | 3286 |
| Lam kanshu | 1635 | Hui Saibath | 741 |

*Cont...*

*Continued*

| | | | |
|---|---|---|---|
| Second part of Nam Chi | 3808 | Fourth part of Nam Chi | 4510 |
| Hui Sammo | 729 | Upper part of Lam Pao | 3282 |
| Third part of Nam Chi | 3244 | Lampanchard | 657 |
| Upper part of Nam Phong | 4424 | Lower part of Lam Pao | 4264 |
| Hui Pui | 916 | Nam Yang | 4145 |
| Lampaneang | 1912 | Lower part of Nam Chi | 2548 |

**Important Dam/Reservior:** Ubolratana 1,854 m.cu.m (constructed in 1996); Chulaporn 144 m.cu.m (1972); Nam Pung 156 m.cu.m (1965); Lam Pae 35 m.cu.m (1968)

**Mean rainfall:** 1842 mm (1952-1996) at station 0140801 Amphur Muang, Khon Kaen province

1131 mm (1952–1996) at station 01041607 Amphur Kosum Pisai, Maha sarakham province

**Runoff:** 122.0 cu.m/sec. (1952-1996) at station 01041601 Wat Thai Kosum Amphur Kosum Pisai, Maha Sarakham province

**Population:** 6,709,329 (1998)

**Provinces involved:** Chaiyaphum, Nakon Ratchasima, Khon Kaen, Loei, Udon Thani, Nong Bua Lam Phu, Maha Sarakham, Roiet, Kalasin, Yasothon and Ubon Ratchathani

**Land use:** Forest 22.2%; paddy 47.5%; upland crops 23.5%; fruit crops and perennial crops 0.2%; urban 1.4%; water area 2.8%; swamp and natural grassland 2.4%

## Table 4. Basic data of Pasak watershed.

**Description**

Name: Pasak River; Watershed Code: 12

Location: Eastern region

Latitude: 14° 21’ 44 – 17° 16’ 02 N

Longitude: 100° 34’ 40 – 104° 104’ 56 E

Area: 15,799 km$^2$; Length of main river: 1039 km

Head watershed: Phetchabum

Lower watershed: Mae Nam Chao Praya

Highest elevation: Dan Sai, Loei province

Lowest elevation: Uthai, Phra Nakhon, Si Ayuthaya

**Geomorphology:** Phu Kradung, Phu Pan and Phra Wihan Formation, Ratburi Formation, Marine Formation, Andesite-Rhyorite, Basalt and its equivalents, Granite, Diorite and quartz diorite

**Important Dam/Reservoir:** Pasak Chonlasit dam 746 m.cu.m. (constructed in 1999)

**Mean annual rainfall:** 1,180 mm (1952–96) at station 03120505 Wichian Buri, Phetchabun province

**Runoff:** 76.70 cu.m/sec (1956–96) at station 0112806 Kaeng Khoi, Saraburi province

**Population:** 1,785,424 (1998)

*Cont...*

*Continued*

**Provinces involved:** Phetchabum, Lop Buri, Saraburi, Phra Nakhon, and Si Ayuthaya

**Land use:** Forest 19.4%; Paddy 19.5%; upland crop 47.6%; fruit crop and perennial crop 2.6%; urban area 2.0%; water area 0.82%; swamp and natural grassland 8.7% (1998)

**Area of watershed**

| Watershed name | Area ($km^2$) | Watershed name | Area ($km^2$) |
|---|---|---|---|
| Upper part of Nam Pasak | 1465 | Hui Kokaew | 520 |
| Hui Nam Phu | 655 | Lam sonti | 1410 |
| Second part of Nam Pasak | 2205 | Lower part of Nam Pasak | 4152 |
| Third part of Nam Pasak | 4717 | Hui Muak lek | 655 |

# The Ecoregional Data

## Rainfall

The rainfall data, collected by Department of Meteorology was selected for 10-year period from 1988 to 1997. The average annual rainfall of the three main watersheds was analyzed based on rainfall data within the area of those watersheds:

- Mae Khong watershed: Data are from the provinces Loei, Nong Khai, Sakon Nakon, Nakhon Phanom, Mukdahan and Amnat Charoen.
- Chi watershed: Data are from the provinces Udon Thani, Khon Kaen, Nong Bua Lam Phu, Chayaphum, Kalasin, Maha Sarakham, Yasothon, Nakhon Ratchsima, Si Sa Ket, Roi Et and Ubon Ratchathani.
- Pasak watershed: Data are from the provinces Phetchabun, Lop Buri and Saraburi.

## Evaporation

The evaporation data, collected by Department of Meteorology, was selected for 10-year period from 1988 to 1997. The average annual evaporation of the three main watersheds was analyzed based on evaporation data within the area of those three watersheds (Fig. 5).

## Temperature

Temperature data, collected by the Department of Meteorology, was selected for 10-year period from 1988 to 1997. The average annual temperature of the three main watersheds was analyzed based on temperature data within the area of those watersheds.

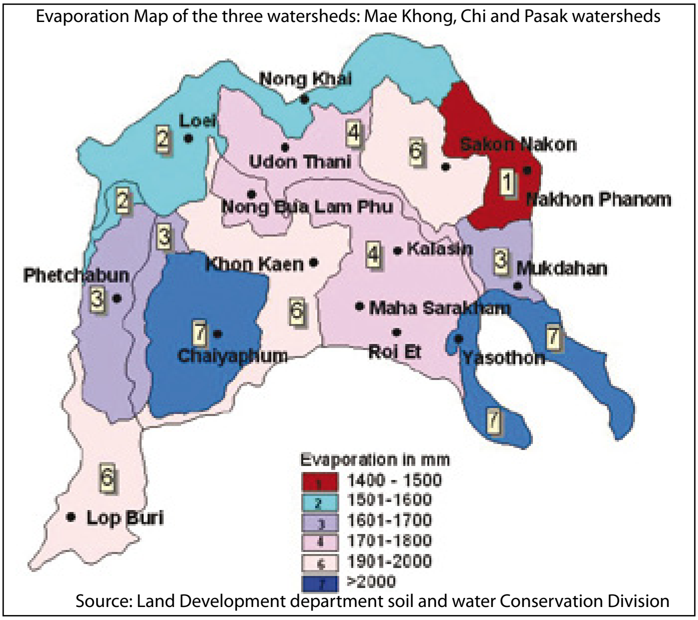



*Figure 5. Evaporation map of the three watersheds: Mae Khong, Chi and Pasak.*

## Topography

Based on the analysis of landform and slope class, map of Tad Fa watershed prepared by DLD is presented (Fig. 6).

## Elevation

The contour map of the Royal Thai Survey has been introduced and used as the base map for analysis of the contour intervals, which are grouped into five levels; 100–200 m, 200–500 m, 500–1000 m, 1000–2000 m and more than 2000 m.

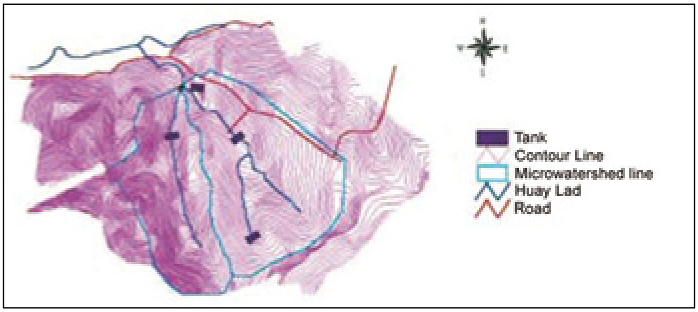



*Figure 6. Topography and drainage lines map of Tad Fa micro-watershed.*

## Soil

The soil distribution has been discussed earlier (Fig. 4).

## Land Use

The land use map is presented in Figure 7 (Source: DLD 1998).

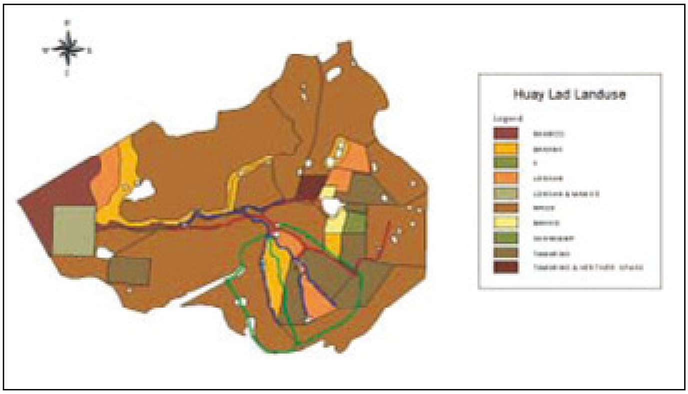



*Figure 7. Land use map of Huay Lad Watershed.*

## Criteria Approach

The following criteria were chosen to analyze and group the data.

**Rainfall:** The data of mean annual rainfall are grouped into four classes: 1000–1200 mm, 1201–1400 mm, 1401–1600 mm and more than 1,600 mm (Table 5). The percentage area of each class is measured (Fig. 2).

**Table 5. Rainfall range in the watershed.**

| Rainfall (mm) | Class |
|---|---|
| 1,000–1,200 | 1 |
| 1,201–1,400 | 2 |
| 1,401–1,600 | 3 |
| >1,600 | 4 |

**Evaporation:** The data of mean annual evaporation are grouped into seven classes (Table 6). The percentage area of each class is measured (Fig. 5).

**Table 6. Evaporation range in the watershed.**

| Evaporation (mm) | Class |
|---|---|
| 1,400–1,500 | 1 |
| 1,501–1,600 | 2 |
| 1,601–1,700 | 3 |
| 1,701–1,800 | 4 |
| 1,801–1,900 | 5 |
| 1,901–2,000 | 6 |
| > 2,000 | 7 |

**Temperature:** The data of mean annual temperature (see Fig. 3) are grouped into four classes (Table 7).

**Table 7. Temperature range in the watershed.**

| Temperature (°C) | Class |
|---|---|
| 25.0-26.0 | 1 |
| 26.1-27.0 | 2 |
| 27.1-28.0 | 3 |
| 28.1-29.0 | 4 |

**Topography:** The topographic maps are introduced to analyze and subdivide into three levels (Table 8).

**Table 8. Topography divisions in the watershed.**

| Topography | Class |
|---|---|
| Slope complex | S |
| Upland | U |
| Lowland | L |

**Hypsography:** Based on the elevation, the region is grouped into five classes (Table 9 and Fig. 8).

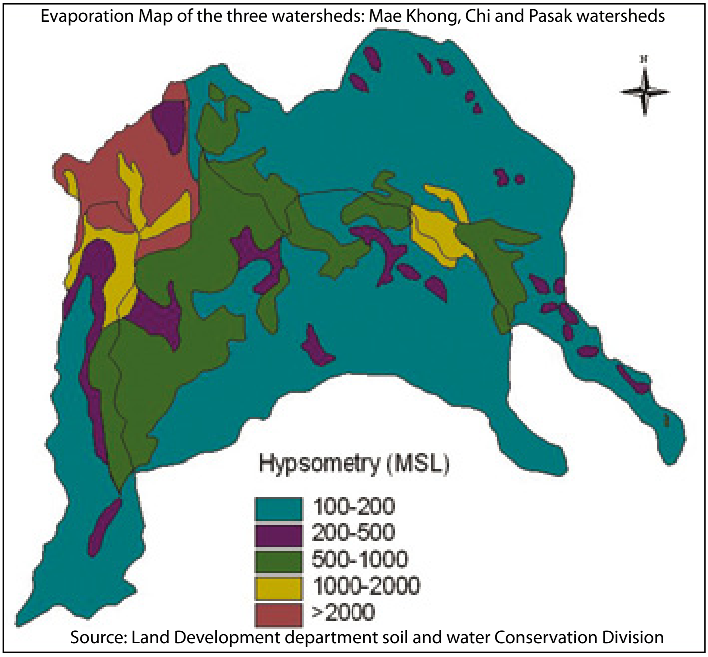



*Figure 8. Hypsometry map of the three watersheds: Mae Khong, Chi and Pasak.*

**Table 9. Hypsographic classes.**

| Hypsometry (MSL) | Class |
|---|---|
| 100–200 | 1 |
| 200–500 | 2 |
| 500–1,000 | 3 |
| 1,000–2,000 | 4 |
| 2,000 > | 5 |

**Soil:** The soil distribution has been discussed earlier (Fig. 4).

**Land use:** The land use map of the watershed is presented in Figure 9 (Source: DLD 1998).

## Agricultural Productivity – Yield Gap Analysis in Northeast Thailand

The amount of rainfall in the region is lower than other regions. So agriculture is based mainly on upland crops such as cassava, sugarcane, maize, upland rice,

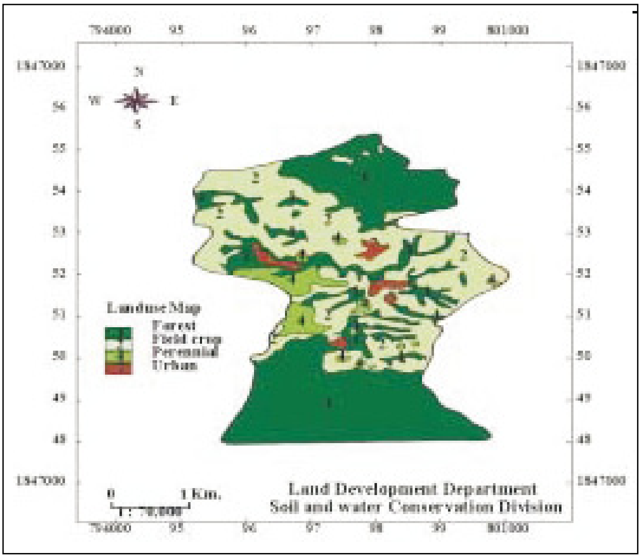



*Figure 9. Land use map of Tad Fa watershed.*

groundnut and soybean. A study was carried out on sustainable agriculture with crops, which minimize the use or destruction of natural resources and improve soil quality. The following five crops were selected for this study: rice, maize, soybean, groundnut and sunflower.

## Rice

Rice is an economic crop important to Thai society. Since 1979, the export of rice has assumed increased importance. The total area of production and productivity are given in Table 10. Yield in the northeastern region is 50 per cent lower than that in research plots and 11 per cent lower than that of the whole country (Table 11). When considering the morphogeology of the northeast, yield in the highland and upland area is lower than that of the whole country and higher in plain flat lands.

**Table 10. Rice production in Thailand in 1998[1].**

| Region | Planted area (rai) | Harvested area (rai) | Production (t) | Yield (kg $rai^{-1}$) |
|---|---|---|---|---|
| Northeastern | 31,040,327 | 28,543,360 | 8,009,659 | 281 |
| Northern | 12,526,986 | 11,217,283 | 4,975,721 | 444 |
| Central Plain | 9,886,193 | 9,406,367 | 4,289,886 | 456 |
| Southern | 2,919,666 | 2,677,407 | 885,449 | 331 |

1. 6.25 rai = 1 ha.

**Table 11. Paddy yield gap in Northeast Thailand.**

| Description | Yield (kg rai$^{-1}$) | Yield gap[1] (kg rai$^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield | 566 | - | - |
| Country yield | 314 | 252 (44) | - |
| Northeastern yield | 281 | 285 (50) | 33 (11) |
| Northeastern on highland yield | 195 | 371 (65) | 199 (63) |
| Northeastern on upland yield | 289 | 277 (48) | 25 (7) |
| Northeastern on lowland yield | 347 | 219 (38) | 33 (10) |

1. Percentage values are given in parentheses.

Upland rice is grown for household consumption. Farmers do not grow them for trading because seed quality is not good as required for the market. The yield of upland rice is 50 per cent lower than that of paddy. The upland rice yield in the northeast is 28 per cent lower than the research plots yield and about 18 per cent lower than the yield of the whole country (Table 12).

**Table 12. Yield gap of upland rice in Northeast Thailand.**

| Description | Yield (kg rai$^{-1}$) | Yield gap[1] (kg rai$^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield | 238 | - | - |
| Country yield | 210 | 28 (11) | - |
| Northeastern on highland yield | 195 | 43 (18) | 15 (7) |

1. Percentage values are given in parentheses.

## Maize

In Thailand, maize is being grown for the past 40 years. During 1988–92, maize production decreased by 7 per cent, mainly due to frequent droughts during the crop season. This has resulted in farmers shifting to other crops such as sugarcane and cassava that are more tolerant to drought. Out of a total production area of 8.8 million rai, 2.3 million rai is in northeastern part of the country (Table 13). The yield is lower than the other regions.

**Table 13. Maize production in Thailand in 1998.**

| Region | Planted area (rai) | Production (tons) | Yield (kg $rai^{-1}$) |
|---|---|---|---|
| Northeastern | 2,336,920 | 915,476 | 392 |
| Northern | 4,106,353 | 1,890,036 | 460 |
| Central Plain | 2,278,877 | 1,116,075 | 490 |
| Southern | 106,409 | 43,750 | 411 |

Maize yield in Northeast Thailand is 47% lower than that in the research plots, and 12% lower than that of the country (Table 14). Considering morphogeology, yield in the highland and upland area is lower than that of the whole country and higher in the lowland.

**Table 14. Yield gap of maize in Northeast Thailand.**

| Description | Yield (kg $rai^{-1}$) | Yield gap[1] (kg $rai^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield | 753 | - | - |
| Country yield | 449 | 304 (40) | - |
| Northeastern yield | 392 | 361 (47) | 57 (12) |
| Northeastern on highland yield | 244 | 509 (67) | 205 (45) |
| Northeastern on upland yield | 382 | 371 (49) | 67 (15) |
| Northeastern on lowland yield | 559 | 194 (25) | 110 (24) |

1. Percentage values are given in parentheses.

## Soybean

In Thailand, soybean is being grown since 1936. In the northern part of the country, farmers were recommended to grow soybean after rice. However the seeds were imported from China and Japan, but were not suitable to the local conditions in Thailand. In 1960, varietal improvement were undertaken and many good varieties were produced. Due to the increase in the livestock population the requirement of soybean has reached 2 million t per year. From the total production area of 2.6 million rai, Thailand can produce 0.5 million t per year. In the northeastern part of the country soybean is grown on 349,613 rai but the yield is low (Table 15). The yield in the northeastern region is 37 per cent lower than that in the research plots, and 1 per cent lower than rest of the country (Table 16). Morphogeologically, yield in the highland and upland area is lower than that of the whole country and higher in lowland.

**Table 15. Soybean production in Thailand region in 1998.**

| Region | Planted area (rai) | Production (t) | Yield (kg rai$^{-1}$) |
|---|---|---|---|
| Northeastern | 349,613 | 71,619 | 190 |
| Northern | 2,061,069 | 385,004 | 190 |
| Central Plain | 308,196 | 70,247 | 200 |
| Southern | 182 | 37 | 200 |

**Table 16. Yield gap of soybean in Northeast Thailand.**

| Description | Yield (kg rai$^{-1}$) | Yield gap[1] (kg rai$^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield | 306 | - | - |
| Country yield | 194 | 112 (36) | - |
| Northeastern yield | 192 | 114 (37) | 2 (1) |
| Northeastern on highland yield | 156 | 150 (49) | 38 (19) |
| Northeastern on upland yield | 180 | 126 (41) | 14 (7) |
| Northeastern on lowland yield | 206 | 100 (32) | 12 (6) |

1. Percentage values are given in parentheses.

## Groundnut

Groundnut is an important crop in Thailand and was introduced by the Portuguese. Since 1962, the Department of Agriculture initiated research efforts to improve the varieties. Out of a total area of 4.5 million rai, the groundnut area in Northeast Thailand is 228,565 rai. The yield is low at 214 kg rai$^{-1}$ (Table 17). The groundnut yield in the northeastern region is 23 per cent lower than that in the research plots, and 7 per cent lower than rest of the country (Table 18). Morphogeologically, the yield on the highland and upland area is lower than that of the whole country and it is higher in the lowland areas.

**Table 17. Groundnut production in Thailand in 1998.**

| Region | Planted area (rai) | Production (t) | Yield (kg rai$^{-1}$) |
|---|---|---|---|
| Northeastern | 228,565 | 50,617 | 214 |
| Northern | 295,850 | 69,919 | 238 |
| Central Plain | 96,881 | 24,465 | 247 |
| Southern | 29,375 | 3,169 | 176 |

**Table 18. Yield gap of groundnut in Northeast Thailand.**

| Description | Yield (kg rai$^{-1}$) | Yield gap[1] (kg rai$^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield (Ey) | 278 | - | - |
| Country yield (Cy) | 231 | 47 (16) | - |
| Northeastern yield (Ny) | 214 | 64 (23) | 17 (7) |
| Northeastern on highland yield (Nhy) | 186 | 92 (33) | 45 (19) |
| Northeastern on upland yield (Nuy) | 211 | 67 (24) | 20 (9) |
| Northeastern on lowland yield (Nly) | 247 | 31 (11) | 16 (7) |

1. Percentage values are given in parentheses.

## Sunflower

Sunflower, which originated in western USA was introduced in Thailand in 1973. But it was not successful because of its low yield and marketing problems. Since 1987, extension efforts have been directed to introduce it as the second crop in the central plain such as Saraburi and Lob Buri. In other areas, it is grown by a few farmers and still cannot be classified as an economic crop (Table 19). In the northeastern region the yield is lower than that of the research plots by 6 per cent and 0.4 per cent lower than that of the country (Table 20).

**Table 19. Sunflower production in Thailand in 1993.**

| Region | Planted area (rai) | Production (t) | Yield (kg rai$^{-1}$) |
|---|---|---|---|
| Northeastern | 63,500 | 14,980 | 235 |
| Northern | 174,820 | 43,005 | 246 |
| Central Plain | 270 | 64 | 238 |

**Table 20. Yield gap of sunflower in the Northeast Thailand.**

| Description | Yield (kg rai$^{-1}$) | Yield gap[1] (kg rai$^{-1}$) | |
|---|---|---|---|
| | | Research plots yield | Country yield |
| Research plots yield | 255 | - | - |
| Country yield | 239 | 16(6) | - |
| Northeastern on highland yield | 238 | 17(6) | 1 (0.4) |

1. Percentage values are given in parentheses.

# Productivity Constraints

It is apparent that in Thailand, few of the factors and constraints involved in agricultural productivity are nationwide. Mostly they have specific regional or provincial relevance. The constraints on productivity are discussed under the following headings:

- Physical constraints
- Technological constraints
- Institutional constraints
- Socioeconomic constraints

## Physical Constraints

Physical constraints have a major impact on agricultural productivity. The main physical constraints are:

- Climatic, especially rainfall, relative humidity, and dry season temperatures
- Topography
- Drainage and flood hazards
- Soils
- Accelerated erosion and runoff

**Climatic constraints:** The major climatic constraint is low rainfall in the dry season. A less important climatic constraint is the high relative humidity in the wet season, which encourages pests and diseases in dryland crops such as maize and sugarcane. Temperatures fall in the dry season. As altitude increases in the mountains temperature restricts the range of introducing tropical perennial crops that can be grown, although at the same time there is possibility of introducing temperate crops. However, the area affected by this constraint is very limited in extent and is generally lacking in agricultural potential due to the topography and soil.

**Topographic constraints:** The steep and uneven slopes result in rapid runoff of rainfall, accompanied by sheet and gully erosion and thus make cultivation difficult.

**Drainage and flood constraints:** Flooding is the major factor resulting from intensive rainfall in the wet season causing rivers to rise and inundate large areas of lowland crops.

**Soil constraints:** The major soil constraint is low fertility, affecting most highland soils and the strongly leached soils on the slightly higher terrain of the older terraces in the lowlands. The other widespread soil limitation is shallow depth and lateritic gravel aggregates, which cause loss of applied nutrients during the wet season, especially on the steep slopes. In addition they reduce the total water-holding capacity of the soil profile, limit rooting depth and increase erosion. Soil depth may be limited by bedrock or by dense and/or compacted lateritic gravels.

**Erosion and runoff constraints:** The increase of cultivation and illegal logging in the past decades in marginal highland areas has resulted in acceleration of soil erosion and rainfall runoff.

## Technological Constraints

The physical constraints can be mitigated by technological measures. Such measures include: irrigation; drainage flood control; system of highland agriculture and forest conservation; application of fertilizers and pesticides and weed control; improvement of seed supply and crop varieties.

## Institutional Constraints

Institutional constraints on agricultural productivity such as inadequate research, training, and extension and availability of agricultural credit are found in most developing countries. But in Thailand, research and training programs are relatively well developed. The government operates numerous agricultural research bodies and research stations. The department of Agricultural Extension Service is established in each province in the capital and at district level and provides a reasonably effective and comprehensive service to farmers. The country has many agricultural training establishments at all levels, which provide the government with competent recruits for its various agricultural departments. The institutional credit to farmers is provided by Bank of Agricultural and Agricultural Cooperatives (BAAC), farmer's welfare funds and commercial banks.

## Socioeconomic Constraints

**Social constraints:** There are few social constraints on agricultural productivity in Thailand: the Thai farmer is capable, adaptable, owns his land, and is generally free from restrictive Government control and direction. The main constraint is seen as the rapid population growth prior to 1975 and the consequent build-up of population pressure on the land. This in turn has led to the expansion of agricultural activity to less suitable lands.

**Economic constraints:** There are a few direct economic constraints on agricultural productivity in Thailand. In addition to the widespread institutional and infrastructure support that it provides to agriculture, the government also attempts to guarantee farmers' income by imposing minimum farm-gate prices for certain crops. At the same time the government avoids applying unnecessary restrictions on the farmers.

## Analysis of the Productivity Constraints

The northeastern part of the country is an important agricultural area of the country and a significant proportion of the production of important crops is from the region. But there are productivity constraints due to droughts and floods; also low soil fertility reduces the yield (Tables 21-23).

### Physical Constraints

**Climate:** Thailand has a tropical climate and there is not much variation in the weather. The limitation is the occurrence of dry period during the rainy season. The climatic constraints could be classified as low.

**Soil:** Soils in the recent past have been degraded due to degradation. The chemical and physical properties of soil in the agricultural area in the northeastern region indicated that the soils were strongly degraded when compared with the forest area. In the flat plain there is salinity. In the northeastern region, the area effected with salinity is 18 million rai or about 17 per cent of the region. So the Kong–Chi–Mun project encouraged cultivation of salt tolerant crops and increasing the forest area.

**Application of fertilizer:** Efforts have been initiated to encourage application of organic fertilizers due to high cost and toxicity of chemical fertilizers. The Soil and Water Conservation Department conducted an experiment in 1999 on the use of compost in rice fields at Roi Et province. Rice with compost gave 23 per cent higher yield than with chemical fertilizer. An experiment on the use of *Sesbania rostrata* before rice planting has shown that rice yield is only 3.6 per cent lower than that with 16-16-16 fertilizer at 20 kg $rai^{-1}$. The Land Development Department aims to decrease the usage of chemical fertilizers and promote the use of compost or green manure along with the promotion of soil and water conservation by the use of vetiver grass and prevention of soil erosion in 5 million rai in a year.

**Improved seeds and varieties:** This constraint is low as government and private sector are working actively to distribute and sell seeds to the farmers. The Department of Agriculture in 1994 has developed the following varieties:

upland rice variety Sew Mae Jan in Khon Kaen province yielding about 320 kg $rai^{-1}$, soybean variety Nakosawan yielding about 265 kg $rai^{-1}$ and sunflower variety Pacific 33 yielding about 228 kg $rai^{-1}$.

**Credit:** Farmers owning larger land holdings have greater access to credit from government or commercial banks whereas the smaller farmers with marginal land holdings rent out their land and have access only to the costlier loans from private moneylenders.

**Agricultural research:** The Government has a technology transfer center in each sub-district. Therefore there is no technological constraint in the institutional mechanism for technology transfer.

## Socioeconomic Constraints

There is shortage of agricultural labor and generally the farmers with marginal land holding prefer to lease-out their land. Another major problem is that some crops have a minimum support price while others do not.

## Table 21. Production constraints of the lowland in the northeastern region[1].

| | Physical constraints | | Technological constraints | | | Institutional constraints | | | Socioeconomic constrains | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crops | Climate | Soils | Irrigation | Drainage and flood control | Fertilizers | Sustainable agriculture | Crop varieties | Financial | Technology/ Institutional | Social | Economic |
| Rice | L | M | M | M | M | M | L | M | M | M | M |
| Maize | L | M | M | M | M | M | L | M | M | M | M |
| Soybean | L | M | M | M | M | M | L | M | M | M | M |
| Mung bean | L | M | M | M | M | M | L | M | M | M | M |
| Sunflower | L | M | M | M | M | M | L | M | M | M | M |

1. Level of constraint: L = Low; M = Moderate; H = High.

## Table 22. Production constraints of the upland in the northeastern region[1].

| | Physical constraints | | Technological constraints | | | Institutional constraints | | | Socioeconomic constraints | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crops | Climate | Soils | Irrigation | Drainage and flood control | Fertilizers | Sustainable agriculture | Crop varieties | Financial | Technology/ Institutional | Social | Economic |
| Rice | L | M | M | M | M | M | L | M | M | M | M |
| Maize | L | M | M | M | M | M | L | M | M | M | M |
| Soybean | L | M | M | M | M | M | L | M | M | M | M |
| Mung bean | L | M | M | M | M | M | L | M | M | M | M |
| Sunflower | L | M | M | M | M | M | L | M | M | M | M |

1. Level of constraint: L = Low; M = Moderate; H = High.

**Table 23. Production constraints of the highland in the northeastern region[1].**

| | Physical constraints | | Technological constraints | | | Institutional constraints | | | Socioeconomic constraints | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crops | Climate | Soils | Irrigation | Drainage and flood control | Fertilizers | Sustainable agriculture | Crop varieties | Financial | Technology/ Institutional | Social | Economic |
| Rice | L | M | M | M | M | M | L | M | M | M | M |
| Maize | L | M | M | M | M | M | L | M | M | M | M |
| Soybean | L | M | M | M | M | M | L | M | M | M | M |
| Mung bean | L | M | M | M | M | M | L | M | M | M | M |
| Sunflower | L | M | M | M | M | M | L | M | M | M | M |

1. Level of constraint: L = Low; M = Moderate; H = High.

## Conclusion

The constraint analysis of agriculture in Northeast Thailand reveals the existence of problems related to infertility of the soil, soil erosion and flooding due to the steep slopy nature of the land. The increasing pressure of the population, which has led to the conversion of forestland to agriculture land, has been a major reason for the above problem. The Department of Land Development in Thailand admits that the magnitude of the problem is large and realistically admits that tackling the problem in its totality requires huge budgetary support, which is a constraint. To address the budgetary constraint problem and to garner greater contribution from the farmers for soil and water conservation works, there is a need to effectively demonstrate that yield increase is possible and the gap between the potential yield in research plots and farmers' fields needs to be reduced. The differences in yields are currently relatively high particularly for rice (50 per cent lower), maize (47 per cent lower), soybean (37 per cent lower), and sunflower (6 per cent lower).

The intervention of the project should provide the scope to demonstrate that cost-effective solutions with farmers' participation (in program conceptualization and financial support) is a possible solution. The intervention process has the advantage of a decentralized agriculture extension system in the country, which can be effectively utilized.

# 2. Integrated Land and Water Management for Controlling Land Degradation and Improving Agricultural Productivity in Northeast Thailand

***Thawilkal Wangkahart, Prabhakar Pathak, Pranee Seehaban, Anuwat Bhotinam, Preecha Chueychoom, Suhas P Wani, AVR Kesava Rao and R Sudi***

## Introduction

Northeast (NE) Thailand is situated between 19° to 14° N latitude and 101° to 106° E longitude. It encompasses 17.02 million ha – roughly one-third of the entire country and is the poorest region of Thailand in terms of resources, economy and household income. Most of the region's inhabitants are small holding, low income farmers who face diverse agricultural and resource problems related to extreme environmental variability, adverse climate, poor soils and limited, often unreliable water resources.

Though NE Thailand has a monsoon climate similar to other parts of Southeast Asia, the region's geophysical characteristics create special conditions. The region has average annual rainfall of 1300 to 1400 mm, but considerable variation is found. More than 90% of the annual rainfall occurs between May and October (ie, rainy season). The western half of the region is relatively drier (1100 mm $yr^{-1}$) as a consequence of the rain shadow effect. In contrast, annual rainfall in the extreme northeast corner of the region is often 1800 mm. The actual amount and pattern of rainfall are often extremely erratic and unpredictable. This creates considerable risk for agricultural production, 80% of which involves rainfed cultivation.

Soils in the northeast region are generally loamy sand or sandy loam, both with low fertility and poor moisture retention capacity. Deforestation has expanded cultivable area rapidly during the 1960s. But in the process, deforestation and other practices have led to changes in the hydrologic environment, and caused widespread salinity problems, soil erosion and soil fertility deterioration. In rainfed areas, water availability is becoming one of the major constraints for increasing and sustaining productivity. Many regions of Thailand have suffered from longer than usual drought periods, higher temperatures and unusual rainfall anomalies, which have devastated rural economies in rainfed areas. Out of 76 provinces, 46 suffer from water shortage. Due to these problems, a vicious cycle of soil degradation, low yields, poverty and low investment has gripped rainfed agriculture, particularly in NE Thailand.

To address these problems several watershed management programs in Thailand have been implemented during the past two decades by various government departments and institutions. Most of the initial watershed programs by Thai Royal Irrigation Department (RID), Ministry of Agriculture and Cooperatives and Kingdom Watershed Management Program were primarily focused on increasing the availability of water for agriculture and other uses. Several other watershed programs by Agricultural Development and Research Center (ADRC) and Department of Land Development (DLD) were focused on reducing land degradation and improving soil quality. More recently, the Integrated Watershed Management Project, implemented by consortium of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Department of Agriculture (DOA), the Department of Land Development (DLD) and Khon Kaen University (KKU), is focused more on increasing the productivity and improving livelihoods of farmers through better management of natural resources. This chapter describes the general landscape, soils, crops and socioeconomic conditions of NE Thailand, reviews the various watershed management programs in NE Thailand and discusses their approach, problems and impact on agricultural productivity and natural resources. The results of integrated watershed management implemented by the consortium of ICRISAT-DOA-KKU-DLD in NE Thailand are covered in detail.

## General Background of Northeast Thailand

### Landscape

Typically, northeastern physiography is a saucer-shaped plateau, bordered to the north and east by Mae Khong river, to the west by Phetchabun mountain range and to the south by Phanom-Dong-Rak mountain range. The plateau is divided into two main basins by the Phu Pan range, namely Sakon Nakon basin in the north and Khorat basin in the south. Land surfaces in association with runoff flow-directions are slightly tilted from northwest to southeast boundaries for Khorat basin, which is drained by Chi river and Mun river, and from the divider-line to northeast boundary for Sakon Nakon basin, which is drained by Song Kram river. The landscape is predominantly characterized by a gently sloping to undulating landform. The average elevation is about 170 m above mean sea level.

