AN ABSTRACT OF THE THESIS OF

Bradford A. Withrow-Robinson for the degree of Doctor of Philosophy in Forest Science presented on August 25, 2000. Title: The Role and Function of Fruit Trees and Fruit Tree-Based Agroforestry Systems in a Highland Watershed in Northern Thailand.

Abstract approved: ______________________________

Dr. David E. Hibbs

Field studies were conducted from 1996 to 1998 in three villages in a Highland watershed in Mae Hong Son Province, northern Thailand. The objectives of the study were to classify and define the fruit-based agroforestry cropping system and investigate management activities used by villagers. In the first part of the study, we developed a conventional classification, which identified 11 fruit-based agroforestry subsystems subdivided into four larger groups. The subsystems were formed subjectively, primarily according to purpose or function of the gardens, and especially of the tree crop component, with secondary definitions relating more to the herbaceous crops grown. In the second part of the study, we developed a separate classification based largely on species composition using multivariate analysis methods. A classification of seven groups was proposed and three key factors characterizing groups were identified. The multivariate analysis showed a wide range and large overlap of group characteristics which seemed to indicate that these gardens did not represent discrete categories as hypothesized, but rather were part of a continuum of gardens with gradually changing and overlapping characteristics. Patterns indicated that landowners tended to mix

functions as well as plant species, without a strong organizational pattern. In the third section, a supporting data set was developed with crop composition, cover, and production input and output factors. The objective was to develop a better understanding of the performance of the fruit-based agroforestry system. We examined a group of economic, environmental and social factors relating to composition, cover, inputs of labor and agricultural chemicals, and the distribution and yield of crops by garden and by household units. Most of the sample households (93%) had one or more garden parcels, which together accounted for 85% of the sample households' upland cropping area. A total of 96 crop species were recorded, with an average of about 24 species raised per household. Fruit crop production was low in 1998 and most of the economic activity in gardens related to herbaceous crops.

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# CONTRIBUTION OF AUTHORS

Dr. David Hibbs was involved in the design, analysis and writing of each manuscript. Mr. Phrek Gypmantasiri assisted in field interview design. Dr. David Thomas assisted in analysis and interpretation of data for the first manuscript.

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# DEDICATION

I dedicate this thesis to my family, who by their support and tolerance made it possible: My parents Barbara and E. Arthur Robinson, my wife Tina and daughter Johannah.

# The Role and Function of Fruit Trees and Fruit Tree-Based Agroforestry Systems in a Highland Watershed in Northern Thailand

## Chapter 1

## Introduction to the Dissertation Project in Northern Thailand

Bradford A. Withrow-Robinson

# BACKGROUND

## Northern Thailand

Northern Thailand is a mountainous region that juts north from the central plain of Thailand towards the foothills of the Himalayas. The landscape of the Upper North (a nine-province region that includes both Chiang Mai and Mae Hong Son provinces) is characterized by low mountains and hills and narrow valleys. Several major mountain ranges run parallel north to south (Smitinand et al., 1978). The region is a very important watershed for Thailand. Most of the Upper North forms the watersheds of the four major tributaries of the Chao Phraya River (the Ping, Wang, Yom and Nam rivers), which in turn supplies water to the important rice growing areas and population centers of central Thailand. Other sections of the Upper North form parts of other important regional watersheds: the western section drains into the Salaween River of Myanmar, while the northern or eastern sections flow first into the Mae Kok River, then into the Mekong River which flows along the eastern boarder with Laos.

Nationally, forest cover in Thailand declined from 53% in 1961 to 25% in 1998, (Royal Forestry Department 1998). In the north, the decline has been from 69% in 1961 to 43 % in 1998, so forest cover in the north is above the national average. Swidden agriculture, fire and unregulated logging all have contributed to forest loss in the North. Frequent fire continues to prevent reestablishment of forest cover in many areas. The rate of forest loss has declined since 1991 due to a strong government commitment to protection and increased public awareness. The Thai government has banned logging concessions, established extensive Forest Reserve Areas (including classification of watershed reserves) and National Parks. Under the new Constitution of 1997, a new Community Forestry Law is also being developed and debated.

Northern Thailand has a monsoonal climate, with distinct wet and dry periods. Thais describe three seasons: the rainy season, the cool season and the hot season. The rainy season extends from May or June through October or November, peaking in July, August and September. Average rainfall in the northern valleys ranges from 1200 to 1700 mm (Smitinand, 1978) and rainfall is heavier in the mountains. The rainy season is followed by a dry period with two seasons. The cool season extends from October or November to February or March, when daytime temperatures are moderate and nights are cool. Frosts and freezing temperatures do occur in the higher mountain areas. The hot season follows from February or March though May or June. Temperatures often reach 35 to 40 degrees Centigrade. Evaporative demand exceeds rainfall about seven months on average (Land Development Department, Report 26). Rainfall allows for a growing season of about seven months (annual crops).