### Soil Features and Management

**Soil features:** Soil in gently undulating land (nearly 80% of NE landform) is covered by Mesozoic and Paleogene Tertiary sedimentary rock formation (ADRC 1989). These soils are characterized by sandy textured top soils. A skeletal soil owing to shallow laterite layer is widespread in Sakon Nakon basin and comprises 13% of the NE. Saline and sodic soils commonly occur in the plateau and cover about 17%. The alluvial plain has fertile soil and is distributed along the Mae Khong, Chi and Mun rivers and their tributaries but it is rather small in area – only 6% of total NE area. Sandy topsoils, salt-affected soils and skeletal soils are regarded as three major problem soils in the NE region. Low soil fertility caused by these soils on the plateau and erratic rainfall are responsible for low agricultural productivity in NE Thailand.

**Soil erosion and nutrient loss:** Soil erosion is a major problem in degradation of natural resources. About 6.77 billion ha (40%) is affected by soil erosion. Mean annual suspended sediment transported by Mae Khong, Chi and Mun rivers is 9.39, 1.04 and 1 million t while soil loss is 0.16, 0.02 and 0.01 mm $yr^{-1}$, respectively. Sedimentation is secondary process after soil erosion, consequently, transported to streams or reservoirs. Soil erosion causes nutrient loss. The NE region recorded very high K loss (Table 1).

**Table 1. Mean annual nutrient loss from different regions of Thailand[1].**

| | Nutrient loss (t $yr^{-1}$) | | |
|---|---|---|---|
| Region | Nitrogen | Phosphorus | Potassium |
| North | 38.29 | 4.47 | 75.59 |
| Northeast | 18.90 | 1.21 | 91.64 |
| Eastern | 17.89 | 1.07 | 30.86 |
| Southern | 17.31 | 0.45 | 13.25 |
| Total | 92.4 | 7.2 | 211.3 |

1. Source: http://www.rid.go.th

**Soil management:** The ADRC in NE is a tri-parties project that involves Thailand, Japan and USA. With the main support of JICA for over the last 10 years, ADRC has played a key role as an international technology center for soil management in NE in collaboration with local Thai multi-research organizations in agricultural sciences such as DLD, DOA and KKU under the coordination of Office of Permanent Secretary (OPS). Several research inputs focused on improving problem soils (sandy, saline, erosion and skeletal) in order to increase crop production. Several types of maps such as agroecological zone map, land suitability map, saline soil map, erosion status map, groundwater and area suitable for small-scale water development map were produced. The study revealed the hypothesis of soil salinization that saline groundwater originates from rock salt that comes up through the fractual zone, silt stone aquifer becomes saline, contaminates shallow aquifer and comes up to surface during dry season. Vetiver grass (*Vetiveria zizanioides*) and ruzi grass (*Brachiaria* *ruzizensis*) planted as contour-strips are promising systems to prevent soil loss and water runoff. *Sesbania rostrata* shows high potential as a promising green manure crop for supplying both N and P in unfertile soils of NE rainfed lowland rice. Stylo (*Stylosanthes hamata*) and sunnhemp (*Crotalaria juncea*) are well suited in upland for crop rotation green manuring. Application of biofertilzers such as mycorrhiza, blue green algae and azolla enhanced the effectiveness of chemical fertilizer. Using 1.5 m wide ridge associated with 14 d at regular intervals resulted in the highest irrigation efficiency in soybean cultivation. Planting eucalyptus trees in the upper part reduced salinity of soil in lowland paddy. Some of these research findings are widely implemented in problem soils of NE (ADRC 1989).

**Land development technology transfers:** The DLD plays a major role in both soil improvement and soil conservation through the conventional concept of extension and technology transfer through three actors, viz, technology development process – researcher, extensionist and implementers (farmers). The mobile unit team consisting of a technical officer, driver and tractor helped farmers to build terraces on sloping land with farmers contributing their share towards petrol and food expenses. However, this approach proved to be ineffective as farmers considered it to be a government scheme and did not maintain the terraces. This is an example of common failure of public resources properties management. The information flow in one direction from researcher to extensionist and to farmers with little or no interaction seldom has good understanding of the farmers' environment and constraints of adoption. The "People-Centered" and "Farmers' Participatory" concepts are now generally accepted. The soil conservation program must work closely with land users from the initial stage. There are "Soil Doctors" also known as "Soil Doctor Volunteers" (SDV) in each Land Development Village (LDV) programs across the country. The SDVs are seemingly good actors as key local "information desk", which is empowered by DLD incentives providing through various forms, viz, cost-sharing of various on-farm conservation measures, farm inputs, job contract to produce seedlings or work on project activities, infrastructure such as village/farm road, education and vocational training, and right to making recommendation for participation of villagers in project activity. In LDV programs, total cost is paid by the government towards establishment of conservation measures, and since there is no contribution from farmers, farmers' participation in the maintenance of the structures is in question.

## Crop Production and Socioeconomic Conditions

According to archaeological excavation at Ban Chiang and Udon Thani, agriculture began to be practiced over 3000 years ago. The lowland areas were first utilized for the cultivation of rice, which became the staple food of the early inhabitants. The upland area was utilized only since the last 40–50 years for additional family income. The first major upland crop was kenaf, followed by cassava in low fertility areas and maize along the fertile land tracts. Other major upland crops introduced in the area were sugarcane, cotton, groundnut, soybean, castor, mung bean and sesame. Kenaf area has experienced a continuous decline due to competition with cheaper synthetic products and marketing problems. Cotton has also rapidly decreased in planting area due to pest-control problems. Currently, even the cassava area has been slowly declining and is being replaced by sugarcane. In recent years, area under sugarcane cultivation has grown rapidly due to relocation of many sugar mills from other parts of the country. Moreover, most of these local mills have been able to increase the crushing capacity, following installation of improved equipment.

Fruit trees were slowly introduced into the cropping systems of the NE region. Commercial fruit-tree production was initiated only two decades ago and in recent years, many large plantations were established because of the availability of cheap land and labor.

The majority of the NE farmers are still dependent on the cultivation of crops. Crop income account for more than 60% of the family's total farm income, while livestock and agricultural employment contribute only about 32%. However, the off-farm income of the average NE farm family was slightly higher than the agricultural income. This fact implies that the low agricultural income is not sufficient to support the family and it has become important for NE farm families to seek employment outside farms.

The economic and social conditions of the country have changed rapidly in the past two decades. As a result, agricultural production in the NE has also been affected. Farm labor were drawn into the industrial and service sectors in other parts of the country. The NE agriculture production needs proper initiatives that would improve family income and tackle the problem of reduced-farm labor for a sustainable production system.

## Water Resources Development in the Northeast

**Strategy of water resources development:** The water resources development strategy for the NE follows two-pronged water policy needs: first to emphasize on distribution system from existing sources of reservoir and rivers. This can be classified into three zones: Zone I comprises 0.34 million ha with 8–9% of farm families and land is irrigable by large-scale reservoir; Zone II consists of 0.31 million ha with 10% of farm families and land is irrigable by pumping from reliable rivers; and Zone III areas are meant to meet basic requirement in every village. These areas are inaccessible from reservoir and reliable rivers. This zone comprises 80% of farm families, and small-scale water resources development can only meet basic domestic water needs and minimal supplementary irrigation requirements (Table 2).

**Table 2. The potential use of alternative sources for small-scale water resources projects[1].**

| Village use and requirement | Weirs | Rehabilitation | Village tanks | Dug ponds | Deep wells | Shallow wells | Roof runoff |
|---|---|---|---|---|---|---|---|
| Drinking | | | | | x,? | x, ? | x |
| Domestic | x | x | x | x | x | x | ? |
| Animal | x | x | x | x | x | x | |
| Wet season crop | x | x | x | x | x, ? | ? | |
| Dry season crop | x | x | x | x, ? | x, ? | ? | |
| Fisheries | x | x | x | x | | | |

1. x = Potential use; ? = Questionable.

Weirs, rehabilitation of natural streams (*Huay*), swamps (*Nhong*) and small reservoirs or village tanks are typically found in all mini watersheds of NE where common land is available for inundation. Dug-out pond or farm ponds are built by excavating the earth below the ground with some sort of seepage control method which are relatively smaller than village tanks and are usually dry in the dry season because of seepage. The deep (tube) wells are dug down to a confined aquifer, which require pumping equipment to draw water. However, in some areas, water quality is poor due to high NaCl content in water. The shallow (open) wells are usually dug manually by villagers down to the water table. And the last alternative is collection of runoff water from household roofs and quality of this water is good and suitable for drinking purpose.

**Water resources development:** The RID has defined the whole Kingdom's watershed into 25 main river basins. Northeast shares only three main river basins – Mae Khong, Chi and Mun. Their coverage is about one-third of watershed area and about 20% runoff drainage of the country (Table 3).

**Table 3. Main river basins, drainage area, runoff and Royal Irrigation Development (RID) water resources development in Northeast Thailand[1].**

| Main river basins | Drainage area ('000 km$^2$) | Mean annual runoff (billion m$^3$) | RID Water Resources Development Schemes | | | |
|---|---|---|---|---|---|---|
| | | | No. large & medium | No. small & others | Stock (mil. m$^3$) | Irrigable (mil. ha) |
| Kingdom | 511.48 | 213.42 | 694 | 9362 | 37.75 | 3.106 |
| Northeast | 165.85 | 44.03 | 178 | 5184 | 6.02 | 0.464 |
| Mae Khong | 46.67 | 13.29 | (Chi) | (Chi) | 1.16 | (Chi) |
| Chi | 49.48 | 11.24 | 75 | 2025 | 1.79 | 0.198 |
| Mun | 69.70 | 19.50 | 109 | 3159 | 3.07 | 0.266 |
| NE (%) share | 32.4 | 20.6 | 25.7 | 55.4 | 15.9 | 7.035 |

1. Source: Consolidated from RID (http://www.rid.go.th)

**Agencies involved in water resources development:** Several departments under the Ministry of Agriculture and Cooperatives are responsible for various aspects of water resources development. The RID plays important roles in the development of water resources and irrigation system facilities. The major responsibilities of the RID are construction and maintenance of various sized (medium and large scale) reservoirs associated with main irrigation systems, which serve 15% irrigated area of the country and also small to second-scale schemes such as village tanks, rehabilitation of natural resources like dredging streams and swamps, levee for flood protection and supply of water through mobile water tanker during emergencies such as in drought relief program. Providing water for agricultural production is the main responsibility of RID. Accordingly, RID project sites are almost implemented in lowland of basins or wide flood plain of the rolling topography.

In sub-river basin context, which is defined as Zone III, gently sloping undulated upland, mini-watersheds are located. The DLD's major responsibility is to take up soil conservation measures and, wherever feasible, water resources projects are included as part of soil conservation measures. Small-scale water resources (SSWR) developments are focused on farm lands, farm ponds, shallow wells, dredged waterways, sediment weirs and earthen bunds. Up to 2004, DLD completed construction of 1807 structures of SSWR, which was recently specified as optional component in almost all LDVs. Similarly, the major responsibility of the Office of Land Reform is land reform and consolidation. It is also empowered to construct water resources projects as a part of agricultural land development. Recently, the OPS has launched integrated farming program under King's New Farming Theory and farm pond is a key component of pilot farms. Generally, various government programs have included farm ponds construction as priority.

The Department of Agricultural Extension (DOAE) initiated deep well pumping project as part of extension promotion program.

The Electricity Generating Authority of Thailand (EGAT) is concerned with construction of the major dams for electricity generation for domestic and multipurpose uses. Domestic water supply, irrigation and flood control facilities are closely connected. The Accelerated Rural Development (ARD), which has been now reorganized, has responsibilities of small reservoir construction, and well drillings program to provide water for basic needs in the village. The major responsibility of the Community Development Department is to take up the RID small-scale water resources project for community development. National Energy Authority (NEA) is involved in providing water for irrigation from medium- and large-scale reservoirs. The results were very promising, but unfortunately NEA is not authority in-line agency in executing this type of work.

Between the several organizations/agencies working on water resource development in NE Thailand, lack of proper coordination and budget allocation were the main problems identified. Also the responsibility of the organization in context of SSWR was not clear. These problems made the water resource development program less effective in NE Thailand. It was suggested that one of the existing dividing line between various agencies, viz, RID, ARD, CDD and DLD is by cost per project execution. These agencies normally are involved with total project cost of not less than one million baht per project.

The socioeconomic impact of three common types of SSWR of RID, typically in lowland, indicated that water availability in dry season enhanced upland crop and vegetables production (Thawilkal 1997). This can be implied that the productivity of paddy in Zone I and Zone II (20% arable) may not need much supplementary irrigation in rainy season, while it is essential during dry season. In contrast, in rolling upland of Zone III (80% arable), SSWR plays a vital role not only for rainy season paddy productivity but also to generate extra farm income through dry season crop cultivation. These findings clearly indicate that water resource development should be given high priority to sustain and increase productivity.

## Integrated Watershed Development Experiences

As discussed earlier, several activities on soil improvement, land development, water resources development, crop and livestock production activities were functioning independently. An area-based problem-focused approach, with the integration of multi-disciplinary partnerships in a holistic system of management, is necessary to combat the problems. The term “watershed” refers to a sub-drainage area of a major river basin (Dixon and William 1991), whereas

“Integrated Watershed Management Approach” is the process of formulating and implementing the course of action involving natural and human resources in the watershed to achieve specific social objectives. This approach requires the linkage between the upland and lowland in both biophysical and socioeconomic aspects.

The Thai-New Zealand Small Watershed Development Project, about 10 years back, had launched a four-year program “People Volunteer’s Weirs” by using participatory approach with the construction of weirs in series on stream flows of two pilot watershed development programs in Huay Yang watershed of Bua Yai district, Nakon Rachima province and Huay Khow San watershed of Det Udom district, Ubon Ratchathani province. Experiences of pilot projects indicate that comprehensive implementation through biophysical and socioeconomic aspects were effective. The project was institutionally well organized and supported with convergence of the government development agencies of multi-agencies and participation of farmers and local stakeholder. The project’s performances were well recognized countrywide and had won awards/prizes periodically. Several training courses, seminars and meetings were organized and dissemination of information through digital maps, manuals and books were published for various stakeholders. This was found to be quite effective in project operation.

Japan International Research Center for Agricultural Sciences (JIRCAS) program on “Comprehensive Collaborative Research Project on Development of Sustainable Agricultural System in Northeast Thailand” focuses on effective utilization of local resources by a comprehensive technology improvement. Several new technologies were introduced to make the system more productive. Direct seeding paddy has resulted in labor saving, thereby giving more profitable paddy production. Forage production for feeding livestock throughout the year was also developed. Small farm machines were introduced to improve efficiency of farm operation. Leguminous tree strip planting, alley cropping, minimum tillage and plastic sheet bed for soil moisture conservation were also demonstrated.

JIRCAS has extended the project titled “Increasing Economic Option in Rainfed Agriculture in Indo-China by Efficient Use of Water Resources” for another seven years to address economic aspects of rainfed agriculture. It aims to demonstrate the promising technologies for farmers to choose. The program is being implemented in Nong Saeng watershed of Ban Had District, Khon Kaen Province. This is aimed to scale-up promising technologies developed by the previous project. During the first year of farmer participatory research, study was on “Mg white enforcement dikes technique” to replace the damaged dikes in paddy caused by upstream runoff erosion in previous rainy season. Although the downstream paddy field dikes were damaged and eroded, sediment was deposited on the fields but it was never an issue with downstream farmers, as the runoff from fertilized sugarcane fields were beneficial to paddy crop and increased yields.

### Integrated Watershed Management with Holistic Approach

The concept of integrated watershed management with holistic approach for increasing agricultural productivity and enhancing people's livelihoods is relatively new in NE Thailand. In 1999, an integrated watershed management program was initiated at Tad Fa village in Phupaman district of Khon Kaen province. A new farmer participatory consortium model for efficient management of natural resources and for reducing poverty has been adopted. A consortium of institutions was formed for project implementation and technical backstopping. The DOA, DLD, KKU and ICRISAT formed a consortium for implementation and technical backstopping at two benchmark sites, viz., Tad Fa watershed in Phupaman district and Wang Chai watershed in Phuwiang district.

## Tad Fa Watershed, Phupaman, Khon Kaen

Tad Fa watershed is part of a large basin of Chi river, which is located at latitude $15^{o}$ 30' N and longitude $101^{o}$ 30' to $140^{o}$ 30' E and is about 150 km northwest of Khon Kaen. It is a junction of three big watersheds namely Chi in east, Mae Khong in the northeast, and Pasak in the southwest. Tad Fa watershed is located in two provinces. In the eastern part of the river, Tad Fa comes under Khon Kaen province, which has nearly 700 ha, while the western side comes under Petchabun province. This watershed project was carried out in the eastern part of Tad Fa watershed of Khon Kaen province. Topographically Tad Fa watershed has high to medium slopes and soils are mostly Ustults. The land use mostly comprises field crops, horticulture and vegetables. The cropping systems under rainfed condition include maize as a cash crop on high and medium slopes and upland rice on the lower slopes. The fruit trees and vegetables are usually grown close to supplementary water resources on the lower slopes. Sometimes, legumes and cereals are rotated with maize.

Out of 700 ha of land in the eastern part of Tad Fa watershed, the middle portion of the watershed called Huay Lad, which had about 200 ha of land under cultivation, was selected covering two villages – Ban Tad Fa and Ban Dong Sakran. Most of the farmers from Ban Tad Fa village had land in the northern Huay Samtada. The watershed activities were concentrated in the Huay Lad area (Dong Sakran village) for research and development work. There are 49 farm ponds in the Huay Lad. Two micro-watersheds were identified for research. One micro-watershed is "traditional". It has moderate slope and nearly 70% of land has fruit trees and in the remaining area other annual crops like maize and upland rice are grown. The other micro-watershed is “improved”. It has moderate as well as steep sloping lands and mostly annual crops like maize and upland rice are grown. All the interventions are carried out in this micro-watershed. In almost 80% of this micro-watershed, “hillside ditches” are dug for soil conservation on contour. Vetiver and maize are planted along the side of “hillside ditches”. Farmers are advised to plant crops like maize along the contour instead of usual up and down the slope. One automatic runoff recorder and sediment sampling system is installed at the lowest point of each micro-watershed to monitor runoff and soil loss. The area of traditional micro-watershed is 17.8 ha with four farmers while that of improved micro-watershed is 12 ha with five farmers. An automatic weather station is installed near the research area to monitor rainfall, temperature, sunshine, humidity, wind velocity and soil temperature continuously at fixed intervals of time. Soil survey of the entire Huay Lad agricultural land is done and detailed soil map and land use map is prepared. Majority of the soil is silty clay loam with a very small fraction of clay loam. Almost all the clay loam has 2–5 and 5–12% slope while a small proportion of silty clay loam has 2–5% slope and the rest has 5–12, 12–20 and even 20–35% slope. There are 13 distinct soil series and their variants in Huay Lad. Detailed baseline survey of households covering size of family, age, education, source of income, size of land holding, land use, crops grown, agricultural implements, animals reared and financial status of farmers involved in the micro-watershed has been carried out. Since the history of cultivation of these lands is only about 80 years, the soils are rich in organic matter and support reasonable crop production.

## Agroclimatic Features of Tad Fa Watershed

**Rainfall characters:** Average annual rainfall of the watershed is about 1300 mm and average annual potential evapotranspiration (PET) is about 1435 mm. Rains generally start by March and continue up to October with above 100 mm of rainfall per month. May, August and September are the rainiest months. Total number of rainy days (receiving more than 2.4 mm per day) in a year is about 71; and more than 10 rainy days per month occur in May, August and September. Generally, there are about four days with a rainfall of more than 50 mm in the rainy season. In 2000, sixteen such events occurred while in 2001 only one event occurred. There is a large variation in rainfall amount and distribution over years and within the season. To understand the variability of rainfall in the region, long-period rainfall data of Khon Kaen was analyzed and is presented in Figure 1.

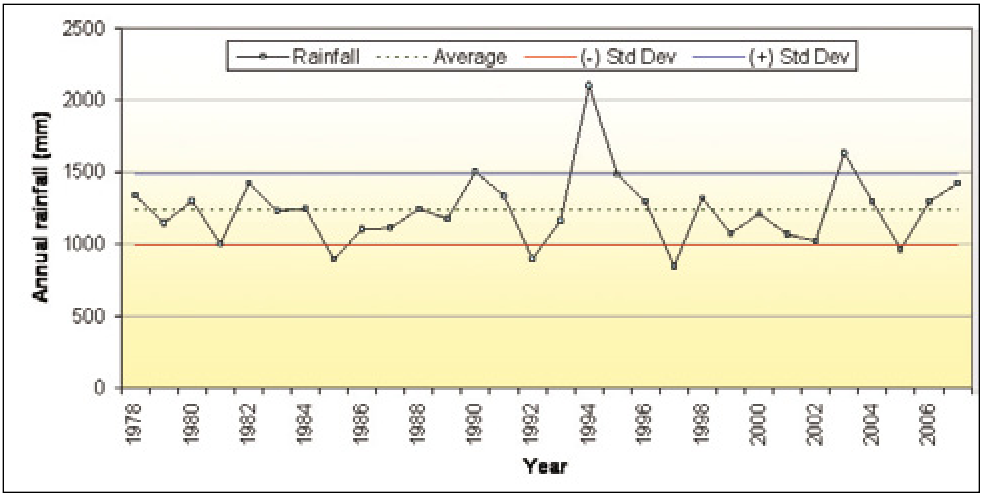



*Figure 1. Variability in the annual rainfall at Khon Kaen.*

Figure 1 shows that during the past 30-year period (1978–2007) at Khon Kaen, rainfall varied from about 2100 mm in 1994 to 850 mm in 1997. However, no trend in rainfall is observed. The long-period average for annual rainfall is about 1240 mm with a standard deviation of 250 mm and the coefficient of variability being 20%.

**Water balance:** Water balance of Tad Fa is computed based on the modified method of Thornthwaite and Mather (1955). The FAO Penman-Monteith method as described by Allen et al. (1998) is used for computing weekly PET. Figures 2 and 3 show the water balance in Tad Fa watershed for the wet year (2000) and dry year (2001) and the distribution of rainfall, PET and actual evapotranspiration (AET) over the meteorological weeks. Periods of water deficit, water surplus, soil moisture accretion and soil moisture use are also demarcated and their areas represent the quantity.

During the wet year 2000, rainfall was more than the PET, starting from the first week of April and this condition continued till the first week of November (Fig. 2). However, there were a few times when rainfall was less than PET. Soil reached its field capacity by the last week of April and water surplus started accumulating. Annual water surplus was 1240 mm. There was negligible water deficit during the rainfed crop-growing period and the annual water deficit was 352 mm. On the other hand, during the dry year (2001), rainfall was more than the PET, from the last week of April and this condition continued up to the middle of September (Fig. 3). A meager water surplus of 77 mm was observed in two weeks (not consecutive) with little prospects of water harvesting. There was considerable water deficit even in the crop-growing period and the annual

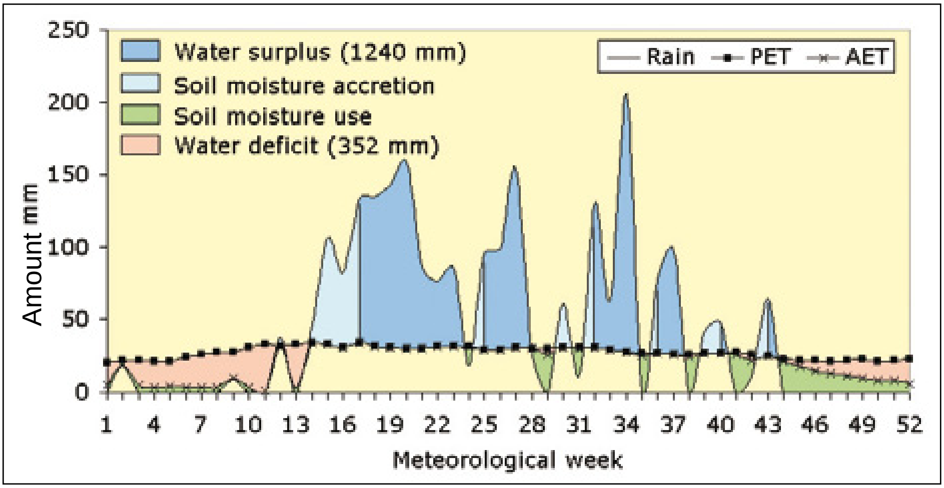



*Figure 2. Water balance during wet year (2000) at Tad Fa watershed.*

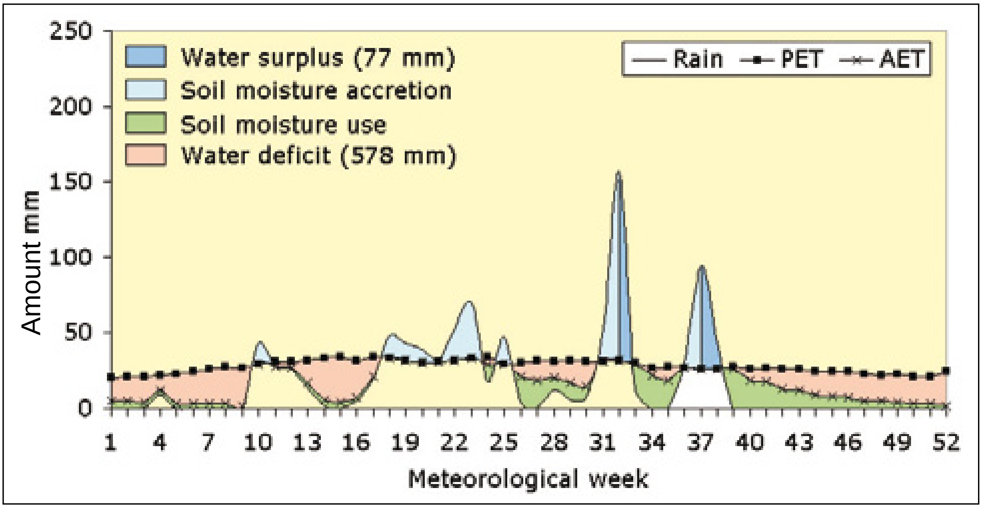



*Figure 3. Water balance during dry year (2001) at Tad Fa watershed.*

water deficit was 578 mm. Water balance diagrams help in understanding the distribution of various water balance elements and their interpretation helps in planning water harvesting and management of crops.

**Length of growing period:** Length of the rainy season is the duration between the onset and end of agriculturally significant rains. The length of growing period (LGP) is defined as the length of the rainy season, plus the period for which the soil moisture storage at the end of rainy season and the postrainy season and winter rainfall can meet the crop water needs. Therefore, LGP depends not only on the rainfall distribution but also on the type of soil, soil depth, water retention and release characteristics of the soil. This assumes greater importance from a watershed perspective where soil depth in a toposequence can also alter the LGP across the watershed – it is longer in the low-lying regions and short in the upper reaches of the watershed.

Using water balance technique, week-wise index of moisture adequacy (IMA) was computed; IWA is defined as the ratio of the actual evapotranspiration to the potential evapotranspiration and expressed as a percentage. Beginning and end of the growing season was identified based on the IMA. The growing season begins when the IMA is above 50 per cent consecutively for at least two weeks, starting from the middle of May. The end of the season is identified when the IMA falls below 25 per cent for two consecutive weeks, when seen backwards starting from the end of December.

Rainfed growing period characters for Tad Fa, as obtained from the LGP analysis, are presented in Table 4. Rainfall records were not reliable for 2004 and hence the results for 2004 were not included. Values of PET, rainfall, water surplus and water deficit are for LGP in the respective years and are not annual values.

**Table 4. Rainfed growing period characterstics at Tad Fa watershed (2000–05).**

| Item | 2000 | 2001 | 2002 | 2003 | 2005 |
|---|---|---|---|---|---|
| Starting | 10 Apr | 10 Mar | 15 May | 20 Feb | 20 Mar |
| Ending | 31 Dec | 20 Nov | 31 Dec | 10 Dec | 15 Dec |
| Length of growing period (days) | 265 | 255 | 230 | 293 | 270 |
| PET (mm) | 1088 | 1098 | 943 | 1246 | 1085 |
| Rainfall (mm) | 2253 | 909 | 1147 | 1806 | 1374 |
| Water surplus (mm) | 1240 | 77 | 333 | 762 | 379 |
| Water deficit (mm) | 105 | 294 | 199 | 209 | 225 |

At Tad Fa, the length of the rainfed crop-growing period varied from 230 to 290 days (Table 4). Even in the dry year (2001), the growing period was as long as 255 days due to the distribution of rainfall. Beginning is more variable compared to the end of the period. Excluding the extreme years, it is observed that about 300–500 mm of water surplus and 200 mm of water deficit are experienced during the growing period. The period from April to mid December appears to be the assured rainfed crop-growing period.

Variability in the distribution of rainfall in the crop-growing period results in dry and wet spells of varying durations. Dry and wet spells during the crop-growing season have been defined based on the IMA. When the rainfall and the soil moisture contribution put together cannot satisfy even 25 per cent of the crop requirement, the period is termed as 'very dry'. If the IMA is between 76 and 99 per cent, crops in general do not suffer from water stress and the period is termed as 'moist'. Some of the 'wet' weeks have heavy rainfall leading to accumulation of runoff for water harvesting and also to soil erosion. The classification of the different periods is as follows:

| Type of spell | IMA (%) |
|---|---|
| Very dry | 0 to 25 |
| Dry | 26 to 50 |
| Semi-moist | 51 to 75 |
| Moist | 76 to 99 |
| Wet | 100 |

Based on the above classification and using the Geographic Information System (GIS) technique, dry and wet spells at the Tad Fa watershed were delineated (Fig. 4). There is no definite relationship between the beginning and length of growing season. Droughts (more than two consecutive weeks with very dry conditions) occur often during the first half of the growing period. Severe dry conditions occurred during 14–16 meteorological weeks (first three weeks of April) in 2001. Growing period extended beyond December in 2002. This analysis helped in identifying optimum time for sowing and choosing suitable crops, varieties and cropping systems matching the moisture regime at Tad Fa.

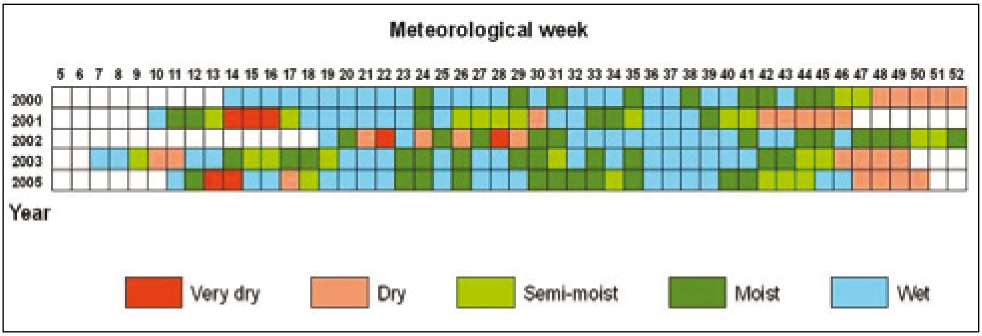



*Figure 4. Dry and wet spells during growing period at Tad Fa watershed.*

## Socioeconomic Survey of Tad Fa Watershed

**Baseline data:** The survey was conducted by following participatory rural appraisal (PRA) techniques to collect socioeconomic data of the village in Tad Fa watershed. The survey was done by organizing “semi-structured interviews of farmers” at different levels, namely village level, household level, activities level and constraints identification and technology verification level. Some of the survey details are given below:

- Village level: Farm leaders in different aspects were interviewed for obtaining information on (a) land use data and history, (b) cropping systems, (c) economic data, (d) infrastructure, (e) farmer groups, (f) culture and festivals, and (g) resource flows.
- Household level: Households were grouped into three groups namely better-off, moderate and poor economic households. These groups were interviewed to collect information on (a) labor use and availability, (b) land holding, (c) cropping activity, (d) income and expenditure, and (e) decision-making at household level.
- Activity level: Information of agricultural production was gathered on the following aspects: (a) decision to grow a particular crop, (b) land preparation, (c) planting, (d) crop management, (e) harvesting, (f) transport, and (g) marketing decision-making. Data at each activity level was collected.
- Constraints identification and technology verification level: (a) Based on the analysis of data at the above three levels, the problems/constraints were listed and these were verified with the farmers; (b) causes of these problems were identified; (c) existing solutions were checked; and (d) broad preliminary technology options were suggested to farmers and their responses were gathered.

Some of the major results of the survey are given below:

Soil: The survey indicated that there are three regions/portions, based on soil quality, in the watershed. The middle portion is the most fertile while the region at the topmost as well as at the lower most is less fertile. The soil depth ranges from 0.5 to 2.0 m. The soil is sandy loam at surface and is clayey loam to loam at sub-surface.

Cropping system: 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 a few farmers, but it is a very risky crop due to diseases and price fluctuations. Soybean crop is grown only in poor soils or less fertile patches since more vegetative growth has been observed in the fertile lands. Very small amount of urea is mixed with rice seeds at sowing. Only maize crop is fertilized. Rice is planted in June and harvested in October. About 2.5 to 3.0 t $ha^{-1}$ of average grain yield is obtained. Maize is often grown twice a year depending on the onset of monsoon. The first crop is grown from March to July and second crop is from July to November. Farmers apply 22:22:22 $N:P_2O_5:K_2O$ kg $ha^{-1}$ through mixed fertilizer. They harvest 3 to 3.5 t $ha^{-1}$ of grain yield. Ginger is grown in March–April and is harvested in December. A very heavy dose of fertilizer (90:90:90 $N:P_2O_5:K_2O$ kg $ha^{-1}$) of 15:15:15 is given.

Water storage structures: There are nearly 80 farm ponds in Tad Fa, of which only four store water throughout the dry season; while the others dry up. This is because the subsoil is very porous and seepage losses are very high.

Plantation of fruit trees: Farmers have planted fruit trees only around their houses and not on steep slopes as desired (and recommended) by government.

Economics: Data on households of three main types of farmer families in Tad Fa watershed was recorded (Table 5). Data on agricultural production at village level is given in Table 6.