The interest in and control over the northern Highlands by the centralized Thai government is a relatively recent development. It evolved within the last century, driven by economic and national security concerns including, in the last three decades, narcotics production issues, and most recently, watershed issues. Thus the government has recently extended its jurisdiction into areas which were, in many cases, already occupied by non-Thai minorities. There are many ethnic minority groups, commonly called "hill tribes," living in the northern Thai Highlands. These groups are ethnically, culturally and linguistically distinct, with unique histories and traditions. Villages of three of these minority groups, the Karen, Lisu and Hmong, were included in this study.

The occupation of the Highlands by some ethnic groups such as the Karen and Lua minorities goes back several hundred years in many areas. Other ethnic minorities include the Hmong and Lisu and have a much shorter history in the area. These groups began significant migrations into northern Thailand within the 20$^{th}$ century, particularly in the second half when much of the region experienced social turmoil. The traditional land use patterns of the different minority groups were described by Kunstadter and Chapman (1978) as short cultivation-long fallow (also called rotational swidden) or long cultivation-very long fallow (pioneer swidden). It is useful historical characteristic of relevance to the current situation, but not an accurate description of current practices.

The Karen have traditionally made permanent settlements in Highland valleys, and practiced wet rice (paddy) cultivation when possible. The Karen have also traditionally practiced rotational swidden cultivation on the uplands. This agroforestry practice is characterized by short-term cultivation (1-2 years) followed by an 8 or 9 year brush fallow. In contrast to the Karen, the Hmong and Lisu have been more migratory, and wholly dependant on upland slash and burn agriculture. As pioneer swiddeners, the traditional practice was to clear a new patch of forestland, cultivate it continuously for 3 to 10 years and then abandon it and open additional forestland. When all the forest near the village had been exploited, the village would be relocated. Pioneer swiddening produced subsistence crops of rice, maize and vegetables but is also associated with opium cash crop production, which required settlements in the higher elevations most favorable for opium production. Both pioneer and rotational swidden practices have declined in use because of rising populations, dwindling forest resources and increasing conservation and regulatory pressure by the Thai government, which together have forced change from the traditional systems towards the practice of permanent, non-rotational agriculture.

## Study Area

The study area was located about 100 km northwest of Chiang Mai city, at approximately 98° 35' East longitude and 19° 10' North latitude in Pai District, Mae Hong Son Province, northern Thailand and lies within the Royal Forest Department's Tung Jaw Watershed Management Unit, in the Mae Taeng Watershed Management District. The unit is about 120 square kilometers and lies along the provincial border between Chiang Mai and Mae Hong Son. The Management Unit Field Office, which houses Royal Forestry Department (RFD) administrative and forest (fire) protection staff, is located about 12 km from the main Chiang Mai to Pai District highway, off a steep, narrow paved road. The Thung Jaw Watershed Management Unit was formerly part of the Sam Mun Highland Development Project (SM-HDP).

The SM-HDP was initially a joint Thai/UN development project led by the RFD (SM-HDP, 1994). The project operated from 1987 to 1994 and has been continued by the Thai government. The project area was an important commercial opium production region and initial funding came from the UN International Drug Control Program. The project focused on improving the quality of life of the people in the project area and on reducing opium production in the area. To accomplish these objectives, the SM-HDP coordinated activities and services of numerous non-government and government agencies as well as the Royal Thai 7$^{th}$ Army. During the life of the project, great progress was made in basic infrastructure and human resource development, including medical services and agricultural extension. The project was instrumental in developing participatory land use planning for community forest and watershed management.

The Thung Jaw Watershed Management Unit includes the Nam Sa River catchment, which flows into the Pai River and so is part of the Salween River watershed. Elevation within the catchment ranges from 2000 meters at the summit of Doi Mea Ya to 700 meters at the outlet. Soils in the area were sandy to loamy lateritic podsols, a soil group which covers large areas in western parts of northern Thailand (Land Development Department, Report 26). Average temperatures range between 10 and 27 C, with occasional frost. Average annual rainfall in the area is 1500 to 1800mm. There are ten villages within the Nam Sa catchment. The three study villages, Khun Sa Nai, lower Mae Muang Luang and upper Mae Muang Luang, are located within this catchment.

Study Villages

Khun Sa Nai (KSN) is a Hmong village of about of about 75 households and 445 people situated at about 1200 meters elevation near the head of a steeply sloped northwest-facing valley on the flank of Doi Mon Ang Khet. Approximately 190 ha are under cultivation, nearly 40 in wet-rice paddy. Most families have some paddy land. The village lies about 10 km south of the Management Unit Field Office on a good dirt road passable in all seasons with motorbikes and regular pick-up trucks. The village was established about 1950. The government grade school was established in about 1967, seven years before the first road was constructed. Litchi trees were introduced from other Hmong villages around 1980. A new road to the district seat and the current school building were built at the start of the SMHDP around 1987. Japanese apricots and improved varieties of peaches apricots were also introduced then. Opium production "ended" around 1990. Cabbage production began in 1991, in response to outside market development and encouragement by traveling merchants. The use of gravity-fed sprinkler irrigation, with PVC pipes delivering water from up-slope streams, was also introduced at that time. The village does not have electricity.