**Table 5. Household economics of three main types of farmer families in Tad Fa watershed.**

| Item | Better | Medium | Worse |
|---|---|---|---|
| Members (No.) | 14 | 20 | 8 |
| Laborers (No.) | 10 | 17 | 4 |
| Plots (No.) | 2 | 9 | 5 |
| Total land (ha) | 7.5 | 16 | 8.5 |
| Subsistent crop | Upland rice | Upland rice | Upland rice |
| Main cash crop | Maize | Maize | Maize |
| Other cash crops | Fruit, vegetable, sword bean | Ricebean, sunflower, ginger, sunnhemp | Sunflower |
| Income in 1998 (Baht) | 102455 | 123575 | 91690 |
| Expenditure in 1998 (Baht) | 78728 | 96900 | 88350 |
| Main expenditure | General agriculture/ Maize | Maize | Maize |
| Debt (Baht) | 33500 | 30500 | 41940 |
| Constraints | Capital labor/land size | Labor, capital, and land size | Capital, labor |

**Table 6. Agricultural economics of Dongsakran village in 1998.**

| Commodity/activity | Production area (rai)[1] | Yield (kg per rai) | Price per kg (Baht) | Total income (Baht) |
|---|---|---|---|---|
| Upland rice | 445 | 300 | 7 | 934500 |
| Maize | 2000 | 700 | 3 | 4200000 |
| Ginger | 180 | 4000 | 2 | 1440000 |
| Sunflower | 200 | 250 | 15 | 750000 |
| Sunnhemp | 10 | 250 | 20 | 50000 |
| Ricebean | 30 | 110 | 8 | 26400 |
| Sword bean | 200 | 300 | 20 | 1200000 |
| Total | | | | 8600900 |

1. 6.25 rai = 1 ha

**Constraints:** Farmers have identified the following constraints and ranked them according to priority of their immediate need to alleviate these constraints rather than on their importance for sustainable rainfed agriculture. These constraints are:

1. Land tenure: Even though farmers have been cultivating this area since 80 years, the government never recognized the villages and they were relocated seven years back and finally only one-third of the villagers have returned to resettle (five years ago). Only in December 1998, the village has once again been recognized by the government. However, the land tenure issue has not yet been settled. Because of this the farmers think permanent land tenure is the most important issue for their future.
2. Lack of capital: Since these farmers are displaced, they do not have much capital to invest. The priority of investing the capital by most farmers is as follows:
   - Education of children is given the highest priority. There is only one primary school in the village. Farmers have to send their children outside their village for high school. They also have to provide transport for their children by investing on motorbikes which again requires considerable capital.
   - Housing is given the second highest priority. Most of the farmers have very poor temporary houses after their resettlement. They try to invest in building new houses after allotting some money for education.

- Capital investment for agriculture is given third priority after meeting the above two items. Fortunately for these farmers, the land is reasonably fertile. Rice is grown as a subsistence crop without much fertilizer application. Only maize, which is grown as a cash crop, is fertilized. However, farmers have to invest a sizeable amount of money in these crops because household labor is very scarce; all operations like land preparation, sowing, weeding and harvesting are given on contract to service providers. Also, hybrid seeds of maize are expensive in addition to the costly fertilizer input. Very few farmers have tried the risky ginger crop with huge investments and most of them suffered heavy losses.

3. Lack of water resources: Since most of the soils are sandy, there are practically no water storage structures for irrigating crops. Hence, almost all crops are grown as rainfed. Sometimes either only one maize crop is grown instead of the usual two because of monsoon delay or the second crop of maize suffers due to shortage of water as a result of the early cessation of monsoon. Lack of permanent water source is a major constraint to the establishment of fruit trees on steep sloping lands.

4. Costly agricultural inputs: As already discussed not only seeds of hybrid maize and fertilizers are costly, but also almost all the farm inputs are expensive.

5. Price fluctuation: Since prices of most of the cash crops fluctuate a lot, it is really a gamble for the farmers to choose a particular crop, viz, ginger and pineapple. Often farmers incur huge losses and as such many cash crops have become risky in economic terms.

6. Lack of government support: Many farmers think that the government should increase its support since they are the recently rehabilitated farmers.

7. Lack of transport facilities: Most of the farmers are complaining about the very poor transport facilities both for people as well as to transport agricultural inputs or produce to and from nearby markets.

8. Weed problems: Farmers complain about the severe weed problem, especially the thorny *Mimosa pudica*. As labor is in short supply, farmers have to give contract to service providers to spray herbicides, eg, gramaxone.

9. Soil erosion: Even though farmers perceive this as a serious problem, especially in steep slopes, they think it is less urgent. This is because the soil in the watershed is reasonably fertile despite sizable quantum of soil erosion. Farmers also know the reasons for soil erosion (a) slope lands, (b) inappropriate plowing method, ie, plowing down-the-slope in steep sloping lands, and (c) too much deep plowing by tractor.

10. Forest fires: In order to control weeds and to remove previous season's crop residues farmers burn them on a particular day. Often the fire goes out of control and damages fruit trees and even sometimes it spreads to nearby forest area. Labor shortage is one of the main reasons why farmers resort to burning as a means for obtaining a clean field for the preparation of reasonable seedbed.

**Scientists' perception:** From the scientists, point-of-view soil erosion is the major problem which will certainly affect sustainable crop production in the future. Since cropping history in these lands is only 80 years, with crop intensification since only 15 years, the soil is reasonably fertile and productive. But as years go by, both soil erosion and inadequate nutrient input supply will cause a decline in soil fertility, leading to low productivity. Scientists think some of the farmers' concerns like land tenure, transport, costly inputs, price fluctuation and labor shortage are quite genuine and will affect agricultural production in due course.

## Watershed Interventions

In NE Thailand, types of land degradation (eg, 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 7). Soil samples at these spots up to 110 cm depth were collected and analyzed for physical, chemical and biological properties (Table 8). 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.

**Table 7. Maize grain yield (t $ha^{-1}$) across toposequence in NE Thailand during 1999–2001.**

| Toposequence | 1999[1] | 2000[1] | 2001[1] |
|---|---|---|---|
| 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.

**Table 8. Biological and chemical properties of soil samples from different depths (cm) from toposequence in Ban Tad Fa watershed in NE Thailand.**

| Toposequence | 0–10 | 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 | | | | | | | |
| Microbial 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 | | | | | | | |

Some of the major research and development activities carried out at Tad Fa watershed are described.

**Watershed development:** In consultation with the farmers, the DLD has constructed about 17 farm ponds, each of 1260 $m^3$ capacity (Fig. 5). The technical specifications of farm ponds constructed in the watershed are shown in Figure 6.

The farm ponds provide water for much needed supplemental irrigation to crops/fruit trees/vegetables, particularly in the postrainy season. In large areas the field bunds have been constructed along with vetiver grass (Fig. 7). This is necessary for controlling soil erosion, which is one of the major problems in Tad Fa watershed. In Tad Fa watershed the annual soil loss of 40–60 t $ha^{-1}$ is quite common.

**Soil and water management:** In order to reduce tillage on very steep slopes, which may trigger enhanced soil erosion, hand dibbling on steep slopes and tractor planting on contour in moderate and mild slopes were tried (Fig. 8). Minimum tillage was found effective in controlling soil erosion. During 2003–04 about 68% area was planted on contour on mild slopes. On mild slopes, cultivation has increased maize yield by 30–40% compared to conventional up and down cultivation. It also significantly reduced the soil loss.

**Integrated nutrient management:** Integrated nutrient management is essential for improving the agricultural productivity in NE Thailand. Results from several nutrient management trials for rice, maize and sugarcane based cropping systems have shown very promising results.

**Diversified land use system:** Fruit trees cultivation is being popularized in the Tad Fa watershed. This has helped in controlling soil erosion and provided better and more sustainable income to the farmers. During 2000–2001 the area under fruit tree cultivation has increased in and around Tad Fa watershed. Several new fruits and varieties have been introduced. To increase the fruit tree system productivity and the survival of fruit trees, several new systems, viz, banana intercrop with other fruit trees, mulching, inter-row water harvesting and growing annual crops along with fruit trees have been introduced (Figs. 9 and 10).

**Improved crops and cropping systems:** Several new crops and their varieties have been introduced in the watershed. New relay and sequential cropping systems have been identified and tested. A large number of farmers have adopted these new crops and varieties.

**Empowerment of community:** Empowerment of communities and individuals and the strengthening of village institutions were done through concerted

*Figure 5. Farm pond at Tad Fa watershed.*

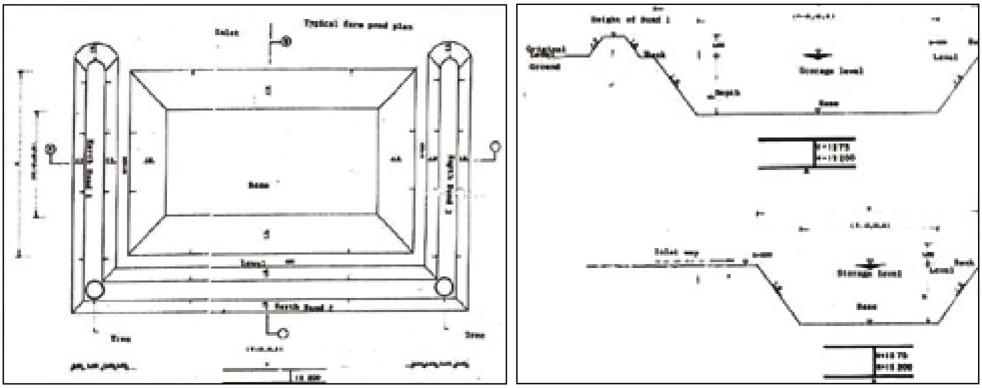


*Figure 6. Technical specifications of farm pond constructed in Tad Fa watershed.*

*Figure 7. Vetiver hedge as field bund at Tad Fa watershed.*

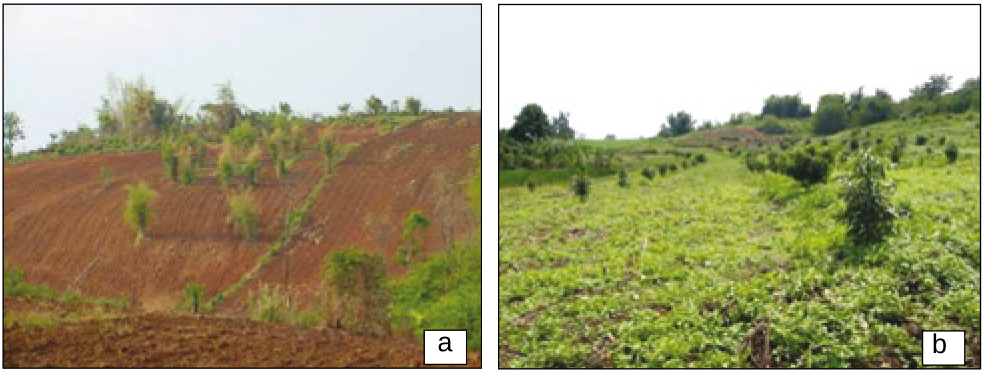



*Figure 8 (a). Conventional practice (before project), and (b) contour cultivation (after project).*

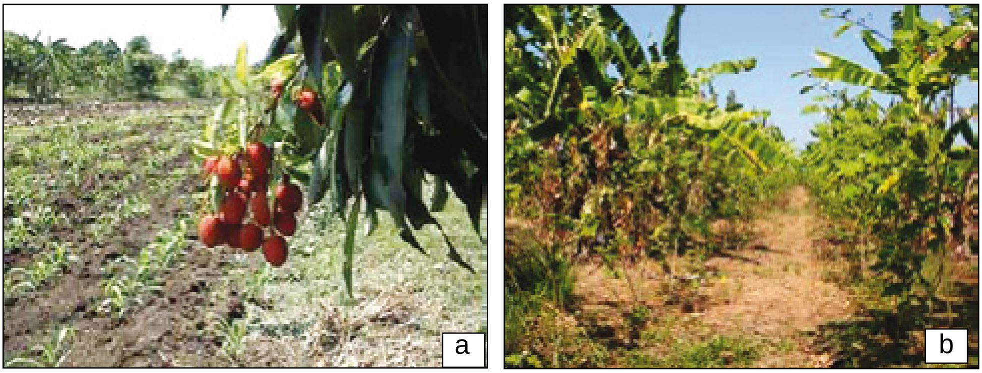



*Figure 9. Cultivation of annual crops with (a) horticultural plants, and (b) banana with fruit trees as crop diversification, at Tad Fa watershed.*

*Figure 10. Semicircular vetiver rings around banana plants for effective soil and water conservation.*

*Figure 11. Hydrological monitoring system at Tad Fa watershed.*

efforts. It was observed that when people are empowered to take decisions and execute the activities, they own the program. They run the watershed activities according to local, social and cultural systems.

**Hydrological measurements:** An automatic weather station was installed in the watershed to monitor rainfall, temperature, sunshine, humidity, wind velocity and soil temperature at fixed intervals. Two digital runoff recorders along with automatic pumping type sediment samplers were installed at two sub-watersheds to monitor the runoff and soil loss from the two land use management systems (Fig. 11). Sub-watershed-I has land under the horticultural tree-based cultivation with some areas under annual crops. Sub-watershed-II has most of the areas under annual crops and cropping systems. The mean runoff and soil loss from the two sub-watersheds during 2001–05 are shown in Table 9.

**Table 9. Mean rainfall, runoff and soil loss from two watersheds at Tad Fa watershed (2001–05).**

| Land use systems | Rainfall (mm) | Runoff (mm) | Soil loss (t $ha^{-1}$) |
|---|---|---|---|
| Annual crops | 1725 | 320 | 34.2 |
| Fruit trees + Annual crops | 1725 | 131 | 6.1 |

## Wang Chai Watershed, Phuwiang, Khon Kaen

Wang Chai watershed is part of Nam-Phong basin and is about 75 km northwest of Khon Kaen city. Wang Chai village is in Phuwiang district in Khon Kaen province. The mean annual rainfall is about 1000 mm. About 90 per cent of the annual rainfall occurs between May and October. Often the actual amount and pattern of rainfall are extremely erratic and unpredictable. This creates considerable risk for agricultural production since most of the watershed area is under rainfed cultivation. The soil in the watershed is mostly sandy or sandy loam with very low water-holding capacity (Table 10). The organic matter content is also very low. Major crops grown in the watershed are rice, sugarcane, cowpea and groundnut. Small areas are also under fruit trees and vegetables. The average productivity of most of the crops is quite low.

## Major Research and Development Activities

Some of the major research and development activities carried at Wang Chai watershed are described.

**Baseline data collection:** The biophysical and socioeconomic baseline data from the Wang Chai watershed have been collected and analyzed. The major constraints for increasing the agricultural productivity were identified. The topographic, land use and soil maps have been prepared (Fig. 12). Most of the areas in the watershed have moderate to low slopes.

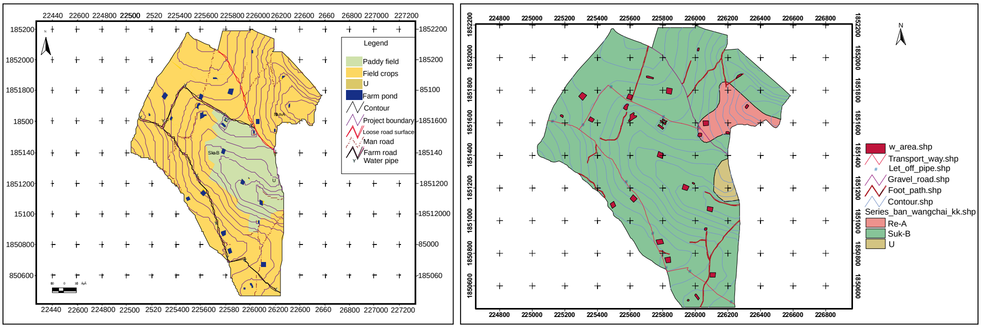



*Figure 12. Topographic, soil and land use maps of Wang Chai watershed.*

**Table 10. Properties of the soil at Wang Chai watershed.**

| Parameter | Soil depth (cm) 0–15 | 15–30 | 30–60 | 60–100 |
|---|---|---|---|---|
| Physical properties | | | | |
| Sand (%) | 91 | 92 | 91 | 89 |
| Silt (%) | 6 | 6 | 6 | 8 |
| Clay (%) | 3 | 2 | 3 | 3 |
| Chemical properties | | | | |
| pH (1:2.5 $H_2O$) | 5.9 | 5.6 | 5.7 | 5.8 |
| Organic matter (g $kg^{-1}$ soil) | 3.6 | 3.5 | 3.1 | 3.1 |
| Total N (%) | 0.018 | 0.017 | 0.016 | 0.016 |
| Available P (mg $kg^{-1}$ soil) | 9 | 6 | 4 | 2 |
| Exchangeable K (mg $kg^{-1}$ soil) | 28 | 22 | 23 | 35 |
| Exchangeable Ca (mg $kg^{-1}$ soil) | 493 | 490 | 709 | 1307 |
| EC (mmhos $cm^{-1}$) | 0.019 | 0.019 | 0.034 | 0.048 |

**Water management and water harvesting:** In consultation with the farmers, 39 farm ponds each of about 1250 $m^3$ storage capacity were constructed. In large areas, field bunding has been done and total 9 km village roads have been constructed. To protect the bunds and roads from erosion, vegetative barriers were planted (Fig. 13). Drains were constructed for safe disposal of excess runoff water. Rainfall, runoff and soil loss have been monitored (Fig. 14).

*Figure 13. Vetiver grass planted along farm road to prevent soil erosion at Wang Chai watershed.*

*Figure 14. Hydrological monitoring station at Wang Chai watershed.*

**Crop and nutrient management and other activities:** During the last two years (2003–05) various research and development activities on integrated nutrient management, water management, crops and cropping systems were taken up. Several self-help groups were formed. Farm and community based activities were initiated to enhance the agricultural productivity and income. New crops and varieties were introduced in the watershed. Village-based purification of rice seed was established. Training was given to farmers for value addition of field crop products.

Farmers are quite happy with the various watershed activities. The construction of farm ponds has significantly increased the cropping area in the postrainy season. Some of the activities have already resulted in increased agricultural productivity and income.

**DLD farm ponds:** DLD constructed 13 farm ponds in project sites (Table 11). Three farm ponds were monitored for water ponding and assessed for water utilization. In 2004 water ponding scales were installed for weekly water level recording. The farm road is protected with vetiver hedge made by DLD in the Wang Chai project site.

While selecting the location of farm ponds, farmers shared their views with DLD. About 82 per cent of farm ponds in paddy field were in higher terrain parts, downstream farm ponds closer to either vetiver bund-ring or upstream farm ponds in forest whereas the other upland field farm ponds were relocated and constructed as indicated in DLD planning (Table 12).

**Table 11. Number of farm ponds in Wang Chai.**

| Location | Downstream to vetiver-ring farm road | Upstream to vetiver-ring farm road | Total |
|---|---|---|---|
| Paddy area | 3 | 6 | 9 |
| Field crop area | 2 | 2 | 4 |
| Total | 5 | 8 | 13 |

**Table 12. Number of farm ponds relocated to appropriate location.**

| | Downstream to vetiver-ring farm road | | | Upstream to vetiver-ring farm road | | | Total | |
|---|---|---|---|---|---|---|---|---|
| Location | Total | Relocated | % | Total | Relocated | % | Relocated | % |
| Paddy area | 3 | 3 | 100 | 6 | 5 | 82 | 8 | 82 |
| Field crop area | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Total | 5 | 3 | 60 | 8 | 5 | 62 | 8 | 61 |

**Water ponding monitoring:** Thirteen ponds were monitored for water ponding levels continuously on weekly basis by farm owners since 2004. Overall monthly rainfall and also overall water ponding levels in 2005 was lower than in 2004. In 2005 the trend of ponding level of farm ponds both inside and outside of vetiver-ring farm road (VRFR) was similar to that in 2004. The overall water ponding level of 5 farm ponds inside VRFR was higher than the 8 farm ponds outside. However, ponding levels of both inside and outside farm ponds have sharply dropped during mid and late rainy season. Figure 15 clearly shows the effect of VRFR on water ponding. The farm ponds located inside VRFR have consistently higher water ponding compared to the farm ponds located outside VRFR.

**Groundwater monitoring:** In 2006, our study on DLD farm ponds revealed that construction of farm ponds in appropriate location played an important role in increasing paddy productivity for both transplanted and direct seeding systems at Wang Chai watershed through effective utilization of stored water in the ponds. The water storage capability of the farm ponds in upland field and in upper paddy field was poor compared to the farm ponds in lower toposequence; also water ponding lasted for short duration in the former. However, water in upper paddy (outside VRFR) was used more for pumping up. Early in the season water storage was good in farm ponds located in the upper portion but very high seepage loss was recorded. The farm ponds in the upper portion were in recharge zone while those in the lower portion were in discharge zone.

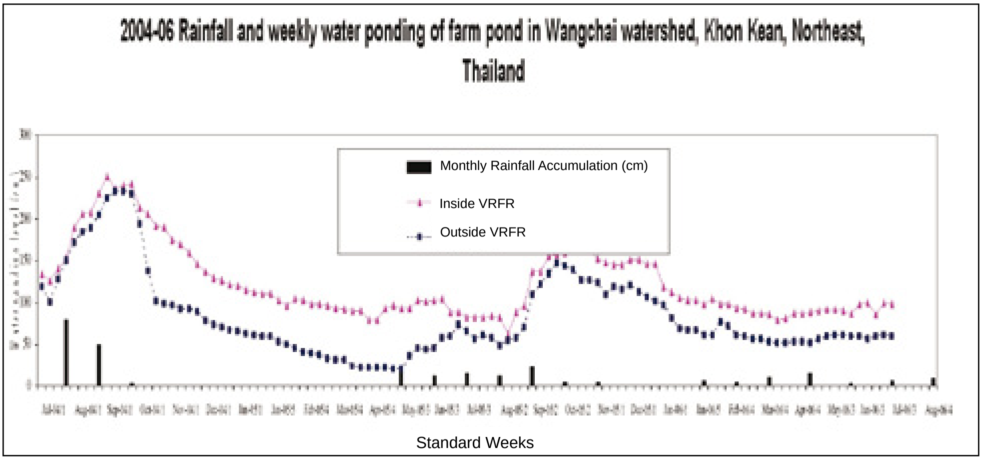



*Figure 15. Water ponding of downstream farms inside vetiver-ring farm road (VRFR) and upstream ponds outside VRFR in Wang Chai watershed.*

There are three farm ponds in the research site: one (FP1) located in the lower side of the valley and the other two (FP2, FP5) in the upper valley. A set of three pizometers was installed for each farm pond up to 3.5 m depth. The pizometers were placed at 10–20 m interval downward farm pond to valley. Weekly groundwater levels were measured from the end of rainy season to the next rainy season. Groundwater levels and water ponding levels of each farm pond are shown in Figure 16.

The results indicated that the farm pond water level has direct influence on groundwater level. A sharp decrease in water ponding in FP2 during the last week of October was due to the use of water for paddy at grain-filling stage. Nevertheless, it was clearly evident that the water ponding level of FP1, which is located in the foot of the valley (discharge zone), performed better than the other two farm ponds in increasing groundwater levels. The increase in groundwater availability has facilitated water application to crops as supplemental irrigation (Fig. 17).

**Economics of farm ponds:** A field survey was conducted to evaluate the utility and economics of farm ponds constructed with DLD and without DLD interventions. For the study, 13 DLD farm ponds and 21 other farm ponds were selected. The results revealed that the average land holding had similar number of farm ponds per household in both the cases. Most of the farmers used farm pond water for the cultivation of paddy. The income from vegetables was same in land holdings having farm ponds both with and without DLD interventions while from fruit trees, there was an increase of 36% with DLD farm ponds compared

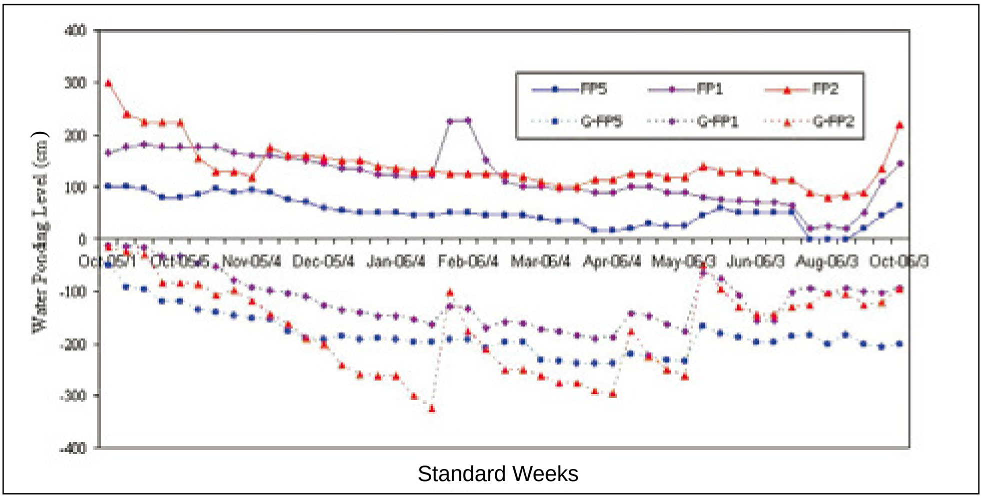



*Figure 16. Water ponding of three farm ponds (FP) and surrounding groundwater (G) level during 2005–06.*

*Figure 17. A recharged well with pumping facility in use for irrigation at Wang Chai watershed.*

to other farm ponds. The income from farm pond fishery was more than three-fold in land holdings without DLD farm ponds compared with DLD farm ponds (Table 13).

Maintenance of DLD farm ponds was better than other farm ponds. Animals were not allowed to drink water directly from DLD farm ponds unlike other farm ponds. Farmers with DLD farm ponds have paid much attention to pond water use as well as deepened the ponds to increase storage capacity for effective use of water than the group of farmers having farm ponds without DLD interventions.

**Paddy productivity influenced by farm ponds:** During 2004 season, paddy area with transplanting system increased in land holdings with DLD farm ponds compared to the previous season (2003). However, there was no change in land holdings while there was a drastic reduction in area with direct seeding method without DLD farm ponds.

**Table 13. General information of households having farm ponds with and without DLD farm ponds in Wang Chai watershed in 2004.**

| Utilization and benefits | DLD farm ponds | Other farm ponds |
|---|---|---|
| Paddy area per household (ha) | 2.7 | 2.4 |
| Average no. of ponds per household | 1.2 | 1.3 |
| Rice as target crop (%) | 100 | 90 |
| Pumping use (%) | 100 | 100 |
| Direct returns from farm ponds | | |
| Fish (Baht $yr^{-1}$) | 600 | 1,878 |
| Vegetables (Baht $yr^{-1}$) | 706 | 700 |
| Fruit trees (Baht $yr^{-1}$) | 435 | 591 |
| Animal drinking (frequency) | 0 | 187 |
| Domestic use (frequency) | 37 | 67 |
| Effective utilization | | |
| Indiscriminate use | 100% | 62% |
| Deepening of pond | 38% | 24% |
| Enlargement of pond | 8% | 10% |

The rice cultivation area with transplanting method and paddy yield of farms with DLD farm ponds increased from 2.1 ha per household and 1.38 t $ha^{-1}$ yield in 2003 to 2.4 ha per household and 1.54 t $ha^{-1}$ yield in 2004 whereas farms without DLD farm ponds had rice area of 1.9 ha per household during 2003 and 2004 and increase in paddy yield from 1.39 t $ha^{-1}$ in 2003 to 1.45 t $ha^{-1}$ in 2004. Also rice area with direct seeding in farms with DLD farm ponds decreased from 1.4 ha to 0.8 ha but with an increase in paddy yield from 0.57 t $ha^{-1}$ in 2003 to 1.19 t $ha^{-1}$ in 2004. But in farms without DLD farm ponds, paddy area increased from 2.7 ha per household (0.37 t $ha^{-1}$ yield) in 2003 to 2.9 ha per household (0.55 t $ha^{-1}$ yield) in 2004 (Table 14). On farms with DLD farm ponds, paddy yields was five times higher (1.58 t $ha^{-1}$) than non-irrigated fields (0.35 t $ha^{-1}$) during 2004 rainy season.

**Table 14. Rainy season paddy production on-farm with and without DLD farm ponds during 2003–04.**

| Description | 2003 | | 2004 | |
|---|---|---|---|---|
| | DLD farm ponds | Other farm ponds | DLD farm ponds | Other farm ponds |
| Area (ha) | | | | |
| Transplanting | 2.1 | 1.9 | 2.4 | 1.9 |
| Direct Seeding | 1.4 | 2.7 | 0.8 | 2.9 |
| Yield (t $ha^{-1}$) | | | | |
| Transplanting | 1.38 | 1.39 | 1.54 | 1.45 |
| Direct Seeding | 0.57 | 0.37 | 1.19 | 0.55 |

**Table 15. Use of water from DLD farm ponds in 2004 and 2005.**

| Parameters | 2004 | 2005 |
|---|---|---|
| Paddy production | | |
| Paddy land holding (ha) | 2.7 | 2.7 |
| Transplanting area (ha) | 2.3 | 2.1 |
| Transplanting yield (t $ha^{-1}$) | 1.6 | 1.9 |
| Direct seeding area (ha) | 0.8 | 0.8 |
| Direct seeding yield (t $ha^{-1}$) | 1.1 | 1.3 |
| Methods of use | - | - |
| Pumping (%) | 100 | 92 |
| Manual pick up (%) | - | 67 |
| Benefit | | |
| Paddy (Baht $yr^{-1}$) | 5200 | 6175 |
| Fish (Baht $yr^{-1}$) | 600 | 812 |
| Vegetables (Baht $yr^{-1}$) | 706 | 475 |
| Fruit trees (Baht $yr^{-1}$) | 435 | 200 |
| Animal drinking (frequency) | 0 | 0 |
| Domestic use (frequency) | 37 | 73 |
| Farmers' perception (%) to improve efficiency of farm ponds | | |
| Indiscriminate use | 100 | 46 |
| Deepening of pond | 38 | 31 |
| Increase in pond size | 8 | - |

**Water harvesting:** Table 15 shows the utilization pattern of farm ponds for various purposes, paddy production, monetary benefits and farmers' perception to improve the efficiency of farm ponds in 2004 and 2005. Higher monetary benefits were reported during 2005 in case of paddy cultivation and fishery (19 per cent and 35 per cent increase, respectively), while benefits in case of vegetables and fruits trees were higher during 2004.

**Land use and crop intensification:** Total cultivated area of Wang Chai watershed was 151 ha (942 rai), in 2005; it can be classified into eight land use pattern classes (Fig. 18). Paddy (47 per cent) and sugarcane (36 per cent) are major upland crops. Some additional area was brought under cultivation for paddy and sugarcane in 2005 due to availability of water. Pararubber is the new crop occupying 1 per cent and it replaced cassava in upland. Some of the farms with DLD farm ponds are classified as mixed farms (Figs. 18 and 19).

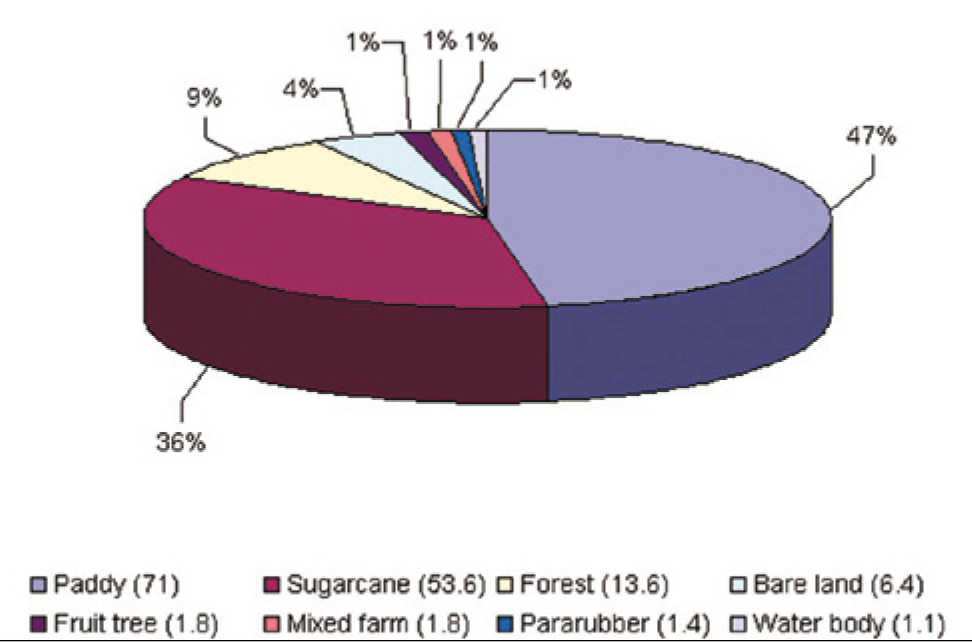



*Figure 18. Land use pattern of Wang Chai watershed during 2005.*

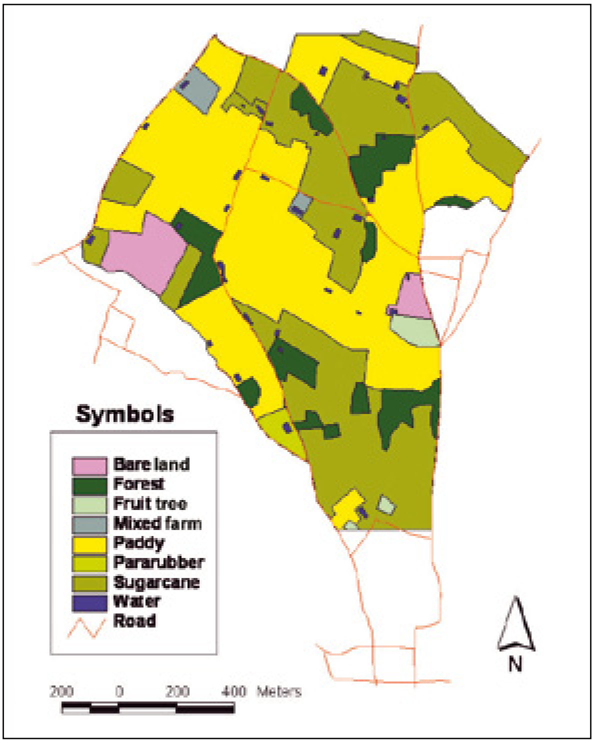



*Figure 19. Land use in Wang Chai watershed in 2005.*

## Conclusion

In NE Thailand, lack of technological progress and increasing population pressure are taking a heavy toll on the productive resource base. Water scarcity, land degradation and productivity loss are becoming major challenges to the eradication of poverty, especially in the mountain areas of Thailand. Depletion of the resource base diminishes the capabilities of poor farmers and increases their vulnerabilities to drought and other natural calamities. Agriculture in NE Thailand is characterized by high risks from drought, degraded natural resources and pervasive poverty. For such rainfed areas, integrated watershed management could be a vehicle of development to conserve natural resources and to alleviate poverty.