The villages of upper Mae Muang Luang (UMML) and lower Mea Muang Luang are 2 distinct populations, one Karen and the other Lisu, which lie close together on the same road about 25 km from the Management Unit Field Office and within the same stream basin. Importantly, the two villages are seen as one administrative unit by the government and so share most public services, which are usually delivered in LMML. The government grade school was established there in 1970. The road to the villages was built about 1976. It is a very rough road, unreliable and very difficult to travel in the rainy season, even with motor bikes and 4-wheel drive vehicles. A clinic was established by the SM-HDP around 1987 and is staffed three days as week by a paramedic. SM-HDP extension personnel introduced temperate fruits (i.e. Japanese apricots and peaches) and some sub-tropical fruits around 1987. Water use rights and crop damage by livestock are recurring sources of conflict between the two communities.

Upper Mae Muang Luang (UMML) is a Lisu village of around 25 households 130 people located at about 1300 meters elevation on the southern slope of Doi Mea Ya. The village was established about 1969. The village used to be very involved with opium production, with large areas above the village cleared and planted to the crop each year. Some production continues on a small scale despite annual eradication efforts by the army. About 65 ha are under cultivation in this village. It is almost entirely upland fields, and there is very little paddy. The village is not self sufficient in rice production. Market crop production is restricted by limited water for dry-season irrigation and the unreliable road. Most families depend on wage labor (many work seasonally for the RFD, or in Chiang Mai city) to buy staples.

Lower Mae Muang Luang (LMML) is a Karen village of about 75 households and 380 people. The village was established about over 100 years ago and is located at about 900 meters elevation on gently sloping land, near the bottom of the southern flank of Doi Mae Ya, about 3 km down the slope from UMML. Villagers here did not raise opium. Approximately 90 ha are under cultivation, about 60 of which are in rice paddy. The village is self-sufficient in rice. A limited number of market crops are grown, but cattle and buffalo are commonly raised for market, which are given free range on the mountain above the village.

## DISSERTATION PROJECT

The agroforestry systems described and investigated in this study include a wide spectrum of species and practices. These systems were developed in response to changing socio-political conditions to meet a variety of objectives. Many of these objectives cannot be articulated and defined by the practitioners. In this study, we begin by describing and classifying fruit-based agroforestry from two different approaches and quantified a group of economic, social and environmental factors to explore a methodological process by which fruit-based agroforestry could be evaluated.

Chapter 2 reports on a preliminary classification developed from the initial survey of gardens in 1996. The classification presented is a straightforward and rather conventional approach to agroforestry classification. Groups were separated and defined by differences in certain compositional and functional characteristics. The process resulted in the description of 11 fruit-based agroforestry subsystems, which were reported in the Journal Agroforestry Systems (Withrow-Robinson et al., 1999). These were readily recognizable from field observations, but the process was subjective.

Chapter 3 takes a different approach to a similar, updated data set from the 1998 survey and explores the use of multivariate analysis methods of description and classification. Multivariate analysis methods are appropriate for this sort of complex and variable data, and work by sorting for similarities among the sample units. Seven garden types emerge as subsystems from this process. The relationship of the gardens, based on the characteristics analyzed, is objective. Garden types identified in this process were less easily recognized as members of a group in the field.

Chapter 4 describes the development of a secondary data set, in which we quantified variables to describe production outputs, inputs of materials, labor and cash, as well as other physical and socio-economic factors. These factors are examined on both a garden and household level. There are limitations in the data that restrict their utility for evaluation purposes. Conceptual merits and logistical problems are identified and discussed.

Chapter 5 summarizes and takes a retrospective look at the overall project to see how the individual parts relate to one another. I discuss some of the limitations to the process and the lessons learned through the project.

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# Chapter 2

## A Preliminary Classification of Fruit-Based Agroforestry in a Highland Area of Northern Thailand

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and David Thomas

Withrow-Robinson B, DE Hibbs, P Gypmatasiri and D Thomas (1999). A preliminary classifcation of fruit-based agroforestry in a highland area of northern Thailand.
Agroforestry Systems 42: 195 – 205.

# ABSTRACT

Tree fruit crops are an increasingly important component of highland cropping systems in northern Thailand. A survey was conducted in three highland hill tribe villages in an upland watershed in Mae Hong Son Province to examine and classify the fruit-based cropping activities used by villagers. Members of ten households in each village were interviewed to establish activities and crop histories for each plot of land held by the household. From the sample of 85 “gardens” (plots with ten or more fruit trees), a field-level classification structure was developed reflecting function of trees, use and nature of herbaceous intercrops, and pattern of components. Through the classification process, four groups and 11 subsystems of highland tree fruit-based agroforestry were identified. The single most abundant subsystem was "mixed home gardens". A strong commercial element was also obvious. The survey indicates a very diverse "customized" use of the fruit cropping system. The classification has potential for use in more extensive surveys of the nature of fruit cropping activities in the highlands and as a tool for further analysis in the study area.