In conclusion, the Tad Fa and Wang Chai watershed programs have made significant positive impacts on natural resources, rural livelihoods and environment. The science-led participatory watershed development through consortium and convergence approach minimized land degradation enhanced agricultural productivity and incomes decreased poverty of rural poor and improved the environment quality. The technical backstopping of watersheds by a consortium approach greatly enhanced the benefits of watershed program to the community. Some of the key learnings from these watersheds are:

- Consortium approach of various research and development organizations, and farmers has been very effective for increasing agricultural productivity and improving livelihoods.
- The integrated watershed program substantially increased productivity and augmented farm income. Some of the watershed activities such as cultivation of fruit trees were found highly successful in attaining the livelihood and environmental objectives of the watershed.
- Participatory planning with the community is found highly beneficial. Due to this the effectiveness and sustainability of various watershed interventions improved significantly.
- In most cases, it was found that the farmers come together for their immediate and private gains rather than only long-term and social gains.
- The formation of SHGs was found to be highly beneficial. Farmers were able to share information about crops, new technologies, and related problem and solution.
- A strong network of information is found necessary for increasing the effectiveness and sustainability of watershed program. In the changing economic regime, the technologies are changing rapidly and affecting competitiveness, markets, consumer preferences and prices.
- The concept of integrated watershed management is relatively new in Thailand. There is a need to address the second- and third-generation problems of integrated watershed management program.

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# 3. Role of Legumes in Improving Soil Fertility and Increasing Crop Productivity in Northeast Thailand

***Banyong Toomsan, Viriya Limpinuntana, Sanun Jogloy, Aran Patanothai, Prabhakar Pathak, Suhas P Wani and KL Sahrawat***

## Introduction

Northeast Thailand constitutes one-third of total area of the whole country and one-third of the total population live in this region. The income of the majority of the people living here is below half of the national average mainly due to low agricultural production and productivity. The low agricultural productivity of the northeast region compared to other regions of Thailand is attributed mainly to erratic rainfall, water shortage during the dry season, undulating terrain and poor and marginal soils. The soils in the region are mostly sandy in texture with low soil moisture holding capacity. The soils are also very low in organic matter and low in general fertility.

Major crops grown in the northeast region of Thailand in this region are rice, cassava, sugarcane and maize. However, the yields are very low compared to those in other regions of the country. Crop productivity can be improved through addition of chemical fertilizers. However, chemical fertilizers are expensive and generally out of reach for many poor farmers. Moreover, in some areas of Thailand, there is evidence to show that non-judicious, long-term use of chemical fertilizers, especially on light-textured soils, can lead to the contamination of surface and groundwater.

Improved crop productivity can also be achieved through the use of organic fertilizers such as compost or farmyard manure and recycling of crop and organic residues in production systems can improve crop productivity. However, lack of availability of organic fertilizers in sufficient quantities in the region and the high cost of transporting the bulky materials are major constraints. Therefore, in this agricultural scenario, the introduction of legumes into the existing cropping systems seems to be a logical approach. Legumes are known to biologically fix atmospheric nitrogen (N) in symbiosis with *Rhizobium* bacteria. The fixed N can at least partly reduce the N fertilizer requirement of the main field crop in rotation. Thus it becomes an affordable source of N for resource-poor farmers in the region (McDonagh et al. 1995a).

This paper summarizes the work done by the researchers in Khon Kaen University in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and other partners in identifying crop, soil and water management practices that improve fertility and increase crop productivity. A special emphasis was placed on the use of legumes in sequence with major crops namely, rice, maize and sugarcane in northeast Thailand.

## Rice-based System

Rice is one of the major crops that are economically important in Thailand and at present the country is among the top exporters of rice. Rice is grown both for domestic consumption and for export. Thailand is considered to be one of the top exporters of rice. In 2004, Thailand exported 10 million t of rice worth 108,393 million bahts (US$ 2970 million) (Centre for Agricultural Information 2006). The total area under rice production in Thailand is approximately 10 million ha, with an average yield of 2.65 t $ha^{-1}$, which is lower compared to the average yields of rice in Japan, China, Vietnam, Indonesia, and Myanmar.

Rice production area in the northeast is about 5 million ha with average yield of 1.9 t $ha^{-1}$, which is lower than the average yield in other regions of the country. Rice is grown during rainy or wet and dry seasons. Rice grown in the rainy season is mainly rainfed, while that grown in the dry season is irrigated. The total area under rice cultivation in the country during the rainy season is about 9.22 million ha while the area under rice in the dry season is only 1 million ha. However, rice yields are higher in the dry season than in the rainy season. Upland rice is also grown in Thailand, especially in the mountainous areas of the North, Northeast and the central regions of the country. The area under upland rice is smaller than that under lowland rice. However, upland rice provides a staple food for the people living in the mountainous areas of the country.

Researchers at Khon Kaen University have studied in detail the effects of legumes in improving the yield of rice. Even though, there are studies on the use of legumes as green manure in improving rice yields, most of the research works are focused on the use of groundnut stover as a source of N (McDonagh et al. 1995a, 1995b, Toomsan et al. 2000). However, green manure legumes do not provide cash or economic returns to the farmers. Besides, there are also problems such as the availability of legume seeds, requirement of P fertilizer and incorporation of green manure legumes in rice production systems. Hence, green manure legumes are not widely accepted by small farmers who have limited resources. On the other hand, as the grain legumes that provide grain appear to be more attractive, groundnut seems to fit well in the production systems (McDonagh et al. 1995a, Whitmore et al. 2000).

Groundnut can be grown after the harvest of rice (December to early January). Our previous studies indicated that groundnut crop can fix substantial amount of N (McDonagh et al. 1993, Toomsan et al. 1995). Our studies revealed that nitrogen harvest index (% NHI) of groundnut in economic yield (pod) was lower than the proportion of N fixed from air (% N derived from air) and thus makes it a suitable crop to improve soil fertility and increase yields of succeeding crops through the residual effects via N (McDonagh et al. 1995a, Toomsan et al. 2000).

Our studies also showed that groundnut can be grown after the harvest of rice and the crop could give good pod and stover yields. Pod yield as high as 3 t ha$^{-1}$ and stover yield of 10 t ha$^{-1}$ can be obtained, depending on the location and the groundnut cultivar used. The N in the stover could be as high as 166 kg N ha$^{-1}$ (Toomsan et al. 1995). In order to get the full benefit of N in groundnut, it is important to return the stover to the soil. At the time of harvest many farmers burn or remove the stover from the field and never return it to the soil. This has a negative effect on growth and yield of succeeding rice crop and on organic matter content. Our studies indicated that growth and yield of rice could be significantly increased by returning the stover to the soil (Table 1).

**Table 1. Grain and total biomass yield of rice grown after groundnut with stover removed (– stover) or returned (+ stover) at two locations in farmers' fields in Khon Kaen, Thailand[1].**

| Groundnut cultivar | Grain yield (kg ha$^{-1}$) – Stover | Grain yield (kg ha$^{-1}$) + Stover | % Difference | Total biomass yield (kg ha$^{-1}$) – Stover | Total biomass yield (kg ha$^{-1}$) + Stover | % Difference |
|---|---|---|---|---|---|---|
| Location 1 (Kranuan, Khon Kaen) | | | | | | |
| KK 60-1 | 3290 | 3870 | 17.7 | 6565 | 8500 | 29.5 |
| KK 60-3 | 2910 | 3660 | 25.9 | 5890 | 7685 | 30.5 |
| Non-nod | 2895 | 3190 | 10.3 | 5390 | 6495 | 20.5 |
| Location 2 (Ban Thon, Khon Kaen) | | | | | | |
| KK 60-1 | 3250 | 3710 | 14.2 | 7390 | 9550 | 29.3 |
| KK 60-2 | 3275 | 3675 | 12.2 | 7430 | 9365 | 26.0 |
| Non-nod | 3210 | 3435 | 6.9 | 7115 | 8220 | 15.6 |

1. Source: Toomsan et al. (1995).

Contrary to the results obtained with groundnut, the effect of soybean had lower proportion of N fixed from the air (% Ndfa) than the nitrogen harvest index (% NHI). Although soybean stover when returned to the soil increased total biomass, it did not increase the rice grain yields (Table 2). This could be attributed to low N content in soybean stover. Nitrogen returned to the soil via soybean stover was about 21–27 kg N $ha^{-1}$ while that returned via groundnut haulms was in the range of 74–166 kg N $ha^{-1}$. The effects of groundnut stover application on growth and yield of lowland rice was also studied (Toomsan et al. 2003). Application of groundnut stover at 3.75 t $ha^{-1}$ along with PK (25 kg $P_2O_5$ + 12.5 kg $K_2O$ $ha^{-1}$) and N fertilizer (14.4 kg N $ha^{-1}$) at the panicle initiation stage gave significantly higher rice yields than the no-chemical fertilizer application (control) treatment and N control treatment (NPK fertilizer application at the recommended rates) (Table 3).

**Table 2. Grain and total biomass yields of rice grown after soybean with stover removed (- stover) or returned (+ stover) in a farmer's field at Ban Thon, Khon Kaen[1].**

| Soybean cultivar | Rice grain yield (kg $ha^{-1}$) | | | Rice total biomass yield (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | – Stover | + Stover | % Difference | – Stover | + Stover | % Difference |
| SJ 4 | 3675 | 3700 | 0.7 | 9020 | 10850 | 20.3 |
| KKU 35 | 3770 | 3530 | -6.3 | 9510 | 10690 | 12.4 |

1. Source: Toomsan et al. (1995).

**Table 3. Grain and total biomass yield of rice as affected by different rates of groundnut stover and chemical fertilizers at Kalasin, Northeast Thailand, 1999[1].**

| Treatment[2] | Yield[3] ($kg\ ha^{-1}$) | | Harvest index (%) |
|---|---|---|---|
| | Grain yield | Total biomass | |
| Stover, no chemical fertilizer (control) | 2600[f] | 5050[e] | 51 |
| + Stover 1.875 t $ha^{-1}$ + PK | 3060[def] | 6400[cd] | 48 |
| + Stover 1.875 t $ha^{-1}$ + PK + N (PI) | 3320[bcd] | 6470[cd] | 51 |
| + Stover 3.75 t $ha^{-1}$ + PK | 3430[bcd] | 6990[bc] | 49 |
| + Stover 3.75 t $ha^{-1}$ + PK + N (PI) | 3770[ab] | 7860[ab] | 48 |
| + Stover 5.625 t $ha^{-1}$ + PK | 3670[abc] | 7860[ab] | 47 |
| + Stover 5.625 t $ha^{-1}$ + PK + N (PI) | 3830[ab] | 8000[ab] | 48 |
| + Stover 7.50 t $ha^{-1}$ + PK | 3770[ab] | 8120[ab] | 46 |
| + Stover 7.50 t $ha^{-1}$ + PK + N (PI) | 4070[a] | 8460[a] | 48 |
| – Stover + $N_0$PK | 2680[f] | 5210[e] | 51 |
| – Stover + $N_0$PK + N (PI) | 3230[cde] | 6370[cd] | 51 |
| – Stover + $N_1$ PK | 2780[ef] | 5430[de] | 51 |
| – Stover + $N_1$PK + N (PI) | 3260[de] | 6390[cd] | 51 |
| F-test | ** | ** | NS |
| CV (%) | 9.61 | 10.99 | 6.03 |

1. Source: Toomsan et al. (2003).
2. – Stover = Stover removed; + Stover = Stover returned; PI = At panicle initiation stage.
3. NS = Not significant; ** = Significant at $P$ <0.01. Figures followed by the same letter(s) in a column are not significantly different.

Although the best response was obtained in the treatment with groundnut stover at 7.5 t $ha^{-1}$ + PK (25 kg $P_2O_5$ + 12.5 kg $K_2O$ $ha^{-1}$) + N (14.4 kg N $ha^{-1}$), it is often difficult for most of the farmers to get such large quantities of groundnut stover to incorporate in the field. It is therefore recommended that groundnut stover at 3.75 t $ha^{-1}$ + PK + N (at panicle initiation stage) should be used for increasing rice growth and yields. Generally, most farmers can get the recommended quantity of groundnut biomass yield in their fields. Groundnut stover decomposes quickly as it has a high percentage of N and low C: N ratio. The released N is prone to losses through leaching and denitrification. To study this, we conducted an experiment to determine the methods and time of stover application on growth and yield of rice. The results are shown in Table 4.

Storing groundnut stover after harvest for a short period before incorporating in the field shortly before rice transplanting helps in improving better growth and yield of rice than the recommended chemical fertilizer application. Stover application prior to planting (ie, 45 days before transplanting) of rice showed slower growth and lower yield than when applied just before planting. Early stover application (45 days before transplanting) may need N fertilizer application at panicle initiation stage of rice. But storing groundnut stover and applying it shortly before rice transplanting requires storage and extra labor to store and return the stover to the field. If this is not feasible, then it is recommended that the groundnut stover can be returned to the field immediately after harvest and plowed under.

**Table 4. Biomass and harvest index of rice as affected by groundnut stover removal (–S) or addition (+S) either applied on surface or incorporated at different days before rice transplanting (DBT), with and without chemical fertilizers at Kalasin, Northeast Thailand, 2000[1].**

| Treatment[2] | Yield[3] ($kg\ ha^{-1}$) Grain | Yield[3] ($kg\ ha^{-1}$) Total biomass | Harvest index[3] (%) |
|---|---|---|---|
| – S – NPK (control) | 2380[d] | 4310[f] | 56[a] |
| + S 45 DBT (surface) + PK | 2910[abc] | 5790[de] | 51[abcd] |
| + S 45 DBT (surface) + $N_p$PK | 2850[bc] | 6480[abcd] | 44[d] |
| + S 45 DBT (incorporated) + PK | 3050[abc] | 6120[cd] | 50[abcd] |
| + S 45 DBT (incorporated) + $N_p$PK | 3340[a] | 6460[abcd] | 52[abcd] |
| + S 27 DBT (incorporated) + PK | 3230[ab] | 6940[abc] | 47[bcd] |
| + S 27 DBT (incorporated) + $N_p$PK | 3340[a] | 7470[ab] | 45[cd] |
| + S 13 DBT (incorporated) + PK | 3160[abc] | 6580[abcd] | 49[abcd] |
| + S 13 DBT (incorporated) + $N_p$PK | 3260[ab] | 6710[abcd] | 49[abcd] |
| + S 6 DBT (incorporated) + PK | 3250[ab] | 7260[ab] | 45[cd] |
| + S 6 DBT (incorporated) – PK | 3160[abc] | 6520[abcd] | 48[abcd] |
| + S 6 DBT (incorporated) + $N_t$PK | 3150[abc] | 6420[abcd] | 49[abcd] |
| + S 6 DBT (incorporated) + $N_p$PK | 3320[a] | 7550[a] | 44[d] |
| – S + PK | 2740[cd] | 5050[ef] | 54[ab] |
| – S + ($N_t$ + $N_p$PK) | 2940[abc] | 5660[de] | 52[abc] |
| F-test | ** | ** | ** |
| CV (%) | 9.0 | 10.5 | 9.4 |

1. Source: Srichantawong et al. (2005).
2. Nt = 25 kg N $ha^{-1}$ at transplanting; Np = 14.4 kg N $ha^{-1}$ at panicle initiation as urea; PK = 10.9 P and 10.4 K kg $ha^{-1}$ at transplanting.
3. ** = Significant at $P$ <0.01. Figures followed by the same letter(s) in a column are not significantly different.

If rice cannot be transplanted within 45 days after incorporation, N fertilizer application at panicle initiation stage is recommended. It is therefore recommended that depending upon local constraints and labor cost involved, farmers should return the groundnut stover shortly before transplanting of the rice crop (6–18 days before transplanting) to get the best results.

We also studied the effect of groundnut stover application in improving growth and yield of rice cultivar KDML 105 in 11 farmers' fields for three years (2002–04). The results revealed that growth and yield of rice grown in the plot, which was kept fallow, was poorer than those in the plot where groundnut was grown in the preceding season. Stover removal also gave lower grain yield but increased total biomass yield (Table 5). When groundnut stover was returned to the field, rice yield was high. The highest rice yield was obtained when stover was returned immediately and incorporated into soils and nitrogen fertilizer was applied at the panicle initiation stage. However, the yield obtained with this particular treatment was not significantly different from the treatment in which stover was stored for short period and returned to the field at 15 days before transplanting. However, when labor cost is taken into account, storing stover requires extra space, time and money and may not be suitable in many situations.

**Table 5. Biomass and harvest index (HI) of rice as affected by different groundnut stover application methods with or without chemical fertilizer during 2002–04[1].**

| Treatment[2] | Yield[3] (kg ha$^{-1}$) Grain | Yield[3] (kg ha$^{-1}$) Total biomass | Harvest index (%) |
|---|---|---|---|
| No GN crop (fallow) | 3160[b] | 9150[b] | 35 |
| + GN crop, – Stover | 3230[b] | 9520[ab] | 34 |
| + GN crop, + Stover (farmer practice) | 3130[b] | 9960[ab] | 34 |
| + GN crop, + Stover (incorporated) + N (PI) | 3970[a] | 11450[a] | 35 |
| + GN crop, + Stover (15 DBT) + N (PI) | 3620[ab] | 11040[ab] | 35 |
| F-test | * | * | NS[4] |
| CV (%) | 9.20 | 11.0 | 9.14 |

1. Source: Groundnut Improvement Project (2006).
2. GN = Groundnut; PI = Panicle initiation stage; DBT = Days before transplanting.
3. * = Significant at $P$ <0.05; figures followed by the same letter(s) in a column are not significantly different at $P$ <0.05.
4. NS = Not significant.

At Wang Chai watershed, we also examined the effect of groundnut stover on growth and yield of rice in three farmers' fields during 2005. The effect of groundnut stover application on rice grain yield was not statistically different (Table 6). This could be attributed to the occurrence of blast disease in two farmers' fields (farmer 1 and farmer 2). It was also noted that the N content in the stover applied to the fields of these two farmers was higher (113 and 131 kg N $ha^{-1}$) than that of the third farmer (85 kg N $ha^{-1}$).

In Tad Fa watershed, we studied the effect of groundnut stover on growth and yield of upland rice. The growth and yield of upland rice was reduced when groundnut stover was removed from the field. Stover application increased growth and yield of the succeeding rice crop (Table 7). Stover removal of non-nod groundnut also showed reduction of rice yield. Stover application gave higher growth and yield of rice and in some cases the rice crop did not require N fertilizer application at the panicle initiation stage. Perhaps N fertilizer application at panicle initiation stage might have resulted in the occurrence of blast disease in rice.

A farmer participatory experiment to study the effect of growing groundnut on succeeding rice was initiated at Tad Fa watershed. Only one out of three farmers was able to plant upland rice after groundnut as the farmers were busy in harvesting their first maize crop and they did not have enough time to harvest groundnut and plant upland rice. Additionally, it was also a severe drought year when the experiment was conducted. During the grain-filling stage of the rice crop, there was severe shortage of water.

**Table 6. Growth and yield of rice grown after groundnut with different groundnut stover management practices at Wang Chai watershed in 2005.**

| Treatment[1] | Yield (kg $ha^{-1}$) | | | Harvest index[2] (%) |
|---|---|---|---|---|
| | Grain | Stover | Total biomass | |
| + GN stover + $N_0$PK + N (PI) | 2750 | 3580[a] | 6330 | 43 |
| + GN stover + $N_1$PK | 2525 | 2840[ab] | 5690 | 44 |
| + GN stover + $N_1$PK + N (PI) | 2594 | 3390[a] | 5980 | 43 |
| – GN stover (fallow) + $N_0$PK | 1835 | 2480[b] | 4240 | 43 |
| F-test | NS | * | NS | NS |
| CV (%) | 24.56 | 14.89 | 23.02 | 2.93 |

1. $N_1$ = 25 kg N $ha^{-1}$ at 2 weeks after transplanting; N (PI) = 14.4 kg N $ha^{-1}$ applied at panicle initiation stage; PK = 25 kg $ha^{-1}$ of $P_2O_5$ and 12.5 kg $ha^{-1}$ of $K_2O$ and applied at 2 weeks after transplanting.
2. NS = Not significant; * = Significant at $P$ <0.05; figures followed by the same letter in a column are not significantly different.

**Table 7. Grain and biomass yield and harvest index of upland rice as affected by different groundnut stover application methods with or without chemical fertilizer at Ban Koke Mon in 2003.**

| Treatment[1] | Yield[2] (kg $ha^{-1}$) | | Harvest index[2] (%) |
|---|---|---|---|
| | Grain | Total biomass | |
| – Stover + $N_0P_0K_0$ (control) | 2560[bc] | 5980[bc] | 43[ab] |
| + Stover (incorporated) + PK | 3620[ab] | 8620[ab] | 42[abc] |
| + Stover (mulch) + PK | 3940[a] | 9250[a] | 43[ab] |
| + Stover (incorporated) + PK + N (PI) | 3750[ab] | 9840[a] | 38[cd] |
| + Stover (mulch) + PK + N (PI) | 4210[a] | 9990[a] | 42[abc] |
| – Stover (non-nod) + PK | 2020[c] | 5600[c] | 36[a] |
| – Stover + (½ N) PK | 3560[ab] | 7890[abc] | 46[a] |
| – Stover + NPK | 3020[abc] | 7200[abc] | 42[abc] |
| – Stover + (2N) PK | 3480[ab] | 8570[ab] | 41[bcd] |
| F-test | ** | * | * |
| CV (%) | 22.64 | 22.31 | 8.13 |

1. N = 25 kg N $ha^{-1}$ applied at 15 days after planting; N (PI) =14.4 kg N $ha^{-1}$ applied as urea at panicle initiation stage; PK = 25 kg $ha^{-1}$ of $P_2O_5$ and 12.5 kg $ha^{-1}$ $K_2O$ applied at 2 weeks after planting.
2. * = Significant at $P < 0.05$; ** = Significant at $P < 0.01$; means followed by the same letter(s) in a column are not significantly different at $P < 0.05$ by DMRT.

The growth and productivity of rice was very poor. Groundnut stover application did not increase rice growth, especially when NPK fertilizers were applied to the crop. Rice yields were very low and there were no significant differences among the various treatments (Table 8).

A good yield of upland rice after groundnut can be obtained when groundnut is planted early (end of March to early April). Also, the cultivar should mature, preferably by the end of June. Therefore, an early-maturing groundnut cultivar or boiling type groundnut should be used in the production systems. After groundnut harvest, a rice crop should be sown as soon as possible (first week of July) so that it will have enough moisture up to the grain-filling stage. This will also avoid labor conflict with maize harvesting.

**Table 8. Grain and biomass yield of rice grown after groundnut with different groundnut stover management practices in a farmer's field at Ban Koke Mon in rainy season 2004.**

| | Yield[1] (kg $ha^{-1}$) | | |
|---|---|---|---|
| Farmer | Grain | Stover | Total biomass |
| – Stover, – NPK | 420 | 1320[b] | 1750[b] |
| – Stover, + NPK | 390 | 1520[b] | 1910[b] |
| + Stover, – NPK | 550 | 1730[b] | 2280[b] |
| + Stover, + NPK | 550 | 2400[a] | 2950[a] |
| F-test | NS | ** | ** |
| CV (%) | 32.9 | 13.63 | 11.57 |

1. ** = Significant at *P* <0.01; NS = Not significant; means followed by the same letter in a column are not significantly different.

## Maize-based System

Maize is another crop that is economically important to Thailand. In Thailand the total area under maize is about 1.09 million ha with an average yield of 3.87 t $ha^{-1}$, which is lower than that reported from Vietnam and China. Major maize production areas in Thailand are in the North, Northeast and central regions of the country (Center for Agricultural Information 2006). Maize production area in the Northeast is about 325,000 ha with average yield of 3.42 t $ha^{-1}$, which is slightly lower compared to those obtained in the North and the central parts of Thailand.

The role of legumes in improving the yield of maize has been studied by several researchers (McDonagh et al. 1993, Phoomthaisong et al. 2003). Under the ADB-ICRISAT-KKU watershed project, research was conducted on the use of groundnut stover at Tad Fa watershed, where maize is the major crop. We did not focus our effort on the use of green manure legumes in maize system because of the reasons discussed earlier. Legume crops that provide cash or economic income will fit better in the production systems practiced by small farmers with limited resources. These small farmers invest their limited resources only when they are sure of getting good returns on their investment of time and labor. Grain or edible legumes seem better alternatives. However, different legumes are known to fix different amounts of N from the air. They also have different nitrogen harvest index (NHI). Some of the legumes store most of the N in their grain and are soil exhaustive crops, while the fertility (%) NHI is lower than the proportion of N derived from air (% Ndfa). However, this is not the case with groundnut.

Our research at Khon Kaen University indicated that the amount of N fixed from the air by groundnut was higher than the amount of N removed through pods. Groundnut crop can improve the soil fertility, provided the stover is returned to the field. We compared the effect of growing mung bean and groundnut cultivars on growth and yield of maize. The crops were grown and harvested for grain and the stover was returned to the fields before maize planting. The results are summarized in Table 9.

The results showed that the total biomass and grain yield of maize grown after mung bean were lower than that grown after groundnut cultivar Tainan 9. The amount of N fixed using $^{15}N$ isotope dilution technique revealed that the NHI (%) of mung bean is higher than % Ndfa. Thus mung bean is a soil fertility exhaustive crop and the succeeding maize crop yield was not significantly different from that following the non-nod groundnut.

**Table 9. Grain and biomass yield and harvest index of maize cultivar NS1 grown after mung bean (MB), groundnut (GN) and fallow treatments at Khon Kaen in 1999–2000[1].**

| | Yield[3] (kg $ha^{-1}$) | | Harvest |
|---|---|---|---|
| Preceding crops[2] | Grain | Total biomass | index[4] (%) |
| MB cv KPS 1 | 1770$^{de}$ | 4480$^{ef}$ | 39 |
| MB cv KPS 2 | 2260$^{bcde}$ | 5960$^{bcdef}$ | 38 |
| MB cv CN 36 | 2650$^{bcd}$ | 6910$^{bcd}$ | 38 |
| MB cv CN 72 | 1670$^{e}$ | 4280$^{f}$ | 39 |
| MB cv UT 1 | 2040$^{cde}$ | 5420$^{def}$ | 38 |
| MB cv PSU 1 | 2090$^{cde}$ | 5310$^{def}$ | 39 |
| GN cv Tainan 9 | 3840$^{a}$ | 10980$^{a}$ | 35 |
| GN cv Non-nod | 2200$^{bcde}$ | 6510$^{bcde}$ | 34 |
| Fallow + $N_0$ | 1570$^{e}$ | 4300$^{f}$ | 36 |
| Fallow + $N_1$ | 1830$^{de}$ | 5650$^{cdef}$ | 32 |
| Fallow + $N_2$ | 3040$^{ab}$ | 7900$^{b}$ | 39 |
| Fallow + $N_3$ | 2930$^{abc}$ | 7630$^{bc}$ | 38 |
| F-test | ** | ** | NS |
| CV (%) | 24.5 | 20.1 | 11.7 |

1. Source: Phoomthaisong et al. (2003).
2. $N_0$, $N_1$, $N_2$, $N_3$ = 0, 30, 60 and 90 kg N $ha^{-1}$.
3. ** = Significant at $P$ <0.01; figures followed by the same letter(s) in a column are not significantly different.
4. NS = Not significant.

The groundnut cultivar Tainan 9 had higher % Ndfa than NHI (%) and thus improves the soil fertility when its stover is returned to the field. The yield of maize grown after groundnut cultivar Tainan 9 was equivalent to maize grown after fallow with the application of 60–90 kg N $ha^{-1}$.

A legume crop, which has higher % Ndfa than NHI (%), will be a soil fertility exhaustive crop if the stover is not returned to the field (Table 10). Thus the groundnut stover removal from the field could reduce growth and yield of maize, which is comparable to the yields obtained in fallow plot that received no N fertilizer. In treatments where the stover biomass was returned to the field, maize yields were higher even following non-nod groundnut cultivar.

**Table 10. Grain and total biomass yield of maize grown after groundnut or after fallow with stover removed (– S) or returned (+ S) to the soil at Khon Kaen in 1990–91[1].**

| Groundnut cultivar | Grain yield (kg $ha^{-1}$) | | | Total biomass (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | – S | + S | Difference (%) | – S | + S | Difference (%) |
| Tainan 9 | 1650 | 2730 | 65 | 3940 | 6420 | 63 |
| KK 60-1 | 1980 | 2960 | 50 | 4700 | 6690 | 42 |
| LK 60-2 | 1970 | 2620 | 33 | 4610 | 6060 | 32 |
| KK 60-3 | 2130 | 3010 | 41 | 5240 | 7300 | 39 |
| Non-nod | 1740 | 2220 | 27 | 4070 | 5320 | 31 |
| | –N | +N[2] | - | –N | +N | - |
| Fallow | 1912 | 2723 | 42 | 4546 | 6394 | 41 |

1. Source: McDonagh et al. (1993).

2. N = 75 kg N $ha^{-1}$ applied as urea.

How much groundnut stover should a farmer return to the field to get the best benefit? To answer this question, we conducted an experiment near Tad Fa watershed using different rates of groundnut stover in combination with chemical fertilizers (Table 11). Application of 7.5 t $ha^{-1}$ of groundnut stover with P and K fertilizer at planting and top dressing of N fertilizer at tasseling stage gave the highest biomass and grain yield. However, this treatment was not significantly different from the treatment that received groundnut stover at 3.75 t $ha^{-1}$. This quantity of stover (3.75 t $ha^{-1}$) should be available for application by farmers and therefore is recommended for sustaining maize yields.

A farmer participatory experiment on the effect of groundnut on the succeeding maize crop was initiated at Tad Fa watershed in 2004. Due to drought year, only one farmer was able to plant maize after groundnut. Most of the farmers got very poor yields (Table 12).

**Table 11. Grain and biomass yield and harvest index of maize grown after groundnut with various rates of stover returned with or without chemical fertilizer at Ban Koke Mon in 2005.**

| Treatment[1] | Yield (kg $ha^{-1}$) | | Harvest index[2] (%) |
|---|---|---|---|
| | Grain | Total biomass | |
| – Stover + $N_0P_0K_0$ | 2230[e] | 6720[e] | 34[bc] |
| + 1.88 t $ha^{-1}$ Stover + PK | 2750[de] | 7020[e] | 38[a] |
| + 1.88 t $ha^{-1}$ Stover + PK + N top dress | 3980[ab] | 9740[bcd] | 40[a] |
| + 3.75 t $ha^{-1}$ Stover + PK | 3210[cd] | 8300[cde] | 39[a] |
| + 3.75 t $ha^{-1}$ Stover + PK + N top dress | 4050[ab] | 10120[ab] | 41[a] |
| + 5.63 t $ha^{-1}$ Stover + PK | 3870[abc] | 9820[bc] | 40[a] |
| + 5.65 t $ha^{-1}$ Stover + PK + N top dress | 3970[ab] | 9880[bc] | 40[a] |
| + 7.5 t $ha^{-1}$ Stover + PK | 3570[bc] | 9310[bcd] | 38[ab] |
| + 7.5 t $ha^{-1}$ Stover + PK + N top dress | 4410[a] | 11790[a] | 38[ab] |
| – Stover + $N_0$PK | 2370[e] | 7980[de] | 30[c] |
| – Stover + $N_1$PK | 3770[abe] | 10000[abc] | 38[a] |
| – Stover + $N_1$PK + N top dress | 4110[ab] | 10780[ab] | 38[a] |
| F-test | ** | ** | ** |
| CV (%) | 14.91 | 13.56 | 8.56 |

1. $N_1$ = 25 kg N $ha^{-1}$ at 2 weeks after transplanting; N top dress = 31.3 kg N $ha^{-1}$ as urea; PK = 47 kg $ha^{-1}$ each of $P_2O_5$ and $K_2O$ applied at 2 weeks after planting.
2. ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

**Table 12. Performance of maize grown after groundnut in a farmer's field at Ban Koke Mon in the rainy season 2004.**

| Treatment | Yield[1] (kg $ha^{-1}$) | | | |
|---|---|---|---|---|
| | Grain | Cob | Stover | Total |
| + Stover, + NPK | 1520 | 290[a] | 1840[a] | 3660[a] |
| – Stover, + NPK | 990 | 165[b] | 1340[b] | 2500[b] |
| F-test | NS | ** | * | * |
| CV (%) | 19.37 | 13.04 | 11.30 | 10.77[b] |

1. NS = Not significant; * = Significant at *P* <0.05; ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

At Tad Fa watershed, we also studied the effects of some green manure and grain legumes, which were grown during August to December 1999, on the growth and yield of maize crop in the 2000 wet season. In this experiment green manure legumes were grown up to maturity and the grain legumes were harvested for grain. The crops were harvested and their residues were kept and applied to the field before planting of the maize crop. The results are shown in Tables 13 and 14.

**Table 13. Performance of maize grown after five leguminous crops at Ban Koke Mon in the rainy season 2000.**

| | Yield[1] (kg $ha^{-1}$) | | | |
|---|---|---|---|---|
| Treatment | Grain | Cob | Stover | Total |
| Ricebean | 820 | 4540[a] | 7070 | 12420 |
| Sunnhemp | 790 | 4720[a] | 6630 | 12140 |
| Sword bean | 660 | 3640[b] | 6670 | 10990 |
| Black gram | 870 | 4490[a] | 6790 | 12150 |
| Maize | 700 | 3520[b] | 5560 | 9780 |
| F-test | NS | * | NS | NS |
| CV (%) | 14.41 | 13.36 | 14.57 | 13.13 |

1. NS = Not significant; * = Significant at $P$ <0.05; figures followed by the same letter in a column are not significantly different.

**Table 14. Nitrogen fixed and benefit realized from legumes in maize-based system at Ban Koke Mon, Tad Fa watershed in 2000.**

| Preceding crop | $N_2$ fixed (kg $ha^{-1}$) | Expected net N benefit[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 $ha^{-1}$) |
|---|---|---|---|---|---|
| Ricebean | 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 – Grain N.

2. Total uptake by succeeding maize – Total N uptake by maize grown after maize.

We evaluated the amount of $N_2$ fixed by preceding crops using the N difference method; the amount of N fixed varied from 20 to 104 kg N ha$^{-1}$ and the net N benefit to the succeeding crop was estimated at 2 to 51 kg N ha$^{-1}$ (Table 14). Maize crop was grown after legumes with 40 kg N ha$^{-1}$ along with the organic matter from legume residues. Grain yield of the succeeding maize crop was significantly ($P \leq 0.05$) higher by 27 to 34% in treatments following black gram, ricebean and sunnhemp over the yield of maize in control treatment (Table 13). Although $N_2$ fixation was highest in sword bean (104 kg N ha$^{-1}$), N benefit expected (51 kg N ha$^{-1}$) was not realized in increased maize yield. 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 improving the soil fertility.

Growing black gram, ricebean and sunnhemp in the system would help in reducing N requirement for the succeeding maize crop. In addition, in the long-term it is expected to improve soil physical properties such as structure. The actual realized benefit 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 benefit from legume through biological nitrogen fixation (BNF) and soil N sparing effect on the maize crop varied from 15 to 64 kg N ha$^{-1}$ (Table 14). In conclusion, growing legumes such as ricebean, sunnhemp and black gram benefits the succeeding maize crop substantially. In the long-term it is expected to also improve the soil structure.

## Sugarcane-based System

Sugarcane is also one of the important economic field crops in Thailand and the country is one of the major sugar exporters of the world. In 2005, it exported 3.04 million t sugar, which was worth 28,362 million bahts (US$ 777.04 million) (Center for Agricultural Information 2006). In Thailand the total area under sugarcane is about 1.17 million ha with average yield of 57.94 t ha$^{-1}$. Sugarcane is grown mainly in the Northeast, Central and Northern parts of Thailand. Sugar factories are shifting from the central to northeast parts of the country due to availability of good quality sugarcane and cheap labor. Consequently the area under sugarcane cultivation in Northeast region is increasing fast.

Sugarcane area in the Northeast is about 0.443 million ha with average yield of 57.24 t ha$^{-1}$, which is only slightly lower than the national average. In the northeast, sugarcane is grown either at the beginning of rainy season (starting in March) or at the end of the rainy season (October–November).

Only one or two ratoon crops can be grown after the harvest. Low soil fertility and erratic rainfall are the main reasons for low sugarcane yield and also for fewer ratoon crops.

Sugarcane yield can be substantially increased with the application of chemical fertilizers. However, chemical fertilizers are expensive and not affordable for many poor farmers. Alternate ways to reduce the use of chemical fertilizers needs to be worked out. Incorporating legumes in the cropping system seems to be one of the alternatives.

Sugarcane crushing season in the Northeast starts in December and continues until April in the succeeding year. Sugarcane sown in March is harvested when it is 8–10 months old while that sown in October is harvested after 14 months. Maximum of two ratoon crops could be obtained in the region. In most cases only one ratoon crop can be harvested. If the next sugarcane crop has to be grown in early rainy season (starting in March) there will be a fallow period of 2–4 months. During this fallow period, hardly any crop can be grown due to the lack of soil moisture. However, if the next sugarcane crop is to be grown next October, then there should be a gap of 6–8 months so that the soil has good moisture availability. Introducing legumes during this gap period in the sugarcane-based system seems to be logical. The legumes could be green manure or grain legumes. Many green manure legumes have been recommended by the Department of Agriculture, particularly sunnhemp (*Crotalaria juncea*) and sword bean (*Canavalia gladiata*). Recently, local leguminous weeds such as hairy indigo (*Indigofera hirsuta*) and *Crotalaria striata* were also evaluated for their potential as a green manure crop.

It is observed that during the gap period between the previous sugarcane harvest and the next sugarcane planting in October, some farmers grow or allow other farmers to grow groundnut in their fields free of charge on the condition that groundnut stover is left in the field. In view of this practice, a study was undertaken to examine the effects of cultivating pigeonpea, sunnhemp, groundnut, soybean, hairy indigo and maize on the succeeding sugarcane crop.

Two experiments were conducted at Wang Chai watershed to evaluate growth and yield of these six crops and their residual N benefits to the succeeding sugarcane grown in October. The first experiment was initiated in July 2003 while the second experiment started in June 2004. The biomass yield of different preceding crops and nutrient content in the stover are shown in Table 15. Maize, which received NPK fertilizers, gave the highest yield of grain, stover and total biomass. Only maize, soybean and groundnut gave economic yields. Soybean had the lowest grain yield because of poor nodulation (due to failure of *Rhizobium* inoculation). The N, P, K and Ca contents of the stover was highest in hairy indigo. Nitrogen content in different plant residues varied, with the highest in hairy indigo (122 kg N $ha^{-1}$) and the lowest in maize (18 kg N $ha^{-1}$) while P content ranged between 7 and 32 kg $ha^{-1}$, K ranged between 28 and 102 kg $ha^{-1}$ and Ca ranged between 15 and 79 kg $ha^{-1}$.

Sugarcane cultivar Khon Kaen 1 was grown after the stover incorporation into the soil. All treatments received P and K fertilizers at 47 kg $ha^{-1}$ each of $P_2O_5$ and $K_2O$, respectively at the time of sugarcane planting with the exception of treatment 7, which received N fertilizer at 47 kg N $ha^{-1}$ in addition to the N applied at the time of planting ($N_1$). NPK fertilizers at 47 kg $ha^{-1}$ each of N, $P_2O_5$ and $K_2O$ were applied uniformly to all treatments at seven months after planting except in treatment 7, which received only P and K fertilizers at 47 kg $ha^{-1}$ each of $P_2O_5$ and $K_2O$. There was no significant difference between treatments in all parameters measured. Millable cane weight was 43.19–50.81 t $ha^{-1}$ and commercial cane sugar (CCS) was 13.75–14.00. This indicated that the N in the stover can supplement N requirement of sugarcane during the first six months of crop growth (Table 16).

**Table 15. Total biomass yields and nutrient contents in the stover of different preceding crops grown before sugarcane at Ban Wang Chai in 2003 (experiment 1)[1].**

| | Yield (kg $ha^{-1}$) | | Total | Nutrient content (kg $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Pod/grain | Stover | biomass | N | P | K | Ca |
| Groundnut | 1780 | 4390$^{c}$ | 6170$^{a}$ | 71$^{bc}$ | 10$^{b}$ | 52$^{b}$ | 79$^{a}$ |
| Soybean | 420 | 1990$^{e}$ | 2410$^{c}$ | 33$^{d}$ | 9$^{b}$ | 28$^{c}$ | 22$^{b}$ |
| Pigeonpea | - | 4020$^{bcd}$ | 4020$^{b}$ | 86$^{b}$ | 11$^{b}$ | 30$^{c}$ | 39$^{b}$ |
| Sunnhemp | - | 3400$^{bc}$ | 3400$^{bc}$ | 43$^{cd}$ | 8$^{b}$ | 42$^{bc}$ | 26$^{b}$ |
| Maize + NPK[2] | 1880 | 6390$^{a}$ | 8270$^{a}$ | 18$^{d}$ | 7$^{b}$ | 33$^{c}$ | 15$^{b}$ |
| Hairy indigo | - | 6030$^{a}$ | 6030$^{a}$ | 122$^{a}$ | 32$^{a}$ | 102$^{a}$ | 77$^{a}$ |
| Fallow | - | 2620$^{bc}$ | 2620$^{bc}$ | 48$^{cd}$ | 7$^{b}$ | 32$^{c}$ | 30$^{b}$ |
| Fallow | - | 2950$^{bc}$ | 2950$^{bc}$ | 43$^{cd}$ | 8$^{b}$ | 42$^{bc}$ | 25$^{b}$ |
| F-test | - | ** | ** | ** | ** | ** | ** |
| CV (%) | - | 25.93 | 28.72 | 33.14 | 25.91 | 22.91 | 38.87 |

1. ** = Significant at $P$ <0.01; figures followed by the same letter(s) in a column are not significantly different.

2. Fertilizer at 47 kg $ha^{-1}$ each of N, $P_2O_5$ and $K_2O$.

**Table 16. Number of millable canes, cane height, cane diameter, millable cane weight and commercial cane sugar (CCS) of sugarcane cultivar Khon Kaen 1 grown after different preceding crops at final harvest in January 2005 (experiment 1).**

| Treatment[1] | Millable cane (no. ha$^{-1}$) | Cane height (cm) | Cane diameter (cm) | Millable cane weight (t ha$^{-1}$) | CCS | Sugar yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|
| (1) Groundnut + $N_2$ | 48,000 | 275 | 2.40 | 49.93 | 13.87 | 6,930 |
| (2) Soybean + $N_2$ | 43,500 | 288 | 2.50 | 50.46 | 13.86 | 6,960 |
| (3) Pigeonpea + $N_2$ | 44,833 | 270 | 2.40 | 43.80 | 13.88 | 6,040 |
| (4) Sunnhemp + $N_2$ | 46,833 | 287 | 2.50 | 50.81 | 14.00 | 7,140 |
| (5) Maize + $N_2$ | 51,667 | 243 | 2.40 | 54.44 | 13.88 | 7,570 |
| (6) Hairy indigo + $N_2$ | 46,333 | 277 | 2.50 | 48.06 | 13.75 | 6,560 |
| (7) Fallow + $N_1$ | 43,000 | 286 | 2.60 | 44.49 | 13.79 | 5,980 |
| (8) Fallow + $N_2$ | 42,167 | 270 | 2.60 | 43.19 | 13.78 | 6,120 |
| F-test | NS[2] | NS | NS | NS | NS | NS |
| CV (%) | 16.06 | 4.52 | 5.36 | 24.40 | 2.85 | 24.88 |

1. $N_1$ = 47 kg N ha$^{-1}$ applied at planting of sugarcane; $N_2$ = 47 kg N ha$^{-1}$ applied when sugarcane was 7 months old.

2. NS = Not significant.

After sugarcane harvest, the ratoon cane was allowed to grow. Since it was a dry year, ratoon cane was not fertilized until 6 months after sugarcane harvest. The N, P and K fertilizers were applied to all treatments at 47 kg ha$^{-1}$ each of N, $P_2O_5$ and $K_2O$, respectively. The last treatment received the same amount of NPK again one month later (ie, 7 months after sugarcane cutting). The growth and yield of the ratoon cane are shown in Table 17. The results indicate that there are significant differences in cane diameter and number of millable canes per hectare. However, cane height, millable cane weight, CCS and sugar yields were not statistically different. This indicates that the beneficial effect of plant stover did not carry through to the ratoon cane.

A second experiment was conducted in 2004 at Wang Chai watershed. The preceding crop treatments were the same as in the first experiment. Growth and yields of preceding crops are shown in Table 18. It was found that groundnut is suitable at this site; its growth and yield was similar to that in 2003. However in the 2004 season, soybean gave better yield (2.3 t ha$^{-1}$) than in 2003. This was partially due to good nodulation after proper *Rhizobium* inoculation. Sunnhemp did not perform well in 2004 due to severe waterlogged conditions. Nutrient contents in the stover varied with crops. Sunnhemp and maize had low nutrient contents due to low biomass yield. It should be noted that maize did not receive any N fertilizer in the 2004 experiment.

**Table 17. Height, diameter, number and fresh weight of millable cane, commercial cane sugar (CCS) and sugar yield of the first ratoon cane (cultivar Khon Kaen 1) grown after different preceding crops (ratoon cane)[1].**

| Treatment | Height (m) | Diameter (cm) | Millable cane (no. $ha^{-1}$) | Fresh weight (t $ha^{-1}$) | CCS | Sugar yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|
| Groundnut (KK 1) | 2.17 | 2.53[ab] | 52056[ab] | 37.2 | 14.69 | 5470 |
| Soybean (SJ 5) | 2.31 | 2.64[a] | 48944[ab] | 40.5 | 14.41 | 5860 |
| Pigeonpea | 2.33 | 2.58[ab] | 56664[a] | 43.0 | 14.61 | 6270 |
| Sunnhemp | 2.24 | 2.55[ab] | 42726[b] | 31.6 | 13.96 | 4450 |
| Maize (NS 72) | 2.24 | 2.51[ab] | 49444[ab] | 38.9 | 14.62 | 4940 |
| Hairy indigo | 2.19 | 2.57[ab] | 48836[ab] | 37.0 | 14.66 | 5360 |
| Fallow | 2.17 | 2.46[b] | 53388[ab] | 34.5 | 15.00 | 5170 |
| Fallow + N | 2.33 | 2.48[b] | 52889[ab] | 41.1 | 15.08 | 6180 |
| F-test | NS | * | * | NS | NS | NS |
| CV (%) | 6.88 | 3.42 | 13.96 | 21.20 | 4.97 | 20.75 |

1. NS = Not significant; ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

Sugarcane cultivar Khon Kaen 1 was grown after stover incorporation in late October. P and K fertilizers were applied to all treatments at the rate of 47 kg $ha^{-1}$ each of $P_2O_5$ and $K_2O$, at the time of sugarcane planting except treatment 7, which received 47 kg N $ha^{-1}$ in addition to P and K fertilizers. At six months after planting, N, P and K fertilizers were applied to all treatments at the rate of 47 kg $ha^{-1}$ of N, $P_2O_5$ and $K_2O$, with the exception of treatment 8 which received only P and K fertilizers. The crops were harvested in the beginning of January 2006.

Significant differences between the various treatments in all measured parameters for sugarcane were recorded (Table 19). Sugarcane grown in fallow plot, which did not receive N fertilizer, gave the lowest growth and yield than other treatments. Amongst the treatments, where biomass from the preceding crops was returned to the field, highest sugarcane fresh weight (56.69 t $ha^{-1}$) was obtained in groundnut treatment, which was significantly higher than soybean treatment. Results clearly show the beneficial effect of legumes in increasing sugarcane yield. Although sunnhemp produced low biomass and had low nutrient contents in the stover, it positively influenced sugarcane yield. This could be due to the fact that sunnhemp suffered from the high water content during late rainy season, which resulted in leaf fall and decay of plants much before the final harvest. This might have released mineral N for use by the sugarcane crop.

**Table 18. Pod/grain/pod yield, biomass and nutrient contents in the stover of different preceding crops grown before sugarcane at Ban Wang Chai in 2004 (experiment 2).**

| | Yield[1] (kg ha$^{-1}$) | | | Nutrient content (kg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Pod/grain | Stover | Total biomass | N | P | K | Ca |
| Groundnut | 1750 | 2500$^{c}$ | 4250$^{bc}$ | 48 | 8 | 46 | 51 |
| Soybean | 2280 | 2180$^{c}$ | 4460$^{b}$ | 48 | 16 | 111 | 67 |
| Pigeonpea | – | 5100$^{b}$ | 5100$^{b}$ | 83 | 14 | 56 | 26 |
| Sunnhemp | 330 | 440$^{d}$ | 770$^{e}$ | 3 | 1 | 7 | 2 |
| Maize | 480 | 1660$^{cd}$ | 2130$^{d}$ | 3 | 4 | 19 | 4 |
| Hairy indigo | – | 2910$^{c}$ | 2910$^{cd}$ | 58 | 9 | 44 | 43 |
| Fallow | – | 8740$^{a}$ | 8740$^{a}$ | 29 | 15 | 90 | 22 |
| F-test | – | ** | ** | – | – | – | – |
| CV (%) | – | 21.18 | 19.75 | – | – | – | – |

1. ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

**Table 19. Height, diameter, number and fresh weight of millable cane, commercial cane sugar (CCS) and sugar yield of sugar cane (cultivar Khon Kaen 1) grown after different preceding crops (experiment 2)[1].**

| Treatment | Height (m) | Diameter (cm) | Millable cane (no. ha$^{-1}$) | Fresh weight (t ha$^{-1}$) | CCS | Sugar yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|
| (1) Groundnut (KK 1) | 2.65$^{bc}$ | 2.70$^{a}$ | 51350$^{ab}$ | 56.7$^{a}$ | 14.60 | 8280$^{a}$ |
| (2) Soybean (SJ 5) | 2.64$^{bc}$ | 2.58$^{ab}$ | 51250$^{ab}$ | 46.9$^{bc}$ | 13.43 | 6290$^{ab}$ |
| (3) Pigeonpea | 2.57$^{c}$ | 2.56$^{ab}$ | 53020$^{a}$ | 52.6$^{ab}$ | 14.82 | 7800$^{ab}$ |
| (4) Sunnhemp | 2.91$^{a}$ | 2.67$^{a}$ | 47710$^{abc}$ | 56.1$^{ab}$ | 15.34 | 8610$^{a}$ |
| (5) Maize (NS 72) | 2.65$^{bc}$ | 2.55$^{ab}$ | 49480$^{abc}$ | 48.6$^{abc}$ | 13.31 | 6470$^{ab}$ |
| (6) Hairy indigo | 2.66$^{bc}$ | 2.64$^{ab}$ | 49580$^{abc}$ | 54.7$^{ab}$ | 14.50 | 7930$^{ab}$ |
| (7) Fallow + NPK | 2.83$^{ab}$ | 2.40$^{b}$ | 45100$^{abc}$ | 48.6$^{abc}$ | 13.83 | 6730$^{ab}$ |
| (8) Fallow + PK | 2.50$^{c}$ | 2.51$^{ab}$ | 43440$^{c}$ | 39.2$^{c}$ | 14.05 | 5520$^{b}$ |
| F-test | ** | * | * | * | ** | * |
| CV (%) | 4.89 | 6.85 | 6.85 | 9.43 | 4.89 | 22.39 |

1. * = Significant at *P* <0.05; * = Significant at *P* <0.01. Figures followed by the same letter(s) are not significantly different.

Economic analysis was made for different treatments in both experiments 1 and 2 and the results are summarized in Tables 20 and 21. The analysis in experiment 1 involves three crops, ie, preceding crops, first sugarcane crop and ratoon sugarcane crop, while in experiment 2 there were only preceding crops and the first harvest of sugarcane crop.

**Table 20. Net profit from growing different preceding crops and followed by sugarcane cultivar Khon Kaen 1 (plant cane and ratoon cane) in experiment 1 (2003–06).**

| | Net profit (US\$ $ha^{-1}$) | | | |
|---|---|---|---|---|
| Treatment | Preceding crops | First sugarcane | Ratoon sugarcane | Total |
| Groundnut | 61.6 (142.8) | 299 | 370 | 732.3 |
| Soybean | –338.5 | 330 | 460 | 450.1 |
| Pigeonpea | –452.9 | 148 | 520 | 211.8 |
| Sunnhemp | –448.6 | 339 | 210 | 100.0 |
| Maize | –440.5 | 416 | 420 | 399.9 |
| Hairy indigo | –437.5 | 250 | 370 | 185.7 |
| Fallow 1 | - | 166 | 307 | 473.1 |
| Fallow 2 | - | 132 | 460 | 590.5 |

**Table 21. Net income from growing different preceding crops and followed by sugarcane cultivar Khon Kaen 1 (plant cane) in experiment 2 (2004–06).**

| | Net income (US\$ $ha^{-1}$) | | |
|---|---|---|---|
| Treatment | Preceding crop | First sugarcane harvest | Total |
| Groundnut | 50.1 | 531.7 | 581.8 |
| Soybean | 220.8 | 185.0 | 405.8 |
| Pigeonpea | –452.9 | 429.4 | –23.5 |
| Sunnhemp | –249.1 | 552.4 | 303.3 |
| Maize | –481.1 | 228.9 | –252.2 |
| Hairy indigo | –437.5 | 473.7 | 36.2 |
| Fallow 1 | - | 235.3 | 235.3 |
| Fallow 2 | - | 76.8 | 76.8 |

Economic analysis of preceding crops in experiment 1 shows that only groundnut gave positive net profit while other preceding crops gave negative net profit. Groundnut gave net profit of US\$ 61.6 $ha^{-1}$ when sold as dry pod at US\$ 0.4 $kg^{-1}$ and net profit of US\$ 142.8 $ha^{-1}$ when sold as boiled groundnut pod at US\$ 2.7 $kg^{-1}$ (Table 20). Soybean and maize had economic yield but gave negative profit because of low yield in the case of soybean and low selling price in the case of maize. Pigeonpea, sunnhemp and hairy indigo did not give economic yield and therefore the net profits were negative ranging from US$ –437.5 to US$ –452.9 ha$^{-1}$. The reason for the negative net profit of green manure legumes was that they received the same crop management as groundnut, soybean and maize but they did not produce any grain.

Economic analysis of first harvest of sugarcane shows that all treatments gave positive net income ranging from US$ 132.7 to US$ 416.4 ha$^{-1}$. The highest net profit was obtained with maize treatment (US$ 416.4 ha$^{-1}$) and the lowest in fallow 2 treatment (US$ 132.7 ha$^{-1}$). Treatment with groundnut gave net income of US$ 299.3 ha$^{-1}$, which was lower than that from sunnhemp and soybean, but greater than that from pigeonpea and hairy indigo.

In ratoon sugarcane, the highest net profit was observed in pigeonpea treatment (US$ 517.1 ha$^{-1}$) and lowest in the case of sunnhemp (US$ 209.0 ha$^{-1}$). Groundnut gave net income of US$ 371.3 ha$^{-1}$, which was similar to hairy indigo, but lower than pigeonpea, soybean, fallow 2 and maize, and greater than those in sunnhemp and fallow 1.

When the net profit from all the three crops were added, groundnut gave the highest net profit (US$ 732.3 ha$^{-1}$ when sold as dry pod and US$ 813.5 ha$^{-1}$ as fresh pod for boiling) followed by fallow 2 (US$ 90.5 ha$^{-1}$), fallow 1 (US$ 473.1 ha$^{-1}$), soybean (US$ 450.1 ha$^{-1}$), maize (US$ 399.9 ha$^{-1}$), pigeonpea (US$ 211.8 ha$^{-1}$), hairy indigo (US$ 185.7 ha$^{-1}$) and sunnhemp (US$ 100 ha$^{-1}$). Results show that groundnut can provide economic return to the farmers in addition to providing residues rich in nutrients for soil application. The green manure legumes did not give economic yield and this was the main reason for negative net profit, which resulted in lower total net profit where these crops were involved.

Economic analysis of the preceding crops and the first harvest of sugarcane in experiment 2 showed that among the preceding crops, only groundnut and soybean gave positive net income (Table 21). The net income involving groundnut in the system was US$ 50.1 ha$^{-1}$ when sold as dry pod and US$ 130 ha$^{-1}$ when sold as boiling type groundnut. Soybean in this experiment gave very high yield of 2.3 t ha$^{-1}$ and therefore had a positive net income of US$ 220.8 ha$^{-1}$, which was contradictory to the results obtained in experiment 1. Good nodulation by proper *Rhizobium* inoculation was the main reason for high grain yield. The rest of the preceding crops gave negative net income ranging from US$ –249.1 to US$ –481.1 ha$^{-1}$. Economic analysis of first sugarcane harvest shows that all treatments gave positive net profit. Maximum net income was obtained in sunnhemp (US$ 552.4 ha$^{-1}$) followed by groundnut, hairy indigo, pigeonpea, fallow 1, maize, soybean and fallow 2. Total system net profit was the highest in groundnut treatment (US$ 581.8 ha$^{-1}$) when sold as dry pod (US$ 661.8

ha$^{-1}$) and when sold as boiling groundnut, followed by soybean (US$ 405.8 ha$^{-1}$), sunnhemp (US$ 303.3 ha$^{-1}$), fallow 1, (US$ 235.3 ha$^{-1}$), fallow 2 (US$ 76.8 ha$^{-1}$) and hairy indigo (US$ 36.2 ha$^{-1}$). Maize and pigeonpea gave negative net profit of US$ –252.2 ha$^{-1}$ and US$ –23.5 ha$^{-1}$.

The results from the second experiment further strengthened the view that the crops grown before sugarcane should be legumes. The legumes should be able to produce grain or economic return to compensate the cost of production. Groundnut seems to be the best crop for the sugarcane system; and if properly inoculated with *Rhizobium,* soybean can also be considered. But it should be noted that soybean stover did not have high nutrients content. Contrary to this, groundnut did not have a lot of leaf fall at maturity and therefore its stover was rich in nutrient contents. This makes it suitable for both soil improvement and increasing the sugarcane yield. The other green manure legumes had high biomass yield but were not economical. Such problems can be solved by lowering their production cost and making them attractive to the small farmers.

## Conclusion

Our studies clearly showed that legumes can help to improve the soil fertility and increase the yield of succeeding crops. The effects of legumes were investigated on three main crops, ie, rice, maize and sugarcane. Some of the conclusions from these studies are given below.

### Rice-based system

1. Both green manure and grain legume crops have been investigated and were found to increase the rice yield. However, our research work focused mainly on the use of grain legumes to improve crop yield because they can provide economic returns to the small farmers.

2. Among the grain legumes, groundnut seems to be best suited for the rice-based cropping system. The crop not only provides economic returns to the farmers, but also helps in improving the soil fertility. The amount of $N_2$ fixed by groundnut exceeded the amount of N contained in economic yield. Therefore, it should be able to help improve soil fertility when its stover is returned to the field after final harvest.

3. Groundnut stover removal resulted in a reduction in rice yield while returning the stover to the soil increased the yield.

4. Groundnut stover should be returned to the field immediately after groundnut harvest and plowed. Rice should be transplanted within 45 days after incorporation. If it is not possible, N fertilizer application (14.4 kg N $ha^{-1}$) during panicle initiation stage is recommended.

5. Groundnut stover application can also increase the yield of upland rice. However, blast disease may be a problem in mountainous areas where the soils are more fertile. Growing upland rice after groundnut may be difficult, because it needs to be done in shorter span of time and would face competition for labor with other crops. Rice also faces moisture stress at the grain-filling stage.

## Maize-based system

1. Groundnut performed better in increasing maize yield than mung bean. This was mainly due to the higher amount of $N_2$ fixed by groundnut than the amount of N removed through its pods. In the case of mung bean, it was vice-versa.

2. Returning groundnut stover to the field could increase maize yield equivalent to the application of 75 kg N $ha^{-1}$.

3. Groundnut stover application at 3.75 t $ha^{-1}$ plus application of N fertilizer (31.3 kg N $ha^{-1}$) at tasseling stage can give maize yield equivalent to the application of N fertilizers at the recommended rates (56.3 kg N $ha^{-1}$).

4. The quality of green manure legumes was found to be quite different, especially when they were harvested at maturity. The quality and quantity both needs to be taken into consideration when we want to use them as green manure to improve maize yield. A good quality stover should release the nutrient to match with the plant N requirement.

## Sugarcane-based system

1. Groundnut has been found to be a profitable crop in sugarcane system.

2. Groundnut gave higher profit than other legumes or crops because it can produce economic yield, which can compensate for its production cost.

3. Green manure crops can compete with groundnut only when their production costs are low.

4. Groundnut should be planted early, so that there is enough moisture at the time of sugarcane planting.

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# 4. Improved Crops and Cropping Systems for Rainfed Northeast Thailand

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## Farm Resources

Northeast Thailand has a population of about 14.5 million and covers an area of 170,000 $km^2$. The region accounts for about one-third of Thailand's population and area. The region is characterized by a relatively poor endowment of natural resources and low living standard of the people. Per capita income of the rural family is about 40 per cent of the country's average and only 30 per cent of the central region (excludes Bangkok). Over 85 per cent of the total population is engaged in agriculture. Family farming is the major characteristic of agricultural production. Farming is done on small scale and crop yield is generally low due to poor soil productivity and erratic rainfall. Farm work is heavily concentrated in May to July and October to November.

The majority of soil types in the Northeast are alluvial, low-humic gley, gray podzolic and red-yellow podzolic soils. These soils are characterized by sandy texture, acid reaction, low organic matter content, low cation exchange capacity, low level of plant nutrients and low water-holding capacity. Continuous cultivation on these soils usually results in rapid decline in fertility level and becomes a major problem for crop production.

The Northeast climate is usually described as semi-arid tropics. The calendar year can be divided into a six-month rainy season (mid-April to mid-October) and six-month dry season (mid-October to mid-April). During the rainy season, most of the rainfall occurs at irregular intervals and at variable intensities. Periods of flooding are interspersed by periods of drought during the season. Rainfall occurs only occasionally in the dry season, and the crop production is feasible only with irrigation. The potential irrigation service area in the Northeast region is relatively small as compared to rainfed area. Irrigation water is not available or will not be available to most of the farms in the foreseeable future. Therefore, rainfed agriculture will still have to play a major role in agricultural production for many years to come.

Temperature is relatively high all year round. Soil and air temperatures during the early rainy season are too high for optimum growth of most crops. The second half of the rainy season is more ideal for crop growth in terms of soil and air temperatures.

## Current Cropping Systems

The present cropping system in the Northeast is monocropping of rice, kenaf and cassava during the rainy season. Rice is the subsistence crop that occupies more than two-thirds of the crop acreage. The region is mostly into production of paddy rice that uses photosensitive varieties. The first half of rainy season is used in soil preparation and growing seedbeds. Only the last half of the wet season is used for crop production. A review on the distribution of paddy and upland fields revealed that more than half of paddy areas are located on soils that are generally suitable for upland crops. This may be due to the fact that farmers have to produce all the rice they need for family consumption and sell only the surplus product. As a result of unfavorable land use conditions, low yields are generally obtained.

Due to rolling topography of the land, paddy fields in the Northeast could be roughly divided into middle and low terraces. The low-terrace (lowland) fields generally have alluvial soils which are suitable for rice growing, and water is usually sufficient for rice crop. On the contrary, soils in the middle-terrace (upper) fields are more coarse in texture with low water-holding capacity and are more suitable for field crops than for rice. A substantially large portion of the upper paddy fields are left fallow most of the years due to insufficient rainfall or delayed onset of the southwest monsoon. Productivity of this type of paddy field could be improved by using the land for production of suitable upland crops.

About one-fifth of the cultivated area is devoted to upland crops. Kenaf and cassava occupy the major portion of the upland areas where soils are generally infertile. Maize and sorghum are grown on fertile soils, which constitute only a small percentage of upland areas. Groundnut is the major food legume grown in the Northeast, while a small acreage is planted with soybean and mung bean. Areas devoted to some other crops are insignificant.

## Need for More Efficient Cropping Systems

Under the present cropping systems where monoculture is the rule, farmers do not utilize the farm resources efficiently. The farming practices in which the same crop is repeated year after year and almost no fertilizer is applied, have resulted in progressive depletion of soil fertility and declining crop yield. Thus, there is a great need for potential cropping systems that would increase productivity of land through better use of natural and human resources. The most suitable cropping systems that fit the farming conditions would be crop intensification or multiple cropping. The need is to develop cropping patterns that fit the local physical and socioeconomic conditions. The cropping patterns to be developed should result in better use of land, water, labor resources, better maintenance of soil fertility, and prolong soil productivity.

A major constraint in developing cropping systems is the lack of adequate research. Most of the research in the past has been focused on improving production of individual crops and not directed towards improving the efficiency of land utilization to maximize return per unit area per unit time. Little attention has been paid to integrate research findings into technological packages and test them at the farmer level. Although considerable research has been done on cropping systems in Thailand, all of them are directed towards developing cropping systems for irrigated areas. There is very little research aimed at developing cropping systems for rainfed conditions. Since irrigation water is not available to 90% of cropped land, research directed towards developing cropping systems for rainfed areas would make a great contribution to agricultural development of the region. Therefore, this project was proposed to fulfill the need of research for more efficient cropping systems.

The Participatory Watershed Management Project for Reducing Poverty and Land Degradation in Thailand has been implemented at Tad Fa watershed, Wang Sawaap Sub-district, District of Phu Pha Man, Khon Kaen since 1999 in partnership with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Research at Wang Chai watershed, Din Dam Sub-district, District of Phu Wiang, Khon Kaen started in 2003. These watersheds have been characterized by topographical conditions. The Tad Fa watershed has sloping mountainous areas with Vertisol soil while the Wang Chai watershed has undulating areas with light red loamy to sandy loam soils. The improved crops and cropping systems are important components of this integrated watershed project.

The major objective of the cropping systems research was to develop cropping systems suitable for rainfed cultivated areas of Northeast Thailand, which will increase the productivity of land through better use of farm resources. In this paper, work done on improved high-yielding varieties and cropping systems evaluated in the two watersheds are discussed in detail.

## Tad Fa Watershed

The Tad Fa watershed is sloping mountainous area under rainfed condition and is characterized by erratic and low rainfall. Loamy to clayey texture soils are common in the watershed. The major constraints to crop production are high soil erosion and severe water scarcity, resulting in low yields of all crops, particularly maize (Fig. 1). The soil chemical properties (0–15 cm depth) determined in 1999 reveal that the soils are extremely low in available phosphorus (P) along the

*Figure 1. Maize cultivation at Tad Fa Watershed: (a) planting in sloping areas, (b) emerging of rock on sloping areas, and (c) wilting due to severe drought late in the rainy season.*

toposequence, mostly due to continuous maize cultivation over a long period without the application of P fertilizer (Table 1). The agronomical interventions at Tad Fa watershed during 2000/01 to 2005/06 consisted of the evaluation of (1) suitable crops and improved crop varieties; and (2) performance of improved cropping systems under various cultural practices. Crop cultivation in Tad Fa watershed can be classified into two categories: fruit trees and annual crops.

**Table 1. Analysis of soil samples taken from 0–15 cm depth at different positions along the toposequence in Tad Fa watershed in 1999.**

| Toposequence | Slope | pH | Organic matter (%) | Available P (mg $kg^{-1}$ soil) | Extractable K (mg $kg^{-1}$ soil) |
|---|---|---|---|---|---|
| Upper | Steep | 5.65 | 2.55 | 2.4 | 237 |
| Middle | Moderate | 5.50 | 2.17 | 2.2 | 259 |
| Lower | Mild | 5.67 | 2.67 | 2.2 | 313 |
| Normal limit | | 6.5–8.5 | 0.5–0.75 | 5–10 | 50–125 |

## Fruit Tree Cultivation

Tad Fa watershed farmers were encouraged to grow fruit trees to reduce erosion on the slopy lands. However, there were some orchards in Tad Fa watershed before 1999 and some fruit trees were planted during ADB-ICRISAT project (1999–2005). Normally, most fruit trees in Tad Fa watershed have been grown in the watershed under rainfed condition in the lower portion on the toposeqence (Fig. 2). Due to better moisture regime in the lower portion of the watershed, the survival of fruit trees was higher.

Four major species of fruit trees, viz, sweet tamarind (*Tamarindus indica*), mango (*Mangifera indica*), longan (*Euphoria longana*) and banana (*Musa* spp) existed in large areas in Tad Fa watershed. These species were grown both as sole and mixed crops (Table 2 and Fig. 3). Besides these species, jackfruit (*Artocarpus* spp), santol (*Sandoricum indicum*), custard apple (*Annona squamosa*) etc were also grown for household consumption.

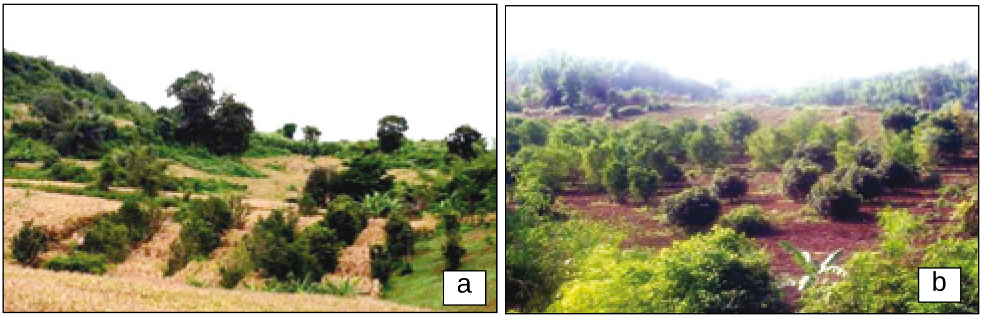


*Figure 2. Fruit tree orchards (a) with maize intercropping between fruit tree rows in lower topography; and (b) sole maize in upper topography at Tad Fa watershed.*

**Table 2. Fruit tree cultivation at Tad Fa watershed before and during project.**

| | Before project (1999) | | Additional planting during project (1999–2005) | |
|---|---|---|---|---|
| Fruit tree | No. of households | Area (ha) | No. of households | Area[1] (ha) |
| Sweet tamarind | 14 | 14.72 | 0 | 0 |
| Mango | 4 | 5.6 | 0 | 0 |
| Longan | 2 | 2.88 | 7 | 3.84 |
| Banana | 3 | 6.4 | 5 | 2.08 |
| Mixed orchard[2] | 8 | 13.92 | 0 | 0 |
| Litchi | 0 | 0 | 5 | 2.08 |
| Longkong | 0 | 0 | 2 | 0.64 |
| Plum | 0 | 0 | 25 (approx.) | 3 plants $hh^{-1}$ |
| Chinese chestnut | 0 | 0 | | 3 plants $hh^{-1}$ |
| Chinese persimmon | 0 | 0 | | 3 plants $hh^{-1}$ |
| Peach | 0 | 0 | | 2 plants $hh^{-1}$ |
| Macadamia | 0 | 0 | | 2 plants $hh^{-1}$ |
| Total | 31 | 43.52 | 48 | 8.64 |

1. hh = household.