# INTRODUCTION

Farming and land use practices in the Highlands of northern Thailand are in transition. In response to many physical and socioeconomic factors, highland farmers, including ethnic minority "hill tribes," have been making a fundamental change from extensive forms of slash and burn agriculture to more intensive short rotation or permanent farming practices (Rerkasem and Rerkasem 1994). This change is often accompanied by a shift in emphasis from subsistence to cash crops. A key element of this change in land use is the recent rise of fruit cropping and fruit-based agroforestry in many highland areas as observed and noted by Poffenberger and McGean (1993), Rerkasem and Rerkasem (1994) and Turkelboom et al. (1996).

There are a number of agroforestry systems now being used in the Highlands. Shifting and rotational agriculture are important traditional systems which emphasize annual crop production and which separate trees and annual crops in time. There are also some traditional systems which mix or utilize trees as crops in the production cycle, such as forest tea gardens ("miang"), and some sparse orchards and home gardens in limited use by different ethnic groups (Del Castillo 1990, C. Korsamphan, pers. comm. 1997). New practices that are part of the transition to permanent farming have also been introduced by development projects over the last two decades. Conservation Farming, including alley cropping, was vigorously promoted in several project areas (Enters 1992). Tree fruit crops were also widely introduced in many areas and trees were frequently distributed to villagers in project areas (Roth et al. 1987, Sam Mun Highland Development Project 1994). But the interest in and adoption of fruit production is not limited to project areas and the fruit system is now an important component of the broader Highland agroforestry picture.

The fruit-based agroforestry system in the northern Thai Highlands incorporates temperate, subtropical and tropical species. The system can be developed from many initial starting conditions and the geographic area which could potentially be converted to this use is large - extending over much of mainland mountainous Southeast Asia. The potential impacts may be large.

Of the crop options available to Highland villagers, fruit cropping appears attractive. In contrast to some agroforestry practices, the fruit-based system contributes products as well as services, some of which have economic potential as cash crops. Also, because of the many crop components and combinations possible, the fruit-based system is highly adaptable and applicable to a wide area and range of physical and social conditions, worldwide. Nair (1984) noted the potential of fruit trees as components of agroforestry systems, and the need to look beyond conventional monoculture research. With the exception of some interest in home gardens, there still has not been much work regarding fruit crop systems. In Mangwende, Zimbabwe, mangoes (*Mangifera indica* L.) were managed as multipurpose trees grown in association with herbaceous crops. The fruit was an important item of home consumption, but not an important source of income

(Musvoto and Campbell 1995). In the Tanzanian highlands, deciduous fruit trees were widespread and common in both fields and homesteads. Fruit trees were seen as contributing to family income, home consumption, land tenure establishment and erosion control (Delobel et al.1991). Suryanata (1994) reported that Fruit-based agroforestry based on commercial production of apples (*Malus domestica* Borkh.) and oranges (*Citrus reticulata* Blanco) was well established in localized areas in highland Java. A change towards more simplified systems with less intercropping was being driven by existing tenure and market pressures. In northern Laos, hill farmers expressed interest in tree crops such as fruit or teak (*Tectona grandis* Linn.f.), but were restricted by market and infrastructure limitations. Commercial fruit plantings in northern Laos remained limited and most tree fruits raised were for home consumption (Roder et al. 1995).

The fruit-based system can be placed in a broader agroforestry classification structure described by Nair (1990) and generally described as an agrisilvicultural, production-oriented system used on sloping lands in a highland moist tropical ecological zone. Although common, the fruit-based system is not uniform, but rather is made up of many different practices or subsystems. An important step in understanding the spread and possible impacts of the fruit-based cropping system is to classify and describe the subsystems in use. An objective of this survey is to develop a practical field-level classification structure for tree fruit-based agroforestry according to physical attributes and functions. The scope of the survey and classification is limited to the fruit-based system used in one watershed area in the Highlands and does not cover all agroforestry systems or all of northern Thailand. Many, but not all, of the fruit-based cropping practices observed are agrisilvicultural mixtures of fruit and other trees with annual crops. Some subsystems do not strictly fit common agroforestry definitions, but are still included to provide a complete picture of fruit cropping activities.

# METHODS

## Survey

A survey was conducted in three Highland villages to examine the nature of tree fruit-based cropping practices employed by the villagers. The study villages were located in the Royal Forest Department's Tung Jaw Watershed Management Unit, Mae Taeng Watershed Management District (formerly part of the Thai-UN Sam Mun Highland Development Project). The Tung Jaw Management Unit was located about 100 km northwest of Chiang Mai city, at approximately 98° 35' East longitude and 19° 10' North latitude in Pai District, Mae Hong Son Province.

The three sample villages were chosen to include a range of environmental, social and ethnic conditions. Khun Sa Nai (KSN) is a Hmong village of about 445 people, lower Mae Muang Luang (LMML) a Karen village with about 380 people, and upper Mae Muang Luang (UMML) a Lisu village of around 130 people. Village elevations ranged from 900 to 1300 m.