2. Sweet tamarind, mango and longan.

The area under sweet tamarind did not increase due to the following problems: (1) production affected by unreliable seedling, (2) labor shortage for harvesting, and (3) fruit damaged by rains. However, the crop still is a good source of income to the farmers. Some farmers even made 17,800 bahts $ha^{-1}$ in 2005. Similarly,


*Figure 3. Four major fruit trees at Tad Fa watershed before 1999.*

mango production was influenced by (1) seasonal fluctuation in flowering and yield during different years, (2) low price of the fruit, (3) falling of young fruits by storms, (4) fruit fly damage, and (5) labor shortage for harvesting.

About 19 farmers planted longan, litchi (*Litchi chinensis*), mango and banana. Also, new fruit trees including longkong (*Lansium domesticum*), Chinese chestnut (*Castanea* spp), Chinese persimmon (*Prunus domestica*), peach (*Prunus persica*) and macadamia (*Macadamia tetraphylla*) were introduced for preliminary evaluation (Table 2). In 2005, among these crops banana gave satisfactory income of about 12,000 bahts $ha^{-1}$, but longan and litchi gave lower yield.

## Evaluation of Improved Cultivars of Annual Crops

Maize (*Zea mays*) commercial hybrid variety was grown as a major crop in Tad Fa watershed while other crops grown were ricebean *(Vigna umbellata),* cowpea (*Vigna unguiculata*) (black testa) and groundnut (*Arachis hypogaea*). Prior to the project, local cultivars of these three legumes were widely grown but their yield potential was low. Therefore, during 2002/03 to 2005/06, emphasis was on the evaluation of new high-yielding improved cultivars of groundnut, ricebean and black testa cowpea to improve the crop yield and water use efficiency. Groundnut is grown in Thailand in small areas in early rainy season for both local consumption and external markets. Ricebean and black testa cowpea were alternative crops grown late in the rainy season as the second crop in maize-based cropping systems. Most of the produce was usually sold in the market, but the prices always fluctuated over time.

**Groundnut:** Although groundnut is more important in Thailand than ricebean and black testa cowpea, it was planted in small areas in Tad Fa watershed during the first few years of project. The North and Northeast are two major groundnut-growing areas in Thailand. Some provinces of the North such as Lampang, Nan, Chiang Rai, Prayao, Chiang Mai and Phrae and in the Northeast as Loei, Kalasin, Nakhon Ratchasima, Udon Thani and Ubon Ratchathani are principal provinces for groundnut production (Table 3) (Field Crops Research Institute 2001).

Baseline survey at Tad Fa watershed in rainy season 1999 indicated that groundnut, normally, was sown in early rainy season in small areas by a small number of farmers. The local cultivar with red testa (valencia type) was sown and gave rather low pod yield with small seed size.

However, field evaluation of KK 5 with pink testa (Spanish type) from Khon Kaen Field Crops Research Center (KKFCRC) (1996) was taken up to compare with the local cultivar with red testa (valencia type) in June 2001 under no fertilizer application and hand weeding done only once. KK 5 gave 16 per cent higher pod yield and with larger seed size than the local cultivar, even though its shelling out-turn was lower than local variety. The duration of improved variety was also one week earlier (Table 4).

**Table 3. Groundnut production in Thailand during 2002/03–2004/05[1].**

| | Planted area ('000ha) | | | Production ('000 t) | | | Pod yield (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 2002/03 | 2003/04 | 2004/05 | 2002/03 | 2003/04 | 2004/05 | 2002/03 | 2003/04 | 2004/05 |
| North | 32.38 | 21.09 | 19.83 | 51.76 | 34.88 | 33.14 | 1,660 | 1,690 | 1,725 |
| Northeast | 27.39 | 19.82 | 18.71 | 41.08 | 31.17 | 29.02 | 1,570 | 1,630 | 1,610 |
| Central | 10.08 | 5.01 | 4.84 | 16.88 | 7.98 | 8.41 | 1,760 | 1,640 | 1,825 |
| South | 1.86 | 1.49 | 1.63 | 2.43 | 2.03 | 2.24 | 1,360 | 1,450 | 1,640 |
| Whole country | 71.72 | 47.42 | 45.01 | 112.1 | 76.1 | 72.8 | 1,630 | 1,650 | 1,675 |

1. Source: Office of Agricultural Economics (2004).

**Table 4. Groundnut cultivar yields and other yield attributes during rainy season in 1999 and 2001 at Tad Fa watershed.**

| Year | Cultivar | Harvested population ('000 plants $ha^{-1}$) | Pods $plant^{-1}$ | Dry pod yield (kg $ha^{-1}$) | Shelling (%) | 100-seed weight (g) |
|---|---|---|---|---|---|---|
| 1999 | Local | 152.8±7.6 | 7.1±0.11 | 1,710±390 | 61.8±3.03 | 27.25±2.28 |
| 2001 | Local | 182.4±32.2 | 14.3±2.80 | 1,980±370 | 60.0±0 | 37.03±0.74 |
| | KK 5 | 171.3±32.6 | 14.7±2.23 | 2,000±255 | 57.3±2.31 | 46.90±1.14 |

**Ricebean:** Ricebean is an important legume crop that is grown in the northwestern part of the Northeast region. About 90 per cent production is exported to Japan, Taiwan and Korea and about 10% is consumed in Thailand as ingredient for some Thai sweets through direct and modified cooking and also for some western foods such as dressing bun. The composition of ricebean grain is shown in Table 5.

**Table 5. Composition of ricebean grain[1].**

| Constituent of dry grain | Amount (per 100 g of grain) |
|---|---|
| Protein | 20.9 g |
| Fat | 0.9 g |
| Carbohydrate | 60.7 g |
| Fiber | 4.8 g |
| Ash | 4.2 g |
| Calcium | 200 mg |
| Phosphorus | 390 mg |
| Iron | 10.9 mg |
| Thiamin | 0.49 mg |
| Riboflavin | 0.21 mg |
| Niacin | 2.4 mg |

1. Source: Na Lampang (1990), Bhag Mal (1994), Toomsaen (1996).

Most ricebean growing areas are in Loei Province and small areas are in the provinces of the Northeast including Khon Kaen, Chaiyaphum and Udon Thani (Nongbua Lamphu) and in the North including Phitsanuloke, Tak, Petchabun and Chiang Rai. During 1999–2001, the areas under ricebean cultivation in Thailand was 3,568, 5,595 and 3,741 ha and production was 4,444, 6,209 and 3,726 t, respectively. Ricebean is a photosensitive crop and starts flowering in October and hence the crop should be planted not later than mid-August. Early sowing of the crop is preferred for better vegetative growth and yield.

Trials for the evaluation of L 28-0395 variety of ricebean to improve grain yield, were conducted in late rainy season during 2002/03 to 2004/05 under two cropping systems: sequential and relay. In sequential system, the sowing of ricebean was done after the maize was harvested in 2002/03 and 2003/04; and in relay system, the sowing of ricebean was done prior to the maturity of the maize crop in 2004/05. The L 28-0395 variety performed better compared to local cultivars at Tad Fa watershed. It gave 122 per cent, 124 per cent and 13 per cent higher grain yield compared to the local cultivar each year (2002/03 to 2005/06), respectively with larger seed size than the local cultivars (Table 6) and also its pods had delayed shattering.

In late rainy season 2005/06, at least 27 farmers grew L 28-0395 both as relay and sequential crops in maize-based cropping systems, and they achieved significantly higher grain yield (20 per cent) than late rainy season 2004/05 due to rainy season delay until November 2005. After harvest of the crops approximately 223 kg seeds of L 28-0395 were returned to the community as common seed stock for the next growing season in 2006.

**Black testa cowpea:** Black testa cowpea is another important leguminous crop grown in a small area of 1,488 ha in Thailand, mostly in North and the Northeast. A large amount of product is consumed in Thailand while a small proportion is exported to Japan, Malaysia, USA and England. In Thailand, grain cowpea (black testa only) is widely used. The composition of black testa cowpea grain is shown in Table 7.

**Table 6. Grain yield and 100-seed weight of two ricebean cultivars as the succeeding crop in maize-based cropping system at Tad Fa watershed in late rainy season during 2002/03-2005/06.**

| Crop year | Cropping System | Grain yield (kg ha$^{-1}$) | | 100-seed wt (g) | |
|---|---|---|---|---|---|
| | | Local | L28-0395 | Local | L28-0395 |
| 2002/03 | Sequential | 310 | 680 | NA[1] | NA |
| 2003/04 | Sequential | 160 | 370 | NA | NA |
| 2004/05 | Relay | 460 | 520 | 9.60 | 10.50 |
| 2005/06 | Relay and sequential | 890 | 1,070 | 10.12 | 10.77 |

1. NA = Data not available.

Prior to the project, the local cultivars of three legumes were widely grown but their yield potential was low. In order to increase productivity and to improve water use efficiency, high-yielding improved cultivars of these three legume crops were introduced and evaluated during the project 2001/02 to 2004/05 (Fig. 4).

**Table 7. Composition of black testa cowpea grain.**

| Constituent of dry grain | Weight (per 100g of grain) |
|---|---|
| Protein | 23.4 g |
| Carbohydrate | 56.8 g |
| Fat | 1.3 g |
| Fiber | 3.9 g |
| Ash | 3.6 g |
| Lysine | 6.6 mg |
| Cysteine | 0.9 mg |
| Methionine | 0.9 mg |
| Histidine | 3.3 mg |
| Threonine | 4.1 mg |
| Tryptophan | 0.9 mg |

Source: Ubon Ratchathani Field Crops Research Institute (2000).

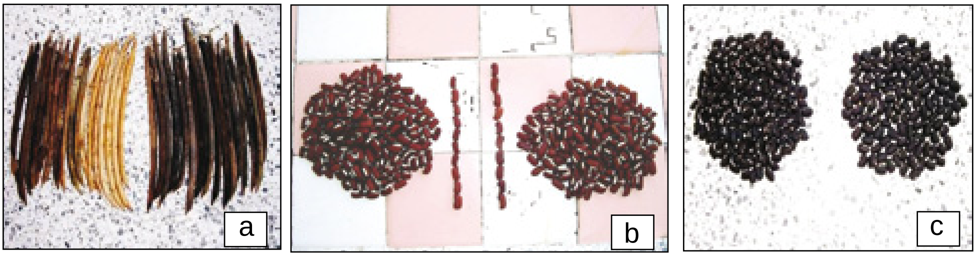


*Figure 4. Pod and seed performance of two legumes: (a) and (b) ricebean cultivars as Local (left) and L 28-0395 (right); and (c) black testa cowpea cultivars as Local (left) and KKU 305 (right).*

The trials for the evaluation of KKU 305 variety of black testa cowpea to improve grain yield were conducted in late rainy season during 2002/03 to 2004/05 and CP 4-2-3-1 variety from International Rice Research Institute (IRRI) and IT 82E-9 from International Institute of Tropical Agriculture (IITA) were also included in the evaluation in 2004/05. They were grown as sequential crops after maize in mildly slopy areas. Low and erratic rainfall and rapid soil water depletion resulted in poor growth and grain yield of ricebean and black testa cowpea; however, the results indicated that KKU 305 was a superior cultivar compared to the local cultivar. KKU 305 variety gave 79 per cent, 142 per cent and 34 per cent of grain yield, respectively during 2002/03, 2003/04 and 2004/05 compared to the local cultivars. CP 4-2-3-1 and IT 82E 9 varieties gave lower grain yield than the local cultivar in 2004/05 (Table 8). Besides higher grain yield, KKU 305 variety had larger seeds than the local cultivar, and also showed delayed shattering of the pods.

**Table 8. Grain yield and 100-seed weight of four black testa cowpea cultivars as the sequential crop in maize-based cropping system at Tad Fa watershed in late rainy season 2002/03-2005/06.**

| | Grain yield (kg ha$^{-1}$) | | | | 100-seed weight (g) | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Local | KKU 305 | CP 4-2-3-1 | IT 82E-9 | Local | KKU 305 | CP 4-2-3-1 | IT 82E-9 |
| 2002/03 | 440 | 790 | NA[1] | NA | NA | NA | NA | NA |
| 2003/04 | 180 | 440 | NA | NA | NA | NA | NA | NA |
| 2004/05 | 280 | 370 | 171 | 230 | 11.78 | 16.08 | 9.68 | 13.72 |
| 2005/06 | 800 | 960 | NA | NA | 15.34 | 19.42 | NA | NA |

1. NA = Data not available.

In late rainy season 2005/06, at least 17 farmers grew KKU 305 as sequential crop after maize in mildly slopy areas and achieved significantly higher grain yield (20%) than late rainy season 2004/05 due to the late withdrawal of rainy season until November 2005.

After harvesting, approximately 110 kg seeds of KKU 305 were returned back to the community as common seed stock for the next growing season in 2006. Some of the characteristics of the three cultivars of black testa cowpea are:

KKU 305: Promising line from Khon Kaen University, large seed, drought tolerant, 50% flowering at 33-37 DAE, pod length $\simeq$ 15-20 cm, seeds pod$^{-1}$ $\simeq$ 10-12 seeds, 1$^{st}$ harvesting $\simeq$ 65-72 DAE, 100-seed wt $\simeq$ 17.7g, dry grain yield ~ 1,125-1,250 kg ha$^{-1}$, shelling $\simeq$ 78%.

CP 4-2-3-1: Introduced cultivar from International Rice Research Institute (IRRI), The Philippines, semi-indeterminate, 50% flowering at 35-38 DAE, pod length $\simeq$ 15-20 cm, 1$^{st}$ harvesting $\simeq$ 70-75 DAE, 100-seed wt $\simeq$ 14.5-15.5 g, dry grain yield ~ 750-937.5 kg ha$^{-1}$.

IT 82E-9: Introduced cultivar from International Institute of Tropical Agriculture (IITA), Nigeria, 50% flowering at 33-37 DAE, pod length $\simeq$ 15-20 cm, 1$^{st}$ harvesting $\simeq$ 65-72 DAE, 100-seed wt $\simeq$ 13.5-15.0 g, dry grain yield $\simeq$ 937-1,250 kg ha$^{-1}$.

## Improved Cultivation Practice

Maize-based cropping system is predominant at Tad Fa watershed and maize is grown both in early rainy season as preceding crop and in the late rainy season as the succeeding crop. Maize planting in the early part of rainy season is a common feature in order to harness maximum benefit from the succeeding crops grown preceding maize cultivation due to better moisture availability in the soil that allows cultivation of two crops. Generally, maize yield has been showing a declining trend due to continuous cultivation compounded with declining soil fertility and decreased water-holding capacity of soil as a result of severe soil erosion. To address some of these problems, an improved cultural practice of planting maize across the slope and incorporation of maize stover into soil to improve soil organic matter and other soil properties was adopted.

## Cultivation of Maize Across Slope/on Contour

Generally, cultivation of maize in slopy areas by using heavy machinery induces severe erosion and also land slides (Fig. 5). Cultivation of maize across the slope gave a marginal increase (3%) over sowing along the slope, while it responded significantly (average of 48% along the toposequence) with fertilizer application (141 kg $ha^{-1}$ of 16-20-0 as basal dose) (Table 9). The grain yield of maize in lower toposequence was higher compared to upper and middle fields on toposequence (Table 10).


*Figure 5. Sloping areas used for maize cultivation: (a) evident land slide and high soil erosion after soil tillage by heavy machinery; and (b) small area of maize in no-tillage soil nearby Tad Fa watershed in early rainy season 2006.*

**Table 9. Effects of two sowing methods on the performance of maize at Tad Fa watershed in early rainy season 2000.**

| Sowing method[1] | Harvested pop. ('000 plants $ha^{-1}$) | Plant height (cm) | Ears $plant^{-1}$ | Grain yield (kg $ha^{-1}$) |
|---|---|---|---|---|
| Across slope | 30.2+4.7 | 204.6+21.1 | 1.3+0.20 | 5,030.2+1,186.5 |
| Up-down | 32.8+5.9 | 196.4+7.8 | 1.2+0.18 | 4,870.8+600.0 |

1. Sown by machines.

**Table 10. Average effects of fertilizer application on three toposequence positions on maize performance at Tad Fa watershed in early rainy season 2004[1].**

| Topo-sequence | Fertilizer application | Harvested population ('000 plants $ha^{-1}$) | Plant height (cm) | Ears $plant^{-1}$ | Threshing (%) | Grain yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|
| Upper | No fertilizer + up-down cultivation | 49.94±16.62 | 89.8±25.7 | 0.66±0.25 | 77.37±12.05 | 1,120.1±956.8 |
| | Fertilizer + across slope cultivation | 53.89±13.96 | 127.1±18.7 | 0.72±0.25 | 84.2±0.36 | 2,370.2±574.3 |
| Middle | No fertilizer + up-down cultivation | 64.80±28.16 | 99.0±13.2 | 0.72±0.17 | 82.77±2.38 | 1,480.0±510.1 |
| | Fertilizer + across slope cultivation | 62.00±9.10 | 145.4±19.2 | 0.83±0.11 | 83.47±0.67 | 2,940.3±208.0 |
| Lower | No fertilizer + up-down cultivation | 62.39±28.17 | 104.0±16.2 | 0.68±0.09 | 83.60±0.30 | 1,390.2±548.1 |
| | Fertilizer + across slope cultivation | 61.85±15.20 | 144.2±8.2 | 0.85±0.11 | 83.87±1.17 | 3,410.8±1,104.7 |

1. Average from three farmers' fields that were sown manually in mid May 2004. About 140.6 kg of 16-20-0 fertilizer was applied basally.

Some of the beneficial cultivation practices were contour planting and incorporation of maize stover (Fig. 6).

## Ricebean as a Relay or Sequential Crop with Maize

Ricebean is a popular legume crop grown in sloping land ecologies of Northeast Thailand. In about 40% of the maize growing area, ricebean is relay planted

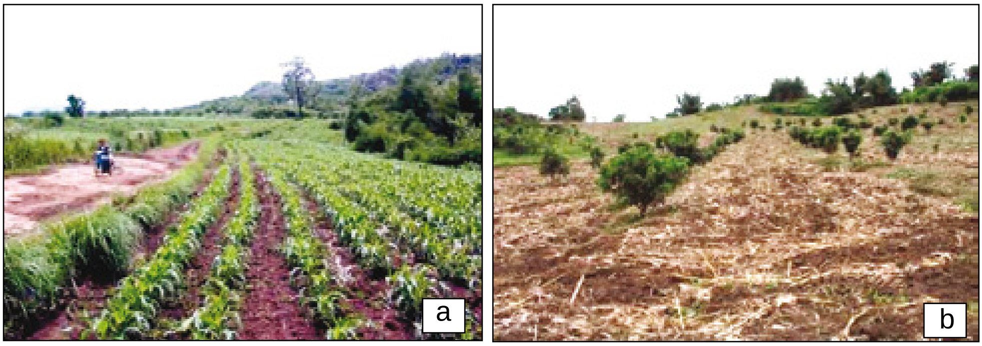

*Figure 6. Beneficial practices of soil-water conservation: (a) contour planting; and (b) incorporating maize stovers.*

during July to August. It is sown in the standing crop of maize at the time of flowering. Since it is sown without any land preparation (unlike sequential planting), relay planting is a soil conservation efficient system. Ricebean is a shade tolerant, climbing type, and a photosensitive crop (Fig. 7). On steeper slope (>15 per cent), the yield (970 kg $ha^{-1}$) is 25–30 per cent less compared to moderate slope (5–15 per cent) (1270 kg $ha^{-1}$) or mild slope (2–5 per cent) (1360 kg $ha^{-1}$). Poor soil as well as less amount of soil moisture may be responsible for low yields on steep slopes. Relay cropping 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. Sometimes they are not able to plant the second crop due to late onset of monsoon and late planting of first maize crop.

Ricebean can also be grown as a sequential crop after harvesting of maize in August to September. Flowering in ricebean starts in October and the crop matures in late December as it is photosensitive. So ricebean should not be

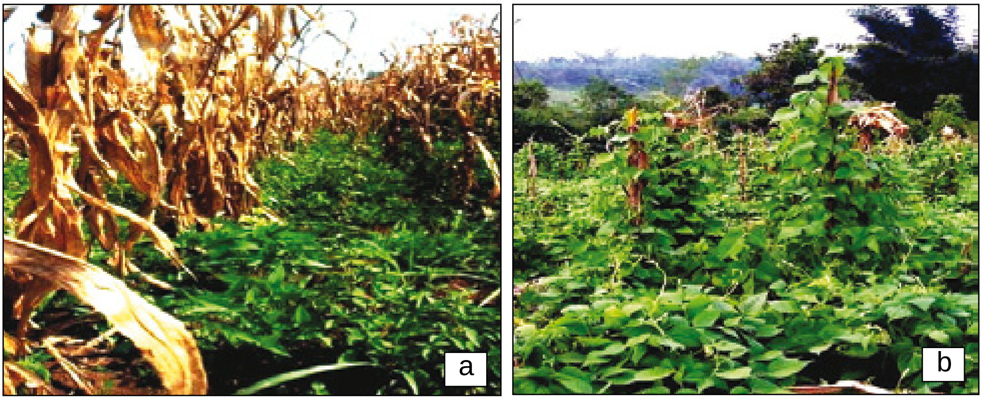

*Figure 7. Characteristics of ricebean: (a) shade tolerant; and (b) climbing type.*

sown later than mid August. Sowing ricebean as relay crop with maize showed better results than as a sequential crop. The farmers are convinced to sow ricebean on steep slopy areas between maize rows without tillage of the soil and use the maize stover for mulching (Fig. 8 and Table 11).

*Figure 8. Relay cropping of ricebean after cutting down maize stover in moderate slope area.*

Ricebean as relay crop in maize crop rows gets longer duration of growth than in sequential system. Trials on relay and sequential cropping were conducted in Tad Fa watershed. The local ricebean cultivar gave higher grain yield (77 per cent increase) in relay system than in sequential system in late rainy season 2003/04 (Table 12). During early rainy season of 2002, improved variety of ricebean (L 28-0395) in relay system gave 110% higher yield than under the sequential system, while during 2003 with local variety, the increase in crop yield in relay system was 67% compared to the sequential system (Table 12). However, sowing ricebean as relay crop with maize had some limitations like increased requirement for labor for seeding and cutting down the maize stover.

**Table 11. Local cultivar of ricebean sown as relay crop with maize and as sequential crop after maize in Tad Fa Watershed in late rainy season 2003/04.**

| Component | Relay crop | Sequential crop |
|---|---|---|
| No. of farms | 7 | 12 |
| Planted area (ha) | 22 | 16 |
| Average grain yield (kg $ha^{-1}$) | 380±251.5 | 220±226.9 |

**Table 12. Improved method of cultivation of ricebean at Tad Fa watershed in early rainy season 2002 and 2003.**

| Year | No. of plots | Treatment | Grain yield (kg $ha^{-1}$) |
|---|---|---|---|
| 2002 | 2[1] | Relay (L 28-0395) | 1,370.0±486.2 |
| | | After maize (L 28-0395) | 650.1±490.6 |
| 2003 | 7[2] | Relay (Local cultivar) | 380.0±251.5 |
| | 8[2] | After maize (Local cultivar) | 180.9±228.3 |

1. Field evaluation under farmers' conditions.
2. Yield evaluation by sampling crop cut individually.

## Black Testa Cowpea as Sequential Crop with Maize and Incorporation of Maize Stover as Mulch

Black testa cowpea is a photo-insensitive, short-duration crop, which matures in less than three months. At Tad Fa watershed, it is usually grown as sequential crop after harvest of maize and the maize stover is incorporated (Fig. 9). Cowpea is sown by broadcasting the seed without tillage. This system of cultivation is suitable for the short period of the remaining crop season under limited residual soil moisture. However, it is recommended only on mild slopy areas where soil erosion is not a serious problem.

## Recommendation for Better Cropping System

Even with moderately sloped lands in Tad Fa watershed, soil is prone to erosion under high intensity of crop cultivation. Maize is still a major crop grown in the early rainy season by using heavy machines that induces severe erosion. However, erosion could be reduced through effective cultivation practices and crop management. Under the Participatory Watershed Management for Reducing Poverty and Land Degradation Project in Thailand at Tad Fa watershed, research activities were undertaken on the improvement of groundnut, ricebean and black testa cowpea and maize-based crop management systems were quite effective for increasing the productivity and maintaining soil fertility, while reducing the degradation of soil and water resources. Some recommendations for improved cropping systems are given below:

- **Improved cultivars and their characteristics of groundnut, ricebean and black testa cowpea**

Some of the promising improved cultivars of groundnut, ricebean and black testa cowpea recommended for Tad Fa watershed are given in Table 13.

*Figure 9. Black testa cowpea grown as sequential crop: (a) after maize in mild slope areas; (b) after maize between fruit tree rows; and (c) after maize between fruit tree rows (maturing stage).*

- **Improved cropping systems through maize-based systems**

Plantation of fruit trees is a long-lasting suitable technology for erosion control, while sowing groundnut, ricebean and black testa cowpea through suitable cultivation is effective in reducing erosion on any degree of slope as shown in the flow chart of cropping systems (Fig. 10).

**Moderate to steep slope areas:** Severe erosion is a common occurrence after heavy rainfall in tilled soil of moderate to steep slopes. Therefore, alternatives to be used in decreasing erosion in this area are: (1) zero tillage after planting fruit trees; and (2) manually relay sowing of ricebean between maize rows prior to its maturity in late rainy season. However, maize sowing in early rainy season, if possible, should be done under no-tillage condition.

**Table 13. Improved cultivars of groundnut, ricebean and black testa cowpea recommended for Tad Fa watershed.**

| Crop | Cultivar | Characteristics |
|---|---|---|
| Groundnut | KK 5 | Higher yield, pink testa for both fresh and dry pod utilization and larger seed |
| Ricebean | L 28-0395 | Higher yield, delayed shattering and larger seed |
| Black testa cowpea | KKU 305 | Higher yield, delayed shattering, larger seed and tolerance to mosaic virus |

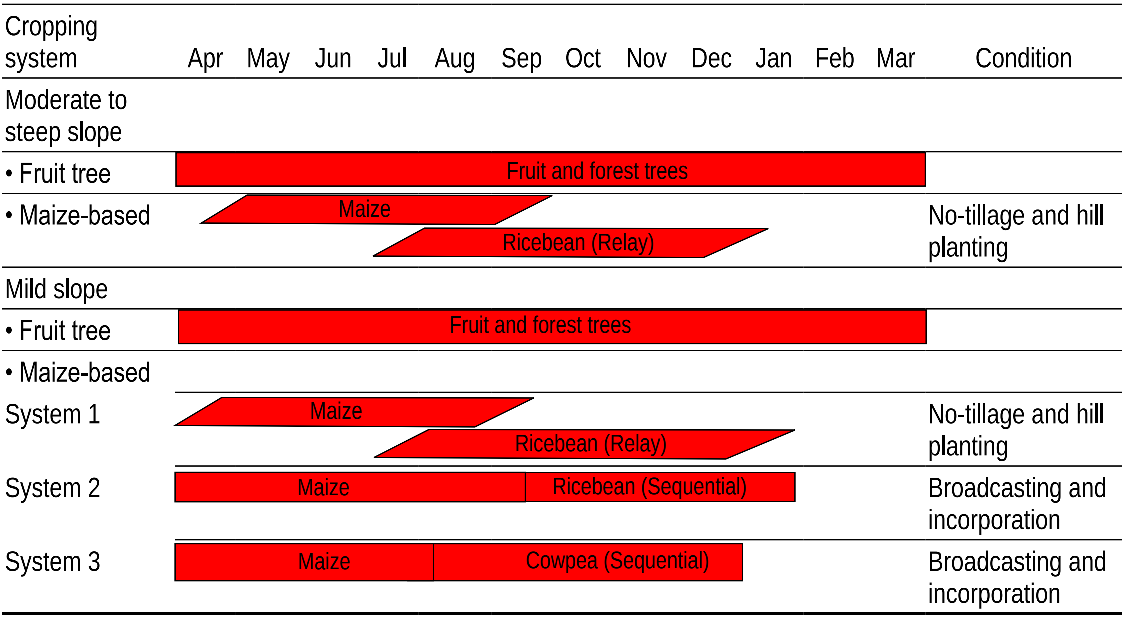


*Figure 10. Flow chart of improved cropping systems at Tad Fa watershed and recommendation for legumes.*

**Mild slope areas:** Erosion also can occur after heavy rainfall in tilled soil of mild slope areas. Therefore, alternatives in decreasing erosion in this area are: (1) sowing maize across slope in early rainy season; and (2) sequential sowing of ricebean or black testa cowpea by broadcasting prior to incorporation of maize stover in late rainy season.

## Wang Chai Watershed

Wang Chai watershed has undulating areas that can be classified into: (1) upper upland, (2) lower upland, (3) upper paddy fields, and (4) lower paddy fields (Fig. 11).


*Figure 11. Cross section of undulating topography at Wang Chai watershed.*

Paddy is a major crop grown under rainfed and partially irrigated conditions. The paddy fields may be classified into two zones: downstream and upstream. Downstream covers lower toposequence of the watershed including the areas along Lam Huay Bong stream where soils are sandy loam to loam and irrigation is available. Upstream covers the upper toposequence of the watershed with sandy loam soils and this upstream area is rainfed. Most soils are loamy sand to sandy loam. The soils in downstream are more fertile than the soils in upstream (Table 14).

**Table 14. Soil properties on toposequence at Wang Chai watershed, 2004/05[1].**

| Location on toposequence[1] | Texture class | pH | Organic matter (%) | Available P (mg $kg^{-1}$ soil) | Extractable K (mg $kg^{-1}$ soil) | Extractable Ca (mg $kg^{-1}$ soil) |
|---|---|---|---|---|---|---|
| Downstream | Sandy loam to loam | 5.2 | 0.95 | 12.8 | 110.0 | 373.3 |
| Upstream | Sandy loam | 6.4 | 0.66 | 9.6 | 48.4 | 489.9 |

1. Average of data from six sites in downstream and from four sites in upstream.

Normally, rice is cultivated in the rainy season and soybean is grown under irrigated conditions along the Lam Huai Bong stream in the dry season. Most rainfed areas are left fallow in dry season due to scarcity of water and low soil fertility in the upstream areas. Crop growth and yield in the dry season are affected by water shortage (Fig. 12). The agronomic interventions at Wang Chai watershed during 2003/04-2005/06 were improved crop varieties and improved cropping systems with better cultural practices.

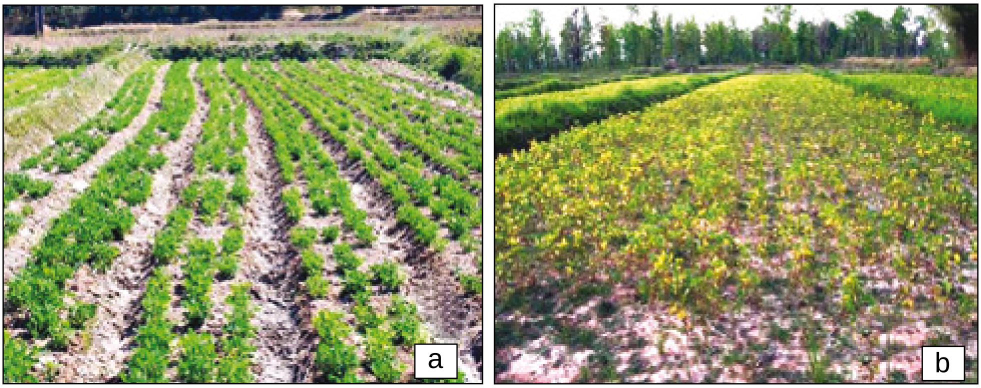


*Figure 12. Performance of crops under harsh condition: (a) low fertile sandy soil in groundnut plot; and (b) water shortage in soybean plot.*

## Improved Crop Cultivars

The existing field crops in Wang Chai watershed are soybean, groundnut and maize. Normally, local cultivars of these crops are grown. The local cultivars usually give low yield. However, during 2003/04 to 2005/06 project period, the focus was on improved cultivars of soybean, groundnut and black testa cowpea.

**Soybean:** Soybean is an important leguminous crop in Thailand and the area planted to the crop was 422,000 ha and production was about 539,000 t during 1988–1991. However, after 1999, the area under soybean decreased due to low profits and erratic rainfall at the crop harvesting stage (Table 15). About 85% of annual production is used for vegetable oil extraction and soybean cake is used as animal feed. Twelve per cent soybean is used as source of protein in the diet of Thai people and 3% is used as seed. Annual production at the end of the 20th century was only 20–30% of domestic demand and Thailand imported about 1.0–1.5 million t of soybean cake during 1978–1998.

Soybean is a major crop in Wang Chai watershed in dry season and SJ 5 was the most extensively sown variety. Normally, soybean is widely grown in the irrigated areas on both sides of Lam Huai Bong stream where full irrigation (4–5 times) by pumping water is done. The evaluation of high-yielding cultivar of soybean "Khon Kaen (KK)" from KKFCRC was taken up in 2004/05. The trial plots were laid out in randomized complete block design (RCBD) with three replications. Soybean was sown in mid December 2004. Seeds were treated with *Rhizobium* and 93.75 kg $ha^{-1}$ of complex fertilizer (16:16:8) was applied. KK gave higher grain yield (19%) and larger seed compared to SJ 5 in the dry season 2004/05 (Table 16 and Fig. 13). The data showed that KK is profitable, and farmers, particularly in downstream areas with irrigation facility, cultivated it on more than 16 ha during dry season of 2005/06.

**Groundnut:** Normally, only a few farmers grow groundnut in the dry season and common cultivars are local cultivars and Tainan 9. Field evaluation of four groundnut cultivars in farmers' fields under full irrigation (four to five times) along the Lam Huai Bong stream was conducted in the dry season 2004/05. New introduced cultivars Khon Kaen 5 (KK 5), Khon Kaen 6 (KK 6) and Khon Kaen (KK) from KKFCRC were compared with the local cultivar Tainan 9 for their performances (Fig. 14).