Data were collected during a series of visits during the 1996 rainy season, primarily from July to September. Semi-structured interviews were conducted with key informants (i.e. the village head or village elders and medical personnel) to develop a historical overview of events within the village. Ten households were randomly sampled in each village. Semi-structured interviews were conducted with one or more adult members of each of the sample households. During the interviews, the number and location of each plot of land held by the family was established, as well as details of the cropping histories of each plot where tree fruits were grown. Site data on location, physical characteristics, species composition and species arrangement were collected in a survey of each plot of land following the interview.

## Classification

This preliminary classification was based on upland farm plots with 10 or more fruit trees held by the 30 sample households. Groups of plots became apparent during the survey process. Key classifying variables were identified to distinguish the different subsystems and later used in a subjective process to revise and refine groupings. Classifying variables included:

Size of planting (number of fruit trees)

Number of tree species

Size of commercial tree species component

Presence of herbaceous intercrops (past or present)

Nature of intercrops (subsistence or cash crops)

Pattern of trees

Pattern of intercrops

Many of the variables had continuous gradients of values rather than distinct groupings between which to make divisions. Some variables needed to be considered as an interactive group (number of trees, number of tree species and number of commercial trees) without a distinct point of division but rather representing a sliding scale. Therefore, there are no sharp lines of division between the different fruit cropping subsystems; there is a gradient of differences.

## RESULTS

The 30 households of the sample reported holding a total of 151 plots of land, including their home sites. Of these plots, 34 (22.5%) were rice paddy and 117 (77.5%) were upland (hillside) sites. Of the upland sites, 85 of the plots (72.6%) were "gardens" (plots with ten or more fruit trees growing on them), another 12 plots (10.3%) had fewer than 10 trees and 20 (17%) had no fruit trees. Of the 85 garden sites, 41 were located in Khun Sa Nai, 23 in lower Mae Muang Luang and 21 in upper Mae Muang Luang (Table 2.1).

In the 85 gardens surveyed, there was a total of 113 cultivated species counted. This was certainly an underestimate of the number of species actually grown in the villages as the survey was not exhaustive and some plants were identified only to genus. Twenty eight species were considered "perennial fruit trees" with bamboo, bananas (*Musa sp.)* and papayas (*Carica papaya* L.) included in this class although they are not strictly trees. There were also 19 other mostly indigenous tree or shrub species found in the gardens for minor products, living fences etc.. There were also 30 herbaceous vegetable and root crops and 20 medicinal or culinary herbs identified. Herbaceous species were very common in gardens. Respondents indicated that 82.5% of all fruit tree gardens had some history of intercropping, and 62.4% still have some herbaceous crop component in the plot.

The total number of crop species identified in individual gardens ranged from 1 to 55 species (average 12.5). The number of fruit tree species ranged from 1 to 20 per garden (average 6). The planting size, or number of trees in the garden, ranged from 11 to 381 trees in a garden (average 83), and the area from less than 0.08 ha to 1.92 ha. The single most abundant species in a garden (often a commercial species) ranged from 3 to 300 trees. The five most abundant tree fruit species were peach (*Prunus persica* (L.) Batsch), litchi (*Litchi chinensis* Sonn.), Japanese apricot (*Prunus mume* Sieb. et Zucc.), banana and mango (1651, 1354, 934, 714 and 650 trees each, respectively). The most

Table 2.1. Abundance of survey plots in sample according to the presence of fruit trees and whether upland or paddy, in Tung Jaw Watershed Management Unit, Mae Hong Son Province, Thailand. All three villages combined (ALL), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML), upper Mae Muang Luang (UMML).

| | ALL | KSN | LMML | UMML |
|---|---|---|---|---|
| Gardens with > 10 trees (basis of classification) | 85 | 41 | 23 | 21 |
| Uplands with <10 trees | 12 | 4 | 3 | 5 |
| Uplands with no trees | 20 | 8 | 2 | 10 |
| Paddy | 34 | 6 | 24 | 4 |
| Total | 151 | 60 | 51 | 40 |

frequently planted tree fruit species, by the percentages of all gardens in which they are growing, were mangos, jackfruit *(Artocarpus heterophyllus* Lam.), peach, banana and Japanese apricot (66%, 53% 53%, 51% and 51% respectively).

Eleven subsystems of the fruit-based agroforestry system were identified through the classification process (see Table 2.2). These may be put together in four larger groups: A. Home Gardens, B. Home Garden-Like Agroforestry, C. Trees in Fields and D. Conventional Commercial Orchards. Each subsystem had between 2 and 18 garden plots in the group. Five of the subsystems were included in the survey sample in all three villages. Another five were found in two of the three villages. One was in just a single location (see Table 2.3).