**Table 15. Soybean production in Thailand during 2002/03–2004/05[1].**

| | Planted area ('000 ha) | | | Production ('000 t) | | | Grain yield (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 2002/03 | 2003/04 | 2004/05 | 2002/03 | 2003/04 | 2004/05 | 2002/03 | 2003/04 | 2004/05 |
| North | 127 | 104 | 110 | 178 | 154 | 162 | 1,450 | 1,510 | 1,490 |
| Northeast | 35 | 320 | 35 | 48 | 48 | 48 | 1,406 | 1,510 | 1,410 |
| Central | 18 | 16 | 16 | 34 | 29 | 29 | 1,360 | 1,450 | 1,480 |
| Country average | 180 | 153 | 162 | 260 | 230 | 240 | 1,490 | 1,540 | 1,510 |

1. Source: Office of Agricultural Economics (2004).


*Figure 13. Comparison of two soybean cultivars: (a) field performance of KK (left) and SJ 5 (right); and (b) seed of SJ 5 (left) and KK (right).*

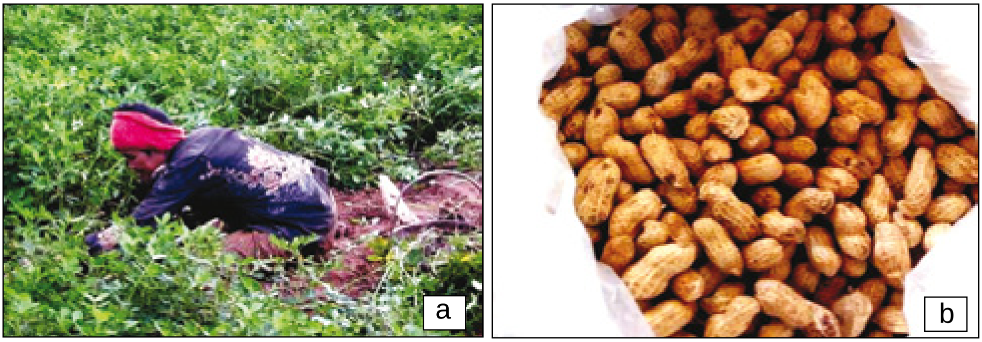


*Figure 14. Performance of two suitable groundnut cultivars for Wang Chai watershed: (a) KK 6 at harvest; and (b) dry pods of KK 5.*

**Table 16. Yield and agronomic traits of two soybean cultivars in paddy fields in Wang Chai watershed[1].**

| Cultivar | Duration (days) | Harvested population ('000 plants ha$^{-1}$) | Height (cm) | Nodes plant$^{-1}$ | Pods plant$^{-1}$ | Seeds plant$^{-1}$ | Grain yield (kg ha$^{-1}$) | 100-seed weight (g) |
|---|---|---|---|---|---|---|---|---|
| KK | 100 | 502.8$^{b}$ | 55.6 | 11.9$^{a}$ | 18.7$^{a}$ | 43.9$^{b}$ | 1,960$^{a}$ | 14.75$^{a}$ |
| SJ 5 | 95 | 997.4$^{a}$ | 55.2 | 9.8$^{b}$ | 13.0$^{b}$ | 27.4$^{b}$ | 1,640$^{b}$ | 12.80$^{b}$ |
| F-test | | ** | NS | ** | * | ** | ** | * |
| CV (%) | | 24.91 | 6.20 | 4.96 | 23.04 | 20.99 | 9.42 | 9.27 |

1. NS = Not significant; * = Significant at $P$ <0.05; ** = Significant at $P$ <0.01; figures followed by the same letter in a column are not significantly different.

The cultivars KK 5 and KK 6 performed better in terms of pod yield (26% and 30% respectively) and shelling out-turn over local variety (Table 17). KK did not show encouraging results even when compared with local cultivar. Farmers gained about 48.8% and 31.5% by selling fresh pods (11.11 bahts kg$^{-1}$) of KK 5 and KK 6 respectively, ie, about 20,554 and 13,254 bahts ha$^{-1}$ higher compared to the local cultivar. The total return from the local cultivar was 42,107 bahts ha$^{-1}$. The soil properties of trial fields are given in Table 18. Some of the major characteristics of KK 5 and KK 6 are given in Table 19.

**Table 17. Comparison of three groundnut cultivars with the local cultivar at five sites in Wang Chai watershed in the dry season 2004/05[1].**

| Cultivar[2] | Duration (days) | Harvested population ('000 plants ha$^{-1}$) | Pod yield (kg ha$^{-1}$) | | Shelling out-turn (%) | 100-seed weight (g) | Bud necrosis virus[3] (%) |
|---|---|---|---|---|---|---|---|
| | | | Fresh | Dry | | | |
| KK 5 | 110 | 247.9$^{b}$ | 4,480$^{ab}$ | 1,959$^{ab}$ | 67$^{a}$ | 51.0$^{b}$ | 17$^{a}$ |
| KK 6 | 120 | 231.5$^{b}$ | 5,180$^{a}$ | 2,017$^{a}$ | 67$^{a}$ | 84.4$^{a}$ | 2$^{b}$ |
| KK | 100 | 266.9$^{a}$ | 3,510$^{b}$ | 1,426$^{c}$ | 62$^{b}$ | 39.9$^{b}$ | 22$^{a}$ |
| Local | 110 | 180.0$^{c}$ | 3,570$^{b}$ | 1,554$^{bc}$ | 66$^{a}$ | 43.7$^{b}$ | 23$^{a}$ |
| CV (%) | | 13.09 | 14.79 | 18.39 | 3.83 | 10.8 | 43 |
| F-test | | ** | ** | * | ** | ** | ** |

1. * = Significant at $P$ <0.05; ** = Significant at $P$ <0.01; figures followed by the same letter in a column are not significantly different.
2. Sowing date: December 2004; Fertilizer: Side dressing of 12-24-12 ~ 162.5 kg ha$^{-1}$ at 1st flowering; Irrigation: (4–5 times).
3. Observations recorded at harvest.

**Table 18. Soil properties of experimental fields at Wang Chai watershed.**

| Site | Farmers | Texture | pH | Organic matter (%) | Available P (mg kg$^{-1}$ soil) | Extractable K (mg kg$^{-1}$ soil) | Extractable Ca (mg kg$^{-1}$ soil) |
|---|---|---|---|---|---|---|---|
| 1 | Mr. Somjit | Loam | 5.1 | 1.039 | 12.5 | 83.85 | 431.7 |
| 2 | Mr. Boonhom | Sandy | 5.1 | 0.863 | 21.9 | 144.9 | 360.6 |
| 3 | Mr. Wichian | Loam | 5.1 | 1.175 | 8.2 | 96.13 | 262.0 |
| 4 | Mrs. Sa-Ngat | Loam | 6.1 | 0.772 | 8.8 | 87.02 | 461.3 |

**Table 19. Positive and negative attributes of the two newly introduced groundnut cultivars as compared to the local cultivars.**

| Cultivar | Advantage | Disadvantage |
|---|---|---|
| KK 5 | Large seed | - |
| KK 6 | Large seed | Duration 10 days more than KK 5 |
| | Resistant to bud necrosis virus (more than KK 5) | About 2 months of seed dormancy |

**Black testa cowpea:** Black testa cowpea was introduced as a new crop in Wang Chai watershed. Three black testa cowpea cultivars, viz, CP 4-2-3-1, IT 82E-9 and KKU 305 were evaluated under both residual soil moisture and partially irrigated condition. The three cultivars were grown after paddy rice in the dry season 2004/05. Table 20 reveals that IT 82E-9 performed better than the other two cultivars (CP 4-2-3-1 and KKU 305) grown under residual moisture condition, while under partial irrigated condition, no specific advantage was found with all the three cultivars (Fig. 15).

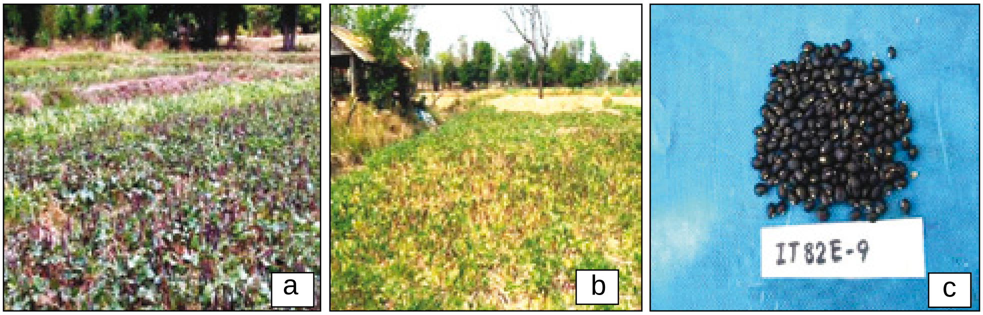


*Figure 15. Performance of black testa cowpea IT 82E-9 at Wang Chai watershed in dry season: (a) under partial irrigation (2–3 times); (b) seed under residual soil moisture; and (c) seed.*

**Table 20. Grain yield of three black testa cowpea cultivars under two different conditions in paddy fields in Wang Chai watershed in dry season 2004/05[1].**

| | | Residual soil moisture | | | Partial irrigation (2-3 times) | | |
|---|---|---|---|---|---|---|---|
| Cultivar | Duration (days) | Harvested population ('000 plants $ha^{-1}$) | Grain yield (kg $ha^{-1}$) | 100-seed weight (g) | Harvested population ('000 plants $ha^{-1}$) | Grain yield (kg $ha^{-1}$) | 100-seed weight (g) |
| CP 4-2-3-1 | 76–84 | 179.6±117.9 | 460±10.7 | 12.8±1.24 | 162.0±104.6 | 520±21.9 | 13.8±1.20 |
| IT 82E-9 | 76–84 | 122.3±18.7 | 570±162.0 | 15.1±0.28 | 145.3±17.9 | 490±53.0 | 13.9±1.65 |
| KKU 305 | 76–89 | 180.4±20.8 | 490±6.1 | 19.0±1.90 | 176.2±22.4 | 480±22.7 | 19.8±1.73 |

1. Fertilizer: Basal of 12-24-12 ~ 125 kg $ha^{-1}$.

## Improved Cropping Systems

The improved cropping systems were focused on the evaluation and expansion of the three legume crops soybean, groundnut and black testa cowpea in: (1) paddy fields in dry season under rainfed and partial irrigation; and (2) uplands in dry season.

### Responses of Three Soybean Cultivars with Supplemental Irrigation

Three soybean cultivars (viz, KK, SJ 5 and CM 2) in paddy fields in dry season with 1–2 irrigations at monthly interval after sowing were evaluated. With one irrigation, CM 2 gave the highest grain yield (13.7% more compared to KK and 20.0% higher compared to SJ 5). Mean grain yield was higher in treatment with two irrigations than in treatment one irrigation (Table 21). More frequency of irrigation increased plant height, nodes and seed weight but decreased green seed percentage (Table 22). The soil properties of trial fields are shown in Table 23.

**Table 21. Effect of irrigation on yield of three cultivars of soybean in paddy field during the dry season 2004/05.**

| | | Yield (kg $ha^{-1}$) | | |
|---|---|---|---|---|
| Cultivar | Crop duration (days after sowing) | One irrigation | Two irrigations | Yield increase (%) |
| CM 2 | 83 | 660 | 870 | 31.3 |
| KK | 95 | 580 | 860 | 47.5 |
| SJ 5 | 91 | 550 | 870 | 57.5 |
| Average | | 600 | 870 | 44.6 |

**Table 22. Comparison of two levels of water application treatments to soybean crop[1].**

| Irrigation[2] | Harvested population ('000 plants ha$^{-1}$) | Height (cm) | Nodes plant$^{-1}$ | Pods plant$^{-1}$ | Grain yield (kg ha$^{-1}$) | 100-seed weight (g) | Green seed[3] (%) |
|---|---|---|---|---|---|---|---|
| One | 230.5±51.3 | 35.8±3.6 | 10.4±0.2 | 16.0±3.4 | 600±57.2 | 10.8±0.52 | 17.9±10.4 |
| Two | 241.1±66.9 | 38.6±4.5 | 10.7±0.5 | 20.0±3.3 | 870.7±5.5 | 12.2±0.51 | 10.7±8.6 |

1. Fertilizer: Basal of 12-24-12 at 156.25 kg ha$^{-1}$.
2. One month interval after sowing.
3. By weight (visual separation).

**Table 23. Soil properties of trial fields.**

| Texture | pH | Organic matter (%) | Available P (mg kg$^{-1}$ soil) | Extractable K (mg kg$^{-1}$ soil) | Extractable Ca (mg kg$^{-1}$ soil) |
|---|---|---|---|---|---|
| Sandy loam | 6.3 | 0.737 | 8.8 | 28.51 | 310.7 |

## Rice Stubble Management in Soybean Cultivation in Paddy Fields

Two experiments with soybean were conducted at two different sites during dry season of 2003/04 and 2004/05. The details of the experiments were as follows:

**Evaluation of soybean cultivation in the dry season after rice:** This experiment was conducted in paddy fields in Phu Kiew District, Chaiyaphum province in dry season 2003/04. The trial consisted of two sub-experiments with two sowing dates (9 and 25 December 2003) in nine lateral areas.

**Experiment design for each sub-experiment:** Split plot in RCB with three replications

**Main plots:** Three soybean cultivars [Chiang Mai 2 (CM 2), Khon Kaen (KK) and SJ 5]

**Sub-plots:** Soybean stand within 1 m row (9, 12, 15, 18, and 21 plants after thinning)

**General practices:** Broadcasted urea (46% N) 62.5 kg ha$^{-1}$ then incorporated rice stubble before sowing

**Fertilizer:** Seed inoculation with *Bradyrhizobium japonicum* and basal application of fertilizer 12-24-12 (156.25kg ha$^{-1}$) at sowing

Non-irrigated (residual soil moisture)

Stubble of rice cultivar RD 6 (sticky rice) was incorporated in rainy season before sowing soybean cultivar: 3,226 kg and 5,920 kg of stubble dry weight (sun-dried) ha$^{-1}$ before sowing date 1 and date 2, respectively. Soil properties are given in Table 24. Soil moisture trends in the trials are shown in Figure 16. Sowing date had a significant effect on crop yield (about 100% in date 1 vs date 2), and yield variation was not significantly different among the three cultivars and five levels of plant populations (Tables 25 and 26).

**Table 24. Soil analysis of surface soil (0–15 cm) in Phu Kiew in dry season 2003/04.**

| Sowing | pH | Organic matter (%) | Available P (mg kg$^{-1}$ soil) | Extractable K (mg kg$^{-1}$ soil) | Extractable Ca (mg kg$^{-1}$ soil) |
|---|---|---|---|---|---|
| Date 1 | 4.9 | 0.62 | 1.8 | 21.0 | 117.0 |
| Date 2 | 5.1 | 0.58 | 1.7 | 21.0 | 147.0 |

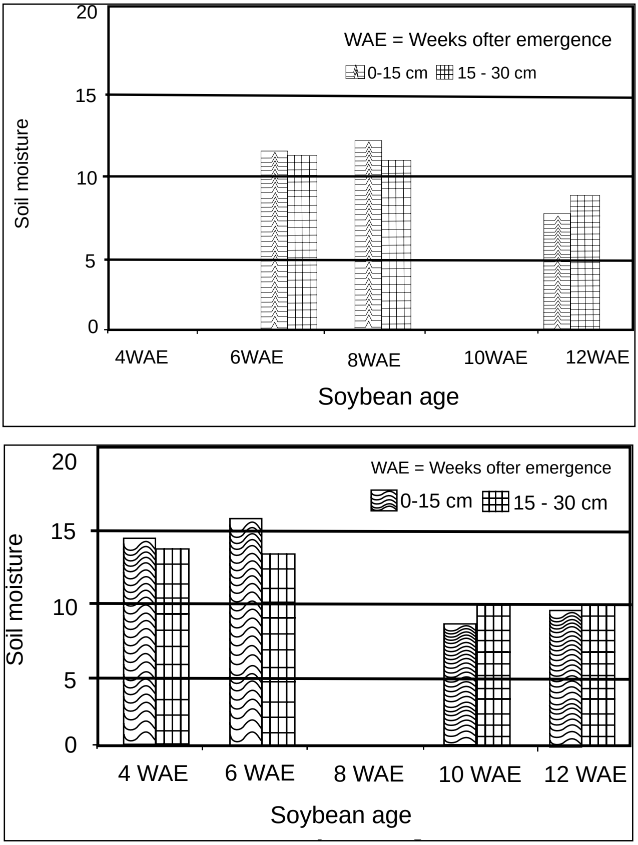


*Figure 16. Soil moisture (%) at 0–15 cm and 15–30 cm in dry season 2003/04: (top) experiment 1; and (bottom) experiment 2.*

**Table 25. Effect of three soybean cultivars and five population densities on grain yield and seed characters in two sowing dates at Phu Kiew district in dry season 2003/04[1].**

| | Sowing date 1 | | | | Sowing date 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Harvested population | Yield | | | Harvested population | Yield | | |
| Treatment | ('000 plants ha$^{-1}$) | (kg ha$^{-1}$) | Green seed[2] (%) | Hard seed[3] (%) | ('000 plants ha$^{-1}$) | (kg ha$^{-1}$) | Green seed[2] (%) | Hard seed[3] (%) |
| Cultivar (A) | | | | | | | | |
| SJ 5 | 492.7 | 600 | 5.3 | 14.9[b] | 504.9 | 350[b] | 20.9[a] | 44.3[a] |
| KK | 470.1 | 580 | 1.1 | 19.2[a] | 467.9 | 390[a] | 1.1[c] | 37.8[a] |
| CM 2 | 518.7 | 630 | 2.4 | 0.7[c] | 480.6 | 240[c] | 5.0[b] | 7.3[b] |
| Plants m$^{-1}$ row (B) | | | | | | | | |
| 9 | 315.2[e] | 580 | 3.1 | 8.0 | 314.8[d] | 320 | 9.4 | 25.6 |
| 12 | 404.4[d] | 610 | 2.8 | 12.8 | 414.5[c] | 340 | 10.2 | 26.1 |
| 15 | 507.6[c] | 660 | 2.9 | 11.0 | 454.3[c] | 320 | 8.3 | 29.9 |
| 18 | 566.5[b] | 530 | 2.8 | 12.6 | 581.0[b] | 290 | 8.5 | 33.6 |
| 21 | 675.4[a] | 640 | 3.0 | 13.7 | 640.0[a] | 350 | 8.6 | 33.8 |
| CV (%) | 7.2 | 16.2 | 27.3 | 49.2 | 8.5 | 32.4 | 63.9 | 30.5 |
| F-test: A | NS | NS | NS | ** | NS | ** | ** | ** |
| B | ** | NS | NS | NS | ** | NS | NS | NS |
| AxB | NS | NS | NS | NS | NS | NS | NS | NS |

1. NS = Not significant; ** = significant at *P* <0.01; figures followed by the same letter in a column are not significantly different.

2. By weight (visual separation).

3. By counting ofter seed germination test.

**Table 26. Combined analysis of soybean yield, yield components and agronomic traits under two sowing dates, three cultivars and five population densities in Phu Kiew in dry season 2003/04[1].**

| Treatment | Harvested population ('000 plants $ha^{-1}$) | Plant height (cm) | TDW[2] (g $plant^{-1}$) | Pods $plant^{-1}$ | Seeds $plant^{-1}$ | Yield (kg $ha^{-1}$) | 100-seed weight (g) | Green seed (%)[3] | Hard seed (%)[4] |
|---|---|---|---|---|---|---|---|---|---|
| Sowing date (D) | | | | | | | | | |
| Date 1 | 493.8 | 50.1 | 1.10 | 8.7[a] | 14.9[a] | 600[a] | 11.9 | 2.90[b] | 11.60[b] |
| Date 2 | 484.5 | 49.3 | 1.16 | 6.9[b] | 11.2[b] | 320[b] | 12.3 | 9.00[a] | 29.78[a] |
| Cultivar (A) | | | | | | | | | |
| SJ 5 | 498.8[a] | 56.1[a] | 1.01[b] | 8.9[a] | 14.2 | 470 | 11.6 | 13.1[a] | 29.57[a] |
| KK | 469.0[b] | 54.6[a] | 1.31[a] | 7.2[b] | 12.6 | 480 | 12.3 | 1.11[b] | 28.50[a] |
| CM 2 | 499.6[a] | 38.3[b] | 1.00[b] | 7.3[b] | 12.3 | 440 | 12.6 | 3.70[b] | 4.00[b] |
| Plants $m^{-1}$ row (B) | | | | | | | | | |
| 9 | 315.0[a] | 48.4[b] | 1.10[ab] | 9.2[a] | 15.3[a] | 450 | 12.4[a] | 6.3 | 16.78 |
| 12 | 409.5[b] | 49.7[ab] | 1.13[ab] | 8.3[a] | 14.1[ab] | 480 | 12.1[ab] | 6.5 | 19.44 |
| 15 | 481.0[c] | 50.8[a] | 1.22[a] | 7.8[ab] | 13.0[bc] | 490 | 12.3[a] | 5.6 | 20.44 |
| 18 | 573.7[d] | 48.3[b] | 1.01[b] | 6.7[b] | 11.3[c] | 410 | 11.8[b] | 5.7 | 23.06 |
| 21 | 666.6[e] | 51.2[a] | 1.20[a] | 6.8[b] | 11.4[c] | 500 | 12.0[ab] | 5.8 | 23.72 |
| CV (%) | 7.9 | 6.5 | 17.6 | 19.4 | 19.1 | 21.8 | 4.6 | 68.7 | 36.6 |
| F-test: D | NS | NS | NS | ** | ** | ** | NS | ** | ** |
| A | * | ** | * | * | NS | NS | NS | ** | ** |
| DxA | NS | NS | NS | NS | NS | * | NS | ** | ** |
| B | ** | * | * | ** | ** | NS | * | NS | NS |
| DxB | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| AxB | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| DxAxB | NS | NS | ** | NS | NS | NS | NS | NS | NS |

1. NS = Not significant; * = Significant at *P* <0.05; ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.
2. Top growth (stalks, pods and seeds) dry weight (sun-dried) at harvest.
3. By weight (visual separation).
4. By counting after seed germination test.

## Response of Three Soybean Cultivars Under Three Management Methods of Rice Stubble

During 2004/05 dry season, a farmers' participatory field trial was conducted with three cultivars of soybean under three methods of rice stubble management in paddy fields in Wang Chai watershed, Phu Wiang district, Khon Kaen province (Fig. 17) and details of the experiment are given below:

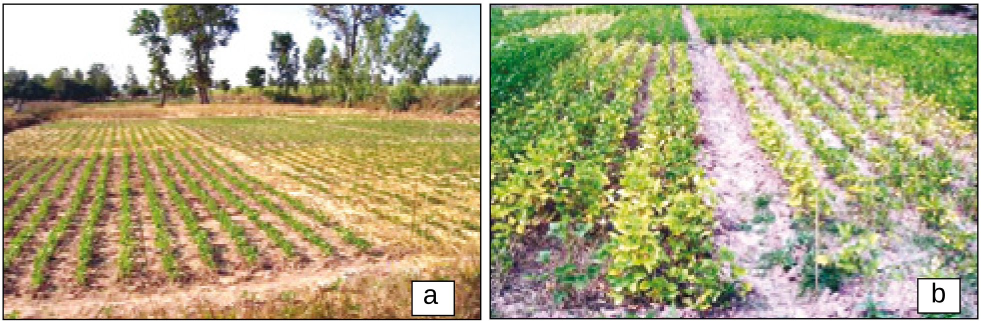


*Figure 17. Rice stubble treatment before sowing soybean cultivar CM 2 (a) pre-flowering stage of crop with mulching; and (b) pre-harvest stage of crop with mulching (left) and incorporation (right) of rice stubble.*

**Sowing date:** 17 December 2004

**Experiment design:** Split plot in RCB with three replications

**Main plots:** Three management methods of rice stubble (mulching, incorporating and burning); rice stubble used in each plot was collected or treated in in-situ areas

**Sub-plots:** Three soybean cultivars [Chiang Mai 2 (CM 2), Khon Kaen (KK) and SJ 5]

**General practices:** Conventionally plowed the soil

**Fertilizer:** Seed inoculation with *Bradyrhizobium japonicum* and basal application of fertilizer 12-24-12 (156 kg $ha^{-1}$) at sowing

Partially irrigated (if necessary)

About 4,150 kg $ha^{-1}$ (dry weight, sun-dried) of stubble of rice cultivar RD 6 was applied before sowing soybean. Soil analysis of surface soil (0 to 15 cm) in Phu Wiang in dry season 2004/05 is shown in Table 27. Soil moisture contents in mulching, incorporation and burning methods are shown in Figure 18.

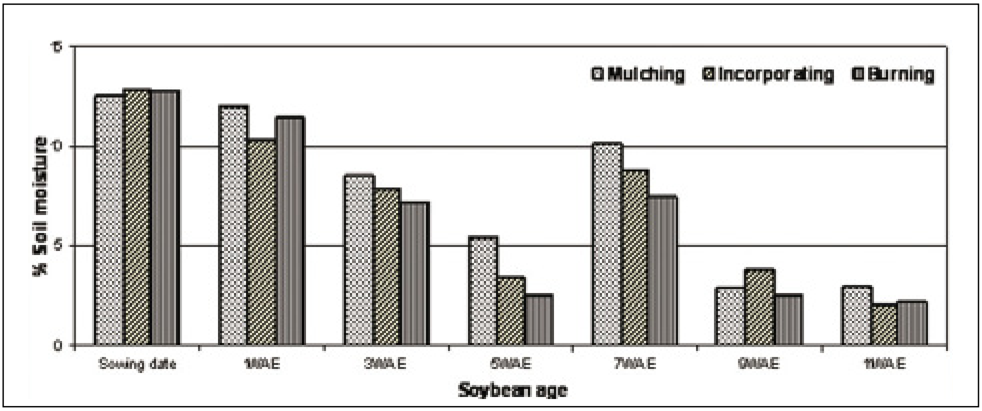


*Figure 18. Soil moisture in surface (0 to15 cm) and subsoil (15 to 30 cm) under different rice stubble management treatments in soybean crop in dry season 2004/05 (Note: WAE = Weeks after emergence).*

**Table 27. Soil analysis of surface soil (0-15 cm) in Phu Wiang in dry season 2004/05.**

| Management | pH | Organic matter (%) | Available P (mg kg$^{-1}$ soil) | Extractable K (mg kg$^{-1}$ soil) | Extractable Ca (mg kg$^{-1}$ soil) |
|---|---|---|---|---|---|
| Before tillage | 7.2 | 0.41 | 12.7 | 35.0 | 178.0 |
| After sowing | | | | | |
| Mulching by rice stubble | 5.5 | 0.36 | 15.4 | 43.8 | 90.4 |
| Incorporating rice stubble | 5.2 | 0.22 | 10.7 | 38.6 | 58.1 |
| Burning rice stubble | 7.0 | 0.09 | 14.0 | 100.0 | 439.7 |

Table 28 shows the detailed statistical analysis of the effect of three methods of rice stubble management on three soybean cultivars on various agronomic traits like grain yield, yield component and other characters. The analysis showed that both the cultivars and rice stubble management system had significant effect on grain yields.

### Response of Groundnut Cultivar KK 5 Under Three Levels of Supplemental Irrigation

Groundnut cultivar KK 5 was grown on loamy sand soil after paddy in the 2004/05 dry season under three levels (1, 2 and 3 times) of irrigation applied at one month interval after sowing. The results showed that one irrigation gave very low yield and shelling out-turn and the application of two and three irrigations gave an increase in pod yield of 238% and 313% compared to yield under one irrigation treatment (Table 29). The frequencies of irrigation also affected growth of groundnut (dry weight, sun-dried) at harvest. The results indicated that application of irrigation had significant effect on yields and other yield attributes. Three irrigations at monthly interval after sowing enhanced crop growth and yield compared to one and two irrigations (Fig. 19).

*Figure 19. Plant growth and pod yield of groundnut cultivar KK 5 after number of irrigations: one (right); two (middle); and three (left).*

**Table 28. Effects of three rice stubble management practices on soybean on grain yield, yield components and agronomic characters at Phu Wiang district in dry season 2004/05[1].**

| Treatment | Harvested population ('000 plants ha$^{-1}$) | TDW[2] (g plant$^{-1}$) | Pods plant$^{-1}$ | Seeds plant$^{-1}$ | Yield (kg ha$^{-1}$) | 100-seed weight (g) | Seed performance: Green seed (%)[3] | Seed performance: Green seed germination (%)[4] | Seed performance: Germination (%)[5] |
|---|---|---|---|---|---|---|---|---|---|
| Rice stubble management (A) | | | | | | | | | |
| Mulching | 466.7 | 168.6 | 12.6 | 23.4 | 580 | 10.9 | 6.7 | 10.9 | 81.6 |
| Incorporating | 461.1 | 117.4 | 9.5 | 15.8 | 430 | 10.3 | 5.3 | 11.3 | 79.6 |
| Burning | 463.5 | 163.0 | 11.2 | 20.0 | 590 | 11.0 | 5.2 | 5.9 | 85.7 |
| Cultivar (B) | | | | | | | | | |
| SJ 5 | 515.7[a] | 157.6[a] | 11.4[ab] | 20.7[a] | 540[a] | 10.1[b] | 12.1[a] | 19.2[a] | 67.6[c] |
| KK | 410.8[c] | 172.4[a] | 12.3[a] | 22.3[a] | 570[a] | 10.5[ab] | 2.6[b] | 8.2[b] | 84.9[b] |
| CM 2 | 464.8[b] | 118.9[b] | 9.6[b] | 16.2[b] | 480[b] | 11.5[a] | 2.5[b] | 0.7[c] | 94.3[a] |
| CV (%) | 6.6 | 13.5 | 13.0 | 17.8 | 9.7 | 6.7 | 38.2 | 50.3 | 6.5 |
| F-test: A | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| B | ** | ** | ** | ** | * | ** | ** | ** | ** |
| AxB | NS | NS | NS | NS | NS | NS | NS | NS | NS |

1. NS = Not significant; * Significant at $P < 0.05$; ** = Significant at $P < 0.01$; figures followed by the same letter in a column are not significantly different.
2. Top growth (stalks, pods and seeds) dry weight (sun-dried) at harvest time.
3. By weight (visual separation).
4. By counting after seed germination test.
5. By counting; germination test 4 months after storing seed under room temperature.

**Table 29. Performance of groundnut cultivar KK 5 under different levels of irrigation in paddy field in Wang Chai watershed in dry season 2004/05.**

| No. of irrigations[1] | Population ('000 plants ha$^{-1}$) | Top growth[2]: Dry weight (kg ha$^{-1}$) | Top growth[2]: Rel. (%) | Pods plant$^{-1}$ | Dry pod yield (kg ha$^{-1}$) | Yield increase (%) | Shelling out-turn (%) | 100-seed weight (g) |
|---|---|---|---|---|---|---|---|---|
| One | 200,556 | 3,187±93 | 100 | 1.40±0.01 | 310±62.9 | 0 | 44.6±4.8 | 48.4±1.92 |
| Two | 212,778 | 4,148±637 | 130.7 | 4.16±1.48 | 1,050.0±149.3 | +237.6 | 64.0±3.9 | 55.0±0.64 |
| Three | 223,333 | 5,625±748 | 177.2 | 8.44±0.05 | 1,280.3±7.9 | +312.5 | 61.4±2.2 | 48.7±1.47 |

1. One month interval after sowing.
2. After detachment of pods.

**Response of Black Testa Cowpea Cultivars with Supplemental Irrigation**

Two black testa cowpea cultivars (CP 4-2-3-1 and IT 82E-9) were sown in paddy field after rice in the dry season and two treatments of no irrigation (residual soil moisture) and one irrigation at one month after sowing were compared. Crop yield increased significantly with one supplemental irrigation compared to the non-irrigated crop; however, crop yield variations between the two varieties was not significant (Table 30).

**Table 30. Grain yield of two black testa cowpea cultivars in paddy fields under different water regimes in Wang Chai watershed in dry season 2004/05.**

| | Grain yield (kg $ha^{-1}$) | | |
|---|---|---|---|
| Cultivar | Residual soil moisture | One irrigation[1] | Yield increase (%) |
| CP 4-2-3-1 | 470 | 670 | +42.0 |
| IT 82E-9 | 460 | 660 | +45.0 |
| Average | 470 | 670 | +43.3 |

1. At 30 days after sowing.

Normally, sugarcane is grown in both upper and lower uplands for two to three years. The harvesting of the last ratoon is in March and the fields are left fallow during April up to October, prior to growing next sugarcane crop. During this period some short-duration crops like soybean, groundnut and black testa cowpea can be grown.

**Evaluation of Three Legumes in Rainy Season in 2004**

Soybean (KK and SJ 5), groundnut (KK 5, KK 6 and local) and black testa cowpea (IT 82E-9 and CP 4-2-31) were planted in upland (loamy sandy) in Wang Chai watershed in early August 2004 (Fig. 20). Due to low soil fertility, waterlogging after heavy rainfall during late August to early September and early withdrawal of rain in September, growth of all crops was affected but black testa cowpea gave reasonable grain yield. CP 4-2-3-1 gave higher grain yield than IT 82E-9 by 16.6%, but its seeds were smaller. Groundnut and soybean gave very low yield. But the large-seeded groundnut Virginia type KK 6 had high shelling out-turn (46%) (Table 31).


*Figure 20. Legumes sown in upland in Wang Chai watershed in rainy season 2004: (a) groundnut with good vegetative growth but low pod yield; (b) soybean with poor performance; and (c) good crop performance of black testa cowpea.*

**Table 31. Effect of growing black testa cowpea in upland in Wang Chai watershed in rainy season 2004.**

| Crop | Cultivar | Yield (kg $ha^{-1}$) | Shelling (%) | 100-seed weight (g) |
|---|---|---|---|---|
| Groundnut | KK 5 | 490 (dry pod) | 35.9 | 29.5 |
| | KK 6 | 140 (dry pod) | 46.3 | 31.1 |
| | Local | 6010 (dry pod) | 15.0 | 29.0 |
| Soybean | KK | 143 (grain) | - | 8.2 |
| | SJ 5 | 100 (grain) | - | 8.2 |
| Black testa cowpea | IT 82E-9[1] | 750 (grain) | 62.5 | 13.1 |
| | CP 4-2-3-1 | 880 (grain) | 66.8 | 11.6 |

1. Susceptible to leaf blight (Ubon Ratchathani Field Crops Research Center 2000).

## Evaluation of Legumes in Rainy Season in 2005

After we found in the dry season 2005 that KK is a suitable soybean cultivar, farmers in Wang Chai watershed adopted it. The evaluation of seed multiplication of KK was conducted in the upper and lower upland in Wang Chai watershed in rainy season 2005. Due to more variation in soil fertility, large variation in soybean performance was found (Table 32 and Fig. 21). Grain yield was higher (202 per cent) in the lower part of upland area than in the upper area. Also harvest index, seed size and seed germination percentage were greater in the lower area than in the upper area (Table 33).