Within Group A, Mixed Home Gardens and Home Gardens (MHG and HG) had a small average planting size (34 and 23 trees) and the smallest planting area (0.21 and 0.17 ha) of the subsystems. Total crop species varied greatly between the two subsystems with 22 for the intercropped MHG and only five without intercrops (HG). The number of fruit tree species was intermediate (7 and 5 species) as was the time since establishment of fruit trees (garden age of 9.1 and 7.6 years) and age spread of trees in the garden (7.8 and 9.2 years). The number of the most abundant species was low.

Table 2.2. Classification of fruit-based agroforestry subsystems identified in the Tung Jaw Watershed Management Unit, Mae Hong Son Province, Thailand.

A. Home Gardens

1. **Mixed Home Gardens (MHG)**
   Subsistence oriented, generally small to medium size, with multiple (to many) tree species, but no commercial species abundant. Herbaceous intercropping, mixed and /or zonal, mostly subsistence, some market crops. Also tend to be irregularly spaced, multiple aged.

2. **Home Gardens (HG)**
   Like MHG , except trees only, no herbaceous intercropping.

B. Home Garden-Like Agroforestry

Commercialized Home Gardens

3. **Mixed Commercialized Home Gardens, subsistence intercropping (MCHG, si)**
   Tree component dual function: strong subsistence orientation but with significant commercial component. Generally small to medium size, with multiple (to many) tree species, but one or more commercial species abundant, with mixed herbaceous intercropping. Subsistence herbaceous intercropping only.

4. **Mixed Commercialized Home Gardens, cash intercropping (MCHG, ci)**
   Like MCHG, si, except with cash and subsistence herbaceous intercropping.

Garden-Like Orchards

5. **Mixed Garden-Like Orchards, cash and subsistence intercropping (MGLO)**
   Tree component dual function: market oriented but with significant home-use component. May be small to large size, with multiple (to many) tree species but with one or more commercial species dominant or abundant. With or without herbaceous mixed intercropping. Both cash and subsistence herbaceous intercropping.

6. **Garden-Like Orchards (GLO)**
   Like MGLO except trees only, no herbaceous intercropping.

Table 2.2. Continued.

C. Trees in Fields

7. **Scattered Trees (ST)**
   Fruit trees in herbaceous crop fields. Both annual crops and tree crops for either subsistence or market. Generally small remnants of larger plantings.

8. **Sparse Orchards (SO)**
   Fruit trees mixed in herbaceous crop fields. Trees generally market oriented (i.e. traditional Hmong peach orchards).

D. Conventional Commercial Orchards

9. **Conventional Orchards, subsistence intercropping (CO, si)**
   Tree component market oriented, very small or no subsistence orientation. May be medium to large size, one or more commercial species dominant or abundant, but may have many tree species. Generally also has regular pattern, few or spatially separate age classes. Subsistence intercropping only.

10. **Conventional Orchards, cash intercropping (CO, ci)**
    Like CO, si, except with cash and subsistence intercropping.

11. **Conventional Orchards (CO)**
    Like CO, si, except trees only, no intercropping.

Table 2.3. Frequency of different subsystems overall and in each of the three sample villages in the Tung Jaw Watershed Management Unit, Mae Hong Son Province, Thailand. All tree villages combined (ALL), Khun Sa Nai (KSN) lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| Subsystem | ALL | KSN | -- Location-- LMML | UMML |
|---|---|---|---|---|
| Mixed Home Gardens | 16 | 1 | 13 | 2 |
| Home Gardens | 7 | 3 | 2 | 2 |
| Mixed Commercialized Home Gardens, subsistence intercropping | 8 | 2 | 3 | 3 |
| Mixed Commercialized Home Gardens, cash intercropping | 10 | 7 | 1 | 2 |
| Mixed Garden-Like Orchards, cash and subsistence intercropping | 6 | 6 | 0 | 0 |
| Garden-Like Orchards | 2 | 1 | 1 | 0 |
| Scattered Trees | 4 | 3 | 0 | 1 |
| Sparse Orchards | 6 | 3 | 0 | 3 |
| Conventional Orchards mixed subsistence intercropping | 10 | 1 | 2 | 7 |
| Conventional Orchards, mixed cash intercropping | 10 | 9 | 0 | 1 |
| Conventional Orchards | 6 | 5 | 1 | 0 |
| Total | 85 | 41 | 23 | 21 |

In Group B, Mixed Commercial Home Gardens with subsistence intercropping and Mixed Commercial Home Gardens with cash intercropping had fairly large average planting sizes (116 and 99 trees respectively) and intermediate area (0.44 and 0.64 ha). The total crop species (23 and 12 species) and number of fruit tree species (11 and 8 species) were higher than for Home Gardens. The garden age was intermediate.

In the same group (Group B), Mixed Garden-Like Orchards and Garden-Like Orchards were similar to Commercial Home Gardens in many ways including intermediate garden area (0.48 and 0.68 ha), total number of species (15 and 12 species) and number of fruit species (9 and 10 species). However, the planting size was the highest of all subsystems with 160 and 265 trees, as was the abundance of dominant species in each garden (93 and 122 trees).

In Group C, Scattered Trees and Sparse Orchards had small planting sizes (16 and 45 trees), low total number of species (7 and 7 species ) and low tree species (3 and 3 species), with an intermediate plot area.

In the final group (Group D), Conventional Orchards, subsistence intercropping, Conventional Orchards, cash intercropping and Conventional Orchards, had intermediate planting sizes of 63, 116 and 126 trees but the largest areas per plot (0.42, 0.83 and 1.07 ha). Total species (9, 8 and 2 species) and fruit tree species (3, 4 and 2 species) were low. Some selected characteristics are presented by fruit cropping subsystem in Table 2.4.

Table 2.4. Characteristics of 11 fruit-based subsystems identified in the Tung Jaw Watershed Management Unit, Mae Hong Son Province, Thailand. Includes subsystem average values for the number of fruit trees per plot (Planting Size), number of all cultivated species (Total spp.), number of fruit tree species (Tree spp.), number of trees of most abundant tree species (Abun. spp 1), years since establishment of garden (Garden Age), the age range of trees in garden (Age Spread) and size of the garden plot (Garden Area).

| Sub-system | Planting Size (trees) | Total spp. (spp.) | Tree spp. (spp.) | Abun. spp.1 (trees) | Garden Age (years) | Age Spread (years) | Garden Area (ha) |
|---|---|---|---|---|---|---|---|
| Mixed Home Gardens | 34 | 22 | 7 | 16 | 9.1 | 7.8 | 0.21 |
| Home Gardens | 23 | 5 | 5 | 11 | 7.6 | 2.9 | 0.17 |
| Mixed Commercialized Home Gardens, subsistence intercropping | 116 | 23 | 11 | 45 | 6.9 | 6.3 | 0.44 |
| Mixed Commercialized Home Gardens, cash intercropping | 99 | 12 | 8 | 47 | 9.3 | 7.9 | 0.64 |
| Mixed Garden-Like Orchards, cash and subsistence intercropping | 160 | 15 | 9 | 93 | 10.5 | 7.3 | 0.48 |
| Garden-Like Orchards | 265 | 12 | 10 | 122 | 9.5 | 9.0 | 0.68 |
| Scattered Trees | 16 | 7 | 3 | 11 | 4.3 | 3.8 | 0.72 |
| Sparse Orchards | 45 | 7 | 3 | 34 | 7.0 | 2.7 | 0.80 |
| Conventional Orchards, mixed subsistence intercropping | 63 | 9 | 3 | 55 | 3.6 | 1.9 | 0.42 |
| Conventional Orchards, mixed cash intercropping | 116 | 8 | 4 | 84 | 7.4 | 5.2 | 0.83 |
| Conventional Orchards | 126 | 3 | 2 | 119 | 4.0 | 1.5 | 1.07 |

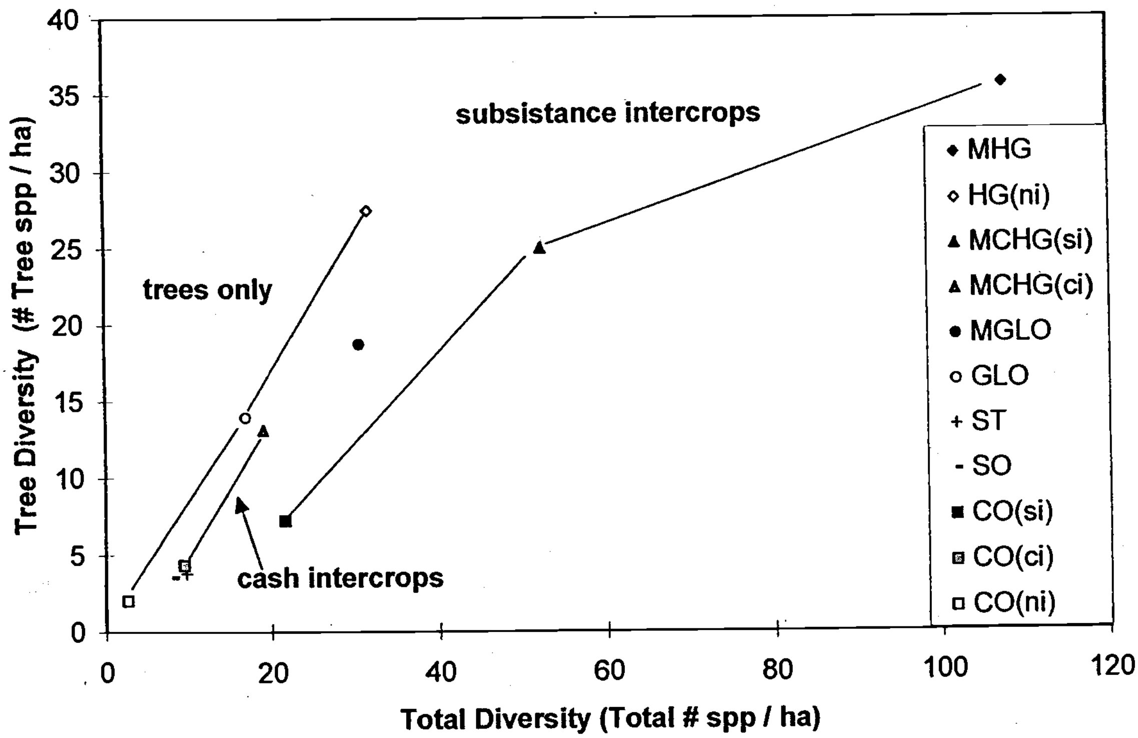
Mango was the most frequently grown fruit tree species in Mixed Home Garden, Home Garden, and both Mixed Commercial Home Garden subsystems (subsistence and commercial intercropping). Banana was second or third most frequent in these subsystems. Litchi was the most frequent species in the Mixed Garden-Like Orchards and Conventional Orchards, Japanese apricot in Scattered Trees and Conventional Orchards (subsistence intercropping) and peach in Sparse Orchards and Conventional Orchards (cash intercropping).