*Figure 21. Performance of soybean cultivar KK in upland in Wang Chai watershed in rainy season 2005: (a) upper upland; and (b) lower upland.*

**Table 32. Soil analysis of different plots in Wang Chai watershed in rainy season 2005.**

| Area | Texture class[1] | pH | Organic matter (%) | Available P (mg kg$^{-1}$ soil) | Extractable K (mg kg$^{-1}$ soil) | Extractable Ca (mg kg$^{-1}$ soil) |
|---|---|---|---|---|---|---|
| Upper upland[2] | SL | 5.1 | 0.45 | 35.0 | 86.8 | 102.2 |
| Lower upland[2] | LS | 6.9 | 0.38 | 175.5 | 81.0 | 269.0 |
| Upper paddy | SL | 5.5 | 0.17 | 90.5 | 89.0 | 83.5 |

1. SL = Sandy loam; LS = Loamy sand.
2. Common soil analysis for evaluations of both groundnut and soybean.

**Table 33. Effect of growing soybean in upland in Wang Chai watershed in rainy season 2005 on yield and yield components of cultivar KK[1].**

| Area | Harvested population ('000 ha$^{-1}$) | Grain yield[2] (kg ha$^{-1}$) | SW/TDW[3] (%) | Good seed by weight (%) | 100-seed weight (g) | Seed germination (%) |
|---|---|---|---|---|---|---|
| Upper upland | 385.0 | 490 | 21.5 | 75.0 | 14.2 | 70.0 |
| Lower upland | 382.8 | 1490 | 46.0 | 95.0 | 15.0 | 90.3 |

1. Sowing date: Early July 2005.
2. Sun-dried.
3. SW/TDW = Seed weight/top growth dry weight.

Groundnut cultivar KK 5 was grown for seed multiplication in three positions on used toposequence (upper upland, lower upland and upper paddy) and three planting dates in Wang Chai watershed in the rainy season 2005 (Figs. 22 and 23). Monthly rainfall during 2005 in Wang Chai watershed is given in Table 34. The results indicated that even though Ca concentration in the upper paddy field seemed to be lower than the lower upland, water deficit throughout the growing season was more serious in the upper upland. Under same amount of rainfall, groundnut sown in the upper paddy field and lower upland had shown better performance than the upper upland (Table 35). Planting in early May to early June was also advantageous (343% increase) than planting during late June to early July (Table 36).

**Table 34. Monthly rainfall and rainy days in Wang Chai watershed in rainy season 2005[1].**

| | Apr | | May | | Jun | | Jul | | Aug | | Sep | | Oct | | Nov | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | E | L | E | L | E | L | E | L | E | L | E | L | E | L | E | L |
| Rainfall (mm) | 0 | 0 | 40 | 139 | 16 | 103 | 97 | 53 | 31 | 95 | 166 | 76 | 43 | 10 | 40 | 0 |
| Rainy days | 0 | 0 | 4 | 7 | 2 | 10 | 4 | 7 | 5 | 8 | 8 | 5 | 3 | 1 | 3 | 0 |
| Total rainfall (mm) | 0 | | 179 | | 119 | | 150 | | 126 | | 242 | | 53 | | 40 | |
| Total rainy days | 0 | | 11 | | 12 | | 11 | | 13 | | 13 | | 4 | | 3 | |

1. E = Early; L = Late.

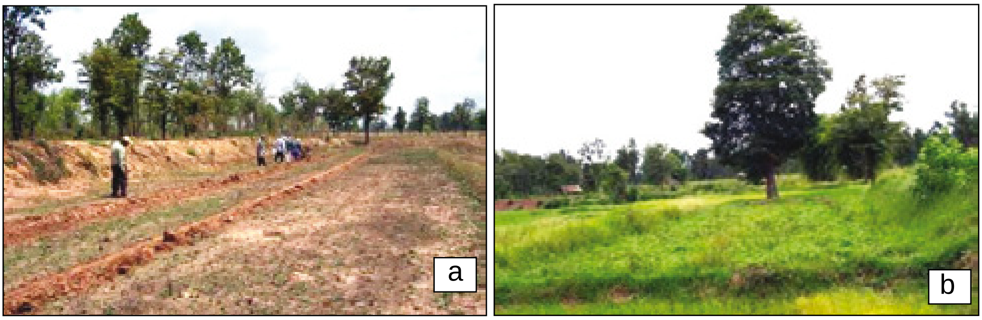


*Figure 22. Groundnut in upper paddy field in Wang Chai watershed in May 2005: (a) sowing; and (b) at harvest.*

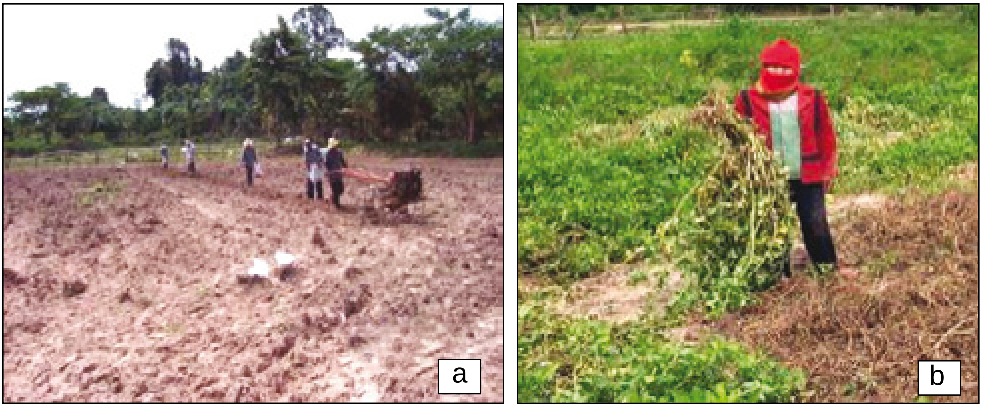


*Figure 23. Groundnut in lower upland in Wang Chai watershed in May 2005: (a) sowing; and (b) at harvest.*

**Table 35. Yield and yield components of groundnut cultivar KK 5 sown in different areas at Wang Chai watershed in rainy season 2005.**

| Area | Harvested population ('000 plants ha$^{-1}$) | Top growth dry weight[1] (kg ha$^{-1}$) | Pods plant$^{-1}$ | Dry pod yield[1] (kg ha$^{-1}$) | Shelling out-turn (%) | 100-seed weight (g) |
|---|---|---|---|---|---|---|
| Upper upland[2] | 184.4±12.6 | 5,070±516 | 6.8±0.2 | 730±134 | 54.5±12.0 | 38.16±5.26 |
| Lower upland[2] | 258.9±2.2 | 6,960±582 | 6.4±1.7 | 1,640±42 | 74.0±2.0 | 55.46±1.79 |
| Upper paddy[3] | 349.4±17.5 | 4,510±1044 | 7.3±0.7 | 1,730±369 | 72.0±2.8 | 41.60±6.46 |

1. Sun-dried.
2. Conventional tillage.
3. No tillage.

**Table 36. Effect of sowing date on groundnut yield and other growth components in uplands.**

| Sowing time | Harvested population ('000 plants ha$^{-1}$) | Top growth dry weight[1] (kg ha$^{-1}$) | Pods plant$^{-1}$ | Dry pod yield[1] (kg ha$^{-1}$) | Shelling out-turn (%) | 100-seed weight (g) |
|---|---|---|---|---|---|---|
| Early–late May | 201.7±50.9 | 5,822±1,239 | 7.2±1.3 | 1,160±488 | 66.6±8.1 | 45.2±10.52 |
| Early June | 171.0±61.2 | 5,210±1,195 | 7.7±2.6 | 1,170±875 | 60.6±16.9 | 46.5±11.01 |
| Late June–early July | 173.8±39.7 | 2,172±701 | 2.7±2.2 | 260±330 | 48.2±35.9 | 33.2±9.40 |

1. Sun-dried.

## Conclusion

As mentioned in the introduction the areas in Wang Chai watershed can be classified into four categories for the purpose of different cropping systems: upper upland, lower upland, upper paddy fields and lower paddy fields. The traditional cropping systems are given in Figure 24 and some improved cropping systems are recommended in Figure 25.

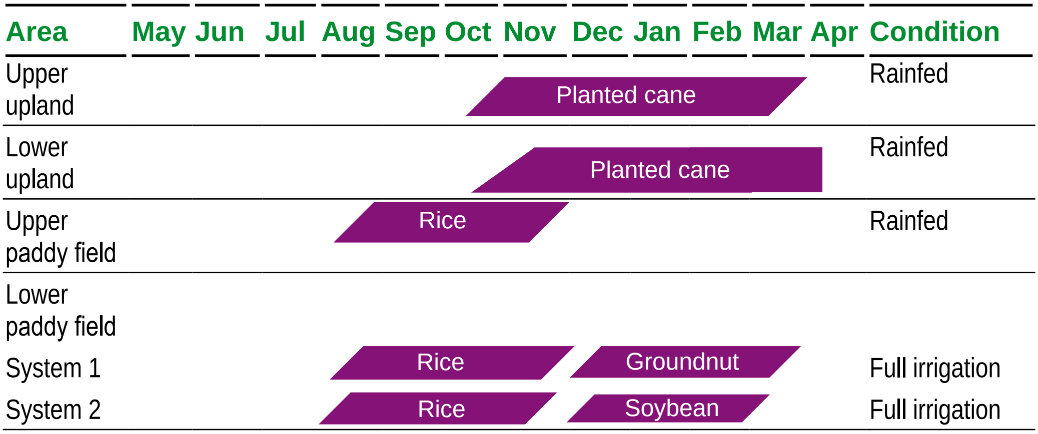


*Figure 24. Flow chart of traditional cropping systems in Wang Chai watershed before 1999.*

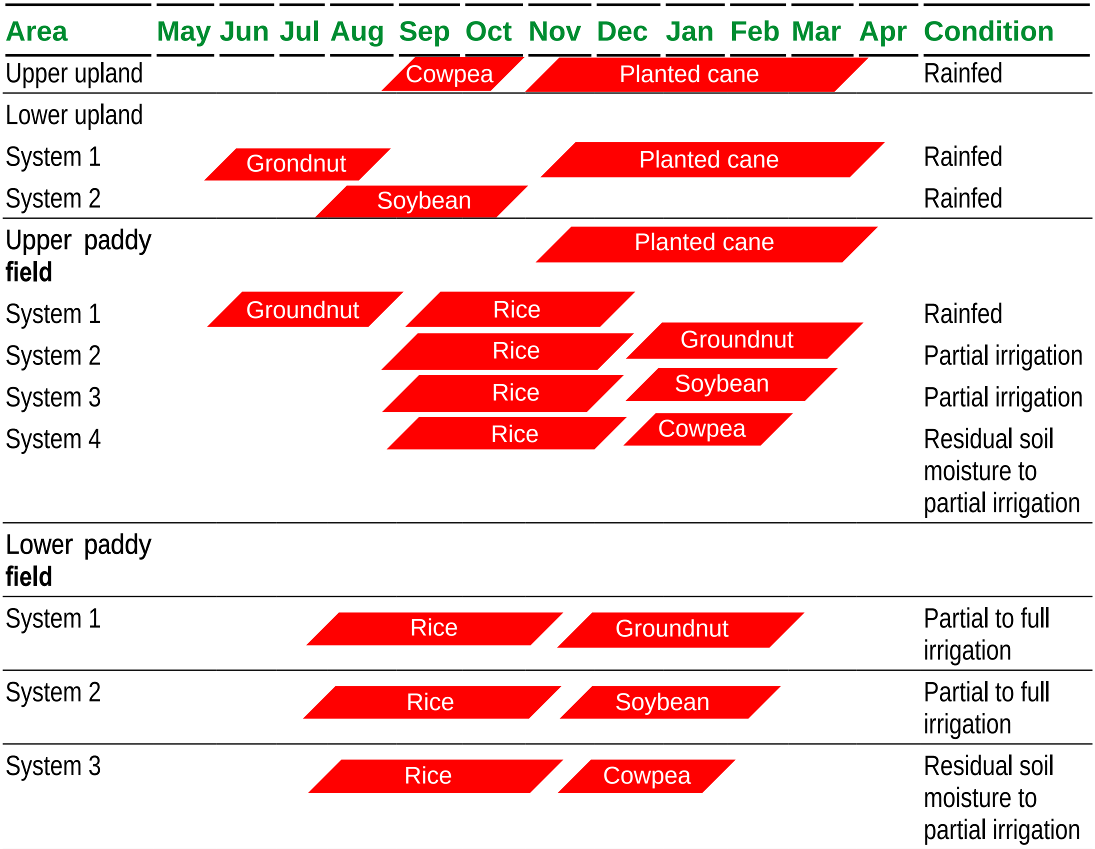


*Figure 25. Flow chart of improved cropping system at Wang Chai watershed after ADB-ICRISAT Project during 1999-2005 and recommendation for legumes.*

## Sowing Legumes in Upper and Lower Uplands

Normally, both areas are occupied by sugarcane and the fields are left fallow for 6–10 months after harvest of the last ratoon. The fallow areas can be used for sowing some short-duration legumes. Therefore, recommendations for sowing short-duration legumes in sugarcane-based cropping systems in the upper and lower upland areas are different.

- **Recommendation for the upper upland in rainy season:** Moreover, soil fertility in the upper upland is low and most areas are rainfed. Often water shortage occurs in the early rainy season and waterlogging occurs in middle rainy season. This can affect crop growth and yield. However, black testa cowpea as a shorter duration crop can be sown but it should be sown in late rainy season. The cultivar CP 4-2-3-1 is suitable.
- **Recommendation for the lower upland in rainy season:** Soil fertility in the lower upland is higher than in the upper upland and water movement downward to the lower area induces sufficient water for crop growth for a longer period. Soybean and groundnut are well-adapted crops to this situation. For groundnut, sowing should be started earlier in early rainy season during May to early June.

## Sowing Legumes in Upper Paddy Fields

Normally, most upper paddy fields are under rainfed condition with small water supplies from farm ponds. Rice can be sown only in rainy season and the fields are left fallow in dry season. However, some legumes can be sown in these areas.

- **Recommendation for rainy season:** Groundnut can be sown in late April to early May, and the crop can be harvested in early August under rainfed condition, prior to transplanting rice.
- **Recommendation for dry season:** Soybean, groundnut and black testa cowpea can be sown after rice but partial irrigation should be applied for good yields, ie, at least two irrigations for soybean, three irrigations for groundnut and one irrigation for cowpea. The results indicated that soybean cultivars CM 2, KK and SJ 5, groundnut cultivar KK 5 and IT 82E-9 and CP 4-2-3-1 can be recommended.

## Sowing Legumes in Lower Paddy Fields in Dry Season

Normally, lower paddy fields are under both rainfed and irrigated conditions and rice is sown in rainy season but extended soybean areas and small areas of groundnut are common practices. However, some of the recommendations for irrigated and rainfed areas are:

- **For irrigated areas:** Soybean, groundnut and cowpea can be sown under both partial and full irrigation. The cultivars of the three legumes, mentioned earlier are recommended for the upper paddy fields in the dry season.
- **For non-irrigated areas:** Black testa cowpea can be sown without irrigation and IT 82E-9 is a suitable cultivar.

In conclusion the improved crops and cropping systems can play a very important role in increasing agricultural productivity and income of farmers and reducing land degradation in Northeast Thailand. Several improved crops and cropping systems were identified for the different toposequence positions of the landscape.

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# 5. Simple and Effective Integrated Pest Management Technique for Vegetables in Northeast Thailand

***Somchai Chuachin, Thawilkal Wangkahart, Suhas P Wani, TJ Rego and Prabhakar Pathak***

## Introduction

Insect pests are one of the major constraints to increase food production and higher agricultural productivity. On a global level, pests are reported to destroy a significant part of the agricultural harvest. A comprehensive study (Oerke et al. 1999) showed that crop losses due to insect-pests range from 25% to over 50%, depending on the crop and agroclimatic conditions. About five million tons of pesticides are used annually in agriculture world-wide and there is ample evidence to show that pesticide use can often aggravate rather than reduce the pest damage in many crops.

In Thailand, the crop and monetary losses due to insect-pests have been substantial particularly on the high-value crops, vegetables and fruits. The use of pesticides has been on increase, particularly during the last 12 years (Figs. 1 and 2) (OAE 2006). Inspite of increase in pesticide use, it is disturbing to note that over the last two decades, the losses in all major crops, vegetables and fruits have increased in relative terms. Inspite of this trend in Thailand, pesticides have become an integral component in sustainable agriculture. However, being inherently toxic, excessive and non-judicious use of pesticides has raised several environmental issues. Contamination of agricultural commodities, environmental pollution, toxicity to non-target and beneficial organisms as well as emergence of resistance in insect-pests and pathogens are a few issues that still are of great concern. The use of pesticides also implicates risk to consumer health, especially when good agricultural practices are not followed. In Thailand, vegetables and flowers are cultivated on 0.5 million ha, which generate an annual income of US$ 326 million. Pesticides constitute the major portion of production cost, which is currently about 40–60% of the total production cost. Many of these agricultural products are being exported to other countries. Due to more stringent regulations on pesticides content in these products along with long-term environmental issues, the Thailand government has planned to reduce the use of pesticides by 30%. Integrated pest management (IPM) is an ecology-based pest management system that promotes the health of crops and humans, and makes full use of natural and cultural control processes and methods. Several IPM efforts through use of nematodes, nuclear polyhedrosis virus (NPV), predatory insects, natural bio-extract, Bt and black light are being promoted (OAE 2006).

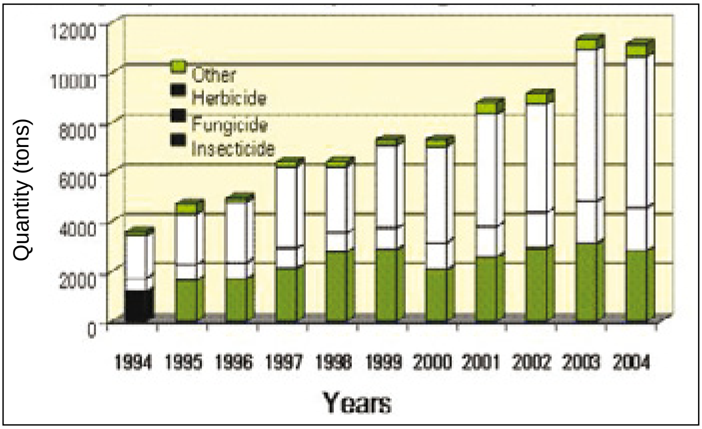


*Figure 1. Amount of pesticides used in Thailand during 1994–2004.*

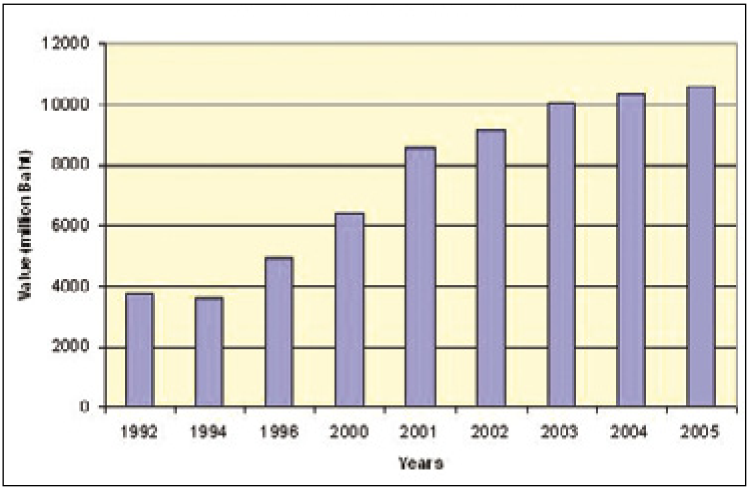


*Figure 2. Import of pesticides in Thailand during 1992–2005.*

## Innovative IPM System for Vegetables: Use of Sugarcane By-product (Molasses)

In 2001, the senior author Mr Somchai Chuachin, Scientist, Department of Agriculture, OARD-3 region, while working on a farmer's field, observed that insects were getting attracted to a farmer's hands, who earlier worked with sugarcane molasses. Later he found many dead insects in a container with waste molasses, which was unintentionally left near the asparagus fields for two days. This gave him an idea that the sugarcane molasses could be used to control the insects. Mr Somchai then started working with several designs of insect trap bottles with various concentrations of molasses to attract insects in asparagus fields under "Participatory Technology Development" (PTD) program in Kalasin project area. In this area, common cutworm was the major insect problem that affected vegetable cultivation. Every year farmers used to spend substantial money on insecticide sprays to control the insect. In 2001, for the first time, Mr Somchai introduced the new IPM system on vegetables to control the insect. In this IPM system, white plastic bottles of 700 ml capacity with two side openings and filled with molasses were placed at about 30 cm from the ground surface on a bamboo stick (Fig. 3). The insects were attracted by the molasses kept in the plastic bottle, and got trapped and killed (Fig. 4).

*Figure 3. Simple IPM system installed in a cabbage field in Northeast Thailand.*

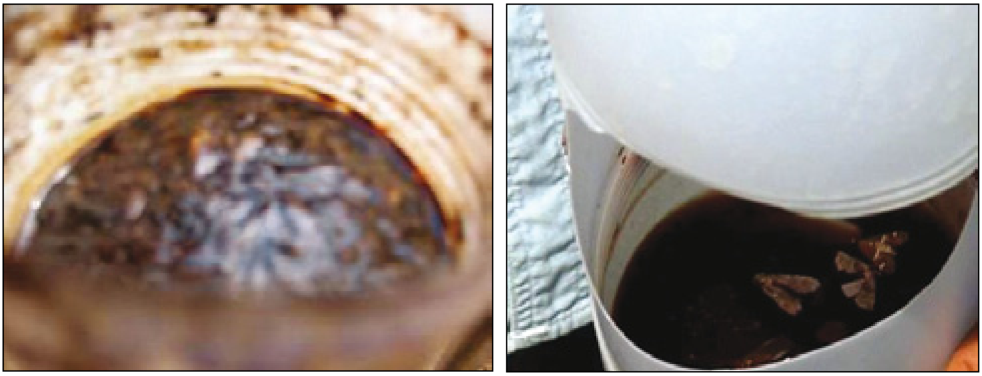

*Figure 4. Insects trapped in the plastic bottles with molasses.*

Mr Somchai along with farmers found molasses IPM system quite effective in controlling the insect population and damage, particularly in cabbage, resulting in reduced cost of insecticides by 30 to 50%. In this system, chemical pesticides are used only when the pest attack exceeds critical damage level. Any additional interventions are made based on the need and this minimizes the total cost and undesirable side-effects.

## Refinement and Evaluation of the Molasses IPM System

The newly identified IPM system was further refined and evaluated in two ADB-ICRISAT project watersheds, viz, Tad Fa and Wang Chai in Northeast Thailand. Cultivation of vegetables is quite prominent in both these watersheds. In Tad Fa watershed, the farmers earn about 45% of the annual income from the vegetables grown during the rainy and postrainy seasons. The major vegetables grown in Tad Fa watershed are cabbage, Chinese kael, Chinese cabbage, coriander, shallots and lettuce. These vegetables are generally grown in yearly rotation to reduce the pest and disease problems. At Wang Chai watershed, most of the vegetables such as long yarn bean, cabbage and others are grown in the winter season. At both the watersheds, farmers were using heavy dose of pesticides to control insects and other pest problems.

During 2002, the newly developed IPM technique using molasses was introduced to control insect damage in vegetables at Tad Fa and Wang Chai watersheds. At both the sites, farmers were trained on various aspects of the new IPM technique. Field exposure visits were also arranged for selected farmers to visit the farms where this technique had been used for the last two years. In a short span of two years, this IPM technique became quite popular with most of the watershed farmers cultivating cabbage and other vegetables (Fig. 5). There is a need to conduct systematic scientific trials on this IPM technique in the farmers' fields to collect data on its effectiveness in controlling different types of insects (Fig. 6). Also, several aspects of this new IPM technique such as height of placing the trap bottles, spacing between the poles on which bottles were to be fixed and other details need to be standardized.

In 2004, on-farm trials were conducted in both Tad Fa and Wang Chai watersheds and detailed data were collected. In Tad Fa watershed, the IPM trial was conducted on three cabbage farms. In each cabbage field, 25 bamboo sticks were placed at a spacing of 5 m x 5 m to fix the insect trap bottles. At each bamboo stick, three

*Figure 5. A farmer explains the simple IPM methodology to visitors.*

*Figure 6. A scientist from the Department of Agriculture checking the insects in the bottle filled with molasses.*

plastic bottles which have two side openings and filled with molasses, were fixed at 50, 100 and 150 cm above the ground surface (Fig. 7).

Every three weeks, the bottles were removed from the fields and from each bottle different types of insects were noted and their numbers were counted. The mean values of insects trapped in the bottles at 50, 100 and 150 cm height are shown in Table 1. The bottles kept at 50 cm above the surface were relatively more effective in trapping insects than the bottles kept at 100 and 150 cm above the ground. The total numbers of insects trapped in the bottles kept at 50, 100 and 150 cm height were 8.8, 6.0 and 4.7, respectively. In this area, the major damage to cabbage is caused by four insects, viz, (i) cabbage looper (*Trichoplusia ni*), (ii) common cutworm (*Spodoptera litura*), (iii) cabbage leaf miner fly (*Liriomyza brassicae*), and (iv) leaf eating beetle (*Phyllotreta* sp).

**Table 1. Insect population in the IPM trap bottles placed at different heights in cabbage fields in Tad Fa watershed in 2004.**

| Insect | No. of insects trapped per bottle | | | Total no. of insects trapped per bottle |
|---|---|---|---|---|
| | 50 cm | 100 cm | 150 cm | |
| Cabbage looper | 2.8 | 2.3 | 1.4 | 6.5 |
| Cabbage cutworm | 1.2 | 2.7 | 0.7 | 4.6 |
| Cabbage leaf miner fly | 1.7 | 1.0 | 1.4 | 4.1 |
| Leaf eating beetle | 3.2 | - | 1.1 | 4.3 |
| Total | 8.9 | 6.0 | 4.6 | 19.5 |

*Figure 7. An experimental plot where the IPM technique was evaluated in Tad Fa watershed.*

The results clearly show that this technique was effective in trapping all the four major insects that damage cabbage. Most of the insects in the bottles were adult female insects, which had major impact in reducing the further multiplication of these insects (Table 2). Based on earlier research work and farmers' experience, the possible damage to cabbage crop without using IPM technique was estimated (Table 2). This estimation is based on the hypothesis that if the female insects would not have been trapped and killed by the IPM technique, they would have produced several thousands new worms/eggs, which could have seriously damaged the cabbage crop. For example, 165 cabbage loopers were trapped and killed through IPM technique. If they had not been trapped/ killed, they would have produced about 123,750 new worms/eggs, which could have damaged about 15% of the cabbage crop. The maximum damage could have been caused by cabbage cutworm, which would have damaged about 73% of the crop. In total, 92% of the cabbage could have been damaged if the IPM technique was not effective in trapping the female insects in the molasses bottles.

**Table 2. Estimation of damage to cabbage crop by insects without using IPM technique[1].**

| Adult insects | No. of insects trapped in bottle | Total larvae (eggs) could have been produced by trapped insects | No. of larvae to potentially damage one plant completely | Degree of damage without IPM (%) |
|---|---|---|---|---|
| Cabbage looper | 165 | 123,750 | 150 | 15 |
| Cabbage cutworm | 115 | 28,750 | 7 | 73 |
| Leaf eating beetle | 108 | 15,050 | 100 | 3 |
| Total | 388 | 167,550 | 257 | 91 |

1. Based on 25 IPM trap sets used in 5,600 cabbage plants.

At Wang Chai watershed, vegetables are grown mostly in the winter season and agroclimatic conditions of this area are quite different than those in the Tad Fa watershed. The IPM trial was conducted in 2004 at Non Thong village, where most of the farmers grow cabbage. A study was conducted to monitor the pattern of trapping of various insects during different growing periods of cabbage. At weekly interval, all the IPM bottles were observed from the fields and various insects and their numbers trapped in the bottles were counted. During the early stage of cabbage growth, relatively few insects were trapped in the IPM bottles (Table 3). Mainly diamondback moths (*Plutella xylostella*) and cabbage looper moths (*Trichoplusia ni*) were trapped in the IPM bottles. The number of insects trapped in bottles during 3$^{rd}$ and 4$^{th}$ weeks of cabbage crop was low. During the first four weeks of crop growth, a total of 37 insects were found in the IPM bottles. During the mid growing period (5$^{th}$ to 8$^{th}$ week), more number of insects were found trapped in the IPM bottles (Table 4). During this period not only the number of insects but also insect species found in the trap bottles increased drastically. The first insect trapped was cabbage webworm moth (*Hellula undalis*), followed by cutworm moth (*Spodoptera litura*) and other insects.

**Table 3. Insect population in the IPM trap bottles during the early stage of cabbage crop growth (seedling) in Wang Chai watershed, 2004.**

| | No. of insects trapped per bottle | | | | |
|---|---|---|---|---|---|
| Insect | Week 1 | Week 2 | Week 3 | Week 4 | Total |
| Diamondback moth | 8 | 6 | 5 | 4 | 23 |
| Cabbage looper | 5 | 4 | 3 | 2 | 14 |
| Total | 13 | 10 | 8 | 6 | 37 |

**Table 4. Insect population in the IPM trap bottles during the mid growth stage (transplanting) of cabbage crop, in Wang Chai watershed, 2004.**

| | No. of insects trapped per bottle | | | | |
|---|---|---|---|---|---|
| Insect | Week 5 | Week 6 | Week 7 | Week 8 | Total |
| Diamondback moth | 8 | 4 | 3 | 2 | 17 |
| Cabbage looper | 4 | 3 | 2 | 1 | 10 |
| Cabbage webworm | 3 | 3 | 3 | 2 | 11 |
| Common cutworm | - | - | - | 5 | 5 |
| Total | 15 | 10 | 8 | 10 | 43 |

During the last phase of crop growth, the proportion of insect population of various species in the IPM bottles was different than the earlier crop growth phase (Table 5). Common cutworm was the dominating insect found in the IPM bottles. About 65% of insects in the IPM bottles were common cutworm. During this period very low numbers of cabbage loopers and cabbage webworm were trapped in the IPM bottles.

**Table 5. Insect population in the IPM trap bottles during the vegetative and pre-harvest stages of cabbage in Wang Chai watershed in 2004.**

| Insect | No. of insects trapped per bottle | | | | Total |
|---|---|---|---|---|---|
| | Week 9 | Week 10 | Week 11 | Week 12 | |
| Diamondback moth | 1 | 3 | 6 | 8 | 18 |
| Cabbage looper | 1 | - | - | - | 1 |
| Cabbage webworm | 3 | 1 | 1 | - | 5 |
| Common cutworm | 5 | 10 | 15 | 15 | 45 |
| Total | 10 | 14 | 22 | 23 | 69 |

Data from the IPM trial clearly show considerable variation in insect species and their population during the cabbage growing period. During the early and mid growing period, diamondback moth appears to be the dominant insect whereas during the main vegetative and harvesting period common cutworm was the dominant insect on the cabbage crop. The population of various insects trapped in the bottles also shows the effectiveness of this IPM technique in trapping major insects that damage the cabbage crop. According to the farmers in Wang Chai watershed, diamondback moths are quite damaging particularly during the early seedling stage of the cabbage crop. Often, farmers have to re-transplant cabbage due to heavy damage by diamondback moths. The behavior of common cutworm is highly unpredictable; therefore, they are difficult to control with pesticides. Often their attack is sudden, and in large numbers and mostly during night. Some of the traditional methods, viz, smoking, irrigation and other methods are not very effective in protecting the cabbage crop. Farmers using this simple IPM technique, reported that generally there was no need to apply pesticides for cabbage, except in some unusual situations where one or two sprays were found necessary. The results in Table 6 show the comparison of cost and benefits of the conventional insect control method (pesticide sprays) with the molasses IPM technique on cabbage. The net profit to farmers who used IPM technique to grow cabbage increased by 51% compared to those who used conventional chemical-based insect control method.

**Table 6. Economics of simple IPM and conventional insect control methods on cabbage, in Wang Chai watershed, in 2004.**

| Item | Cost (Baht ha$^{-1}$) Conventional chemical insect control | IPM technique |
|---|---|---|
| Land preparation | 3000 | 3000 |
| Seeds | 1620 | 1620 |
| Fertilizer (16-20-0) | 7560 | 7560 |
| Green fertilizer (25-8-8) | 1800 | 1800 |
| Insecticides (Lannat, Abamactin, Atabon) | 21000 | 1200 |
| Fuel cost for irrigation | 3000 | 3000 |
| Transportation | 12000 | 12000 |
| Total cost | 49980 | 30180 |
| Yield (kg ha$^{-1}$) | 37200 | 38100 |
| Price of cabbage (Baht kg$^{-1}$) | 2.50 | 2.50 |
| Income (Baht ha$^{-1}$) | 93000 | 95250 |
| Benefit (Baht ha$^{-1}$) | 43020 | 65040 |

1. US$ 1 = 37 Baht.

## Scaling-up of the Molasses IPM Technique

In a short span of time, the simple IPM technique has become quite popular with cabbage growing farmers in NE Thailand. Also, pesticide-free cabbage is preferred by consumers when sold in the market (Fig. 8). Many farmers have adopted this new IPM technique on their own for growing the cabbage crop.

*Figure 8. Good quality cabbage grown with IPM being transported to the market.*

The Department of Agriculture, Region-3 has already conducted several short training programs, field visits and farmers' days to popularize the molasses IPM technique for the protection of cabbage and other vegetables (Fig. 9).


*Figure 9. IPM Field Day organized by the scientists from OARD-3 during 2005: (a) Registration for IPM Field Day 2005; (b) IPM Field Day posters and other display items.*

## Conclusions

Even though the ever increasing use of pesticides in Thailand has led to increased food, feed and fiber production as well as improved public hygiene, it has also brought into focus several health hazards and pertinent environmental issues. To minimize farmers' over dependence on pesticides in crop protection and to avoid harmful effects on human and ecosystems, the Government of Thailand is encouraging IPM methods. The simple molasses-based IPM system reported in this paper has shown high potential in controlling insects on cabbage and other vegetables. Some of the key advantages of this IPM system are:

- Simple technique and easy to adopt;
- Uses locally available materials (bamboo sticks, molasses and plastic bottles);
- Low cost;
- Increases net profits; and
- Environment-friendly, with no harmful effects on humans and ecosystem.

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# About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

ICRISAT is headquartered in Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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