Figure 2.1 uses diversity indexes, the number of tree species and total number of crop species, both calculated on a per hectare basis, to highlight some of the patterns among the subsystems. First, the similarities within each of the four groups of subsystems (Table 2.2) are much greater than among the four groups or all 11 subsystems together. Second, there is a clear and strong trend of complexity of tree and crop species composition from systems with a commercial emphasis to systems dominated by home use.

## DISCUSSION

This survey and classification indicate a wide range of diversity within the fruit-based cropping system used in a highland area in northern Thailand. Villagers "customize" the system to meet their own needs, which are reflected in subsystems that use different patterns and combinations of components. The classification is based on

Figure 2.1. Relationship of tree species diversity and overall crop species diversity in 11 fruit-based subsystems identified in the Tung Jaw Watershed Management Unit, Mae Hong Son Province, Thailand.



form and functional factors relating to economic objective, nature of crops grown, and structure and composition of whole gardens rather than a listing of individual crop species or combinations observed in the survey area.

Fruit cropping has been widely accepted in the study area, where the majority of upland farm plots are now some type of garden. Fruit is grown for both home consumption as well as for commercial reasons, both of which were project objectives of the Sam Mun Highland Development Project. Home gardens and home garden-like agroforests are very abundant and crop diversity is generally high. Economic objectives clearly also have an important role in Home Garden-Like Agroforestry as well as more conventional Commercial Orchard subsystems. Few of the commercial orchards have exclusively cash crops. The majority have some small home-use function as well. Most of the subsystems appear to incorporate dual home and commercial functions.

These systems are very dynamic, as indicated by the age structures and age ranges of the gardens. Composition and abundance of species are changed frequently through death and additional planting. Few gardens are established within a year. Many of the gardens are not yet "mature" but are still in development. It can be concluded that many gardens' classifications would likely be different five years before and again five years after the current classification. The composition of young orchards does not necessarily indicate what the nature of the garden will be in the future. Although each subsystem represents a coherent group, there are no sharp lines of division between the different fruit cropping subsystems but rather a gradient of differences. These groups could be rearranged or further subdivided if the list of classifying variables were altered.. Also, the survey was not exhaustive, but limited in area and not all possible patterns were encountered. However, a framework now exists to which other subsystems can be added.

This classification can be useful in two important ways. First, it can be used as a tool for further analysis in the study area. Second, it can be used as a survey tool to help develop a better picture of the nature of fruit cropping activities over a wider area of the Highlands in northern Thailand, mainland Southeast Asia, and perhaps elsewhere. Both uses are relevant to ongoing development and resource management activities in northern Thailand. In the next phase of this study, we will examine the economic, social and ecological costs and benefits of these systems.

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# Chapter 3

## A Classification of Fruit-based Agroforestry in a Highland Area of Northern Thailand

Bradford A. Withrow-Robinson and David E. Hibbs

# ABSTRACT

Tree fruit crops have become an important component of Highland cropping systems in northern Thailand over the last two decades. In 1998 we conducted a survey in three Highland hill tribe villages in an upland watershed in Mae Hong Son Province to examine and classify the fruit-based cropping activities used by villagers. Members of ten households in each village were interviewed to establish activities and crop histories for each parcel of land held by the household. Eighty-two gardens (parcels with 10 or more trees) were surveyed and data collected on crop species composition, species abundance, perennial crops age groups and other physical factors. Multivariate analysis was used to investigate relationships and to classify types of fruit-based agroforestry gardens in the study area. Non-metric multidimensional scaling (NMS) analysis was used to assist in screening a large data set for selection of variables to be included in the classification data set and in interpretation of analysis gradients. Hierarchical Cluster Analysis was used to divide the gardens into seven clusters, each cluster representing a different type of fruit-based agroforestry subsystem, or garden type. Indicator species analysis was used to shed light on factors most influential in the formation of garden types. Interpretation of the NMS graphs shows overall crop diversity, herbaceous food crops, and size and market potential of the fruit planting as important classifying factors.

The seven garden types are described by summary statistics, location in ordination space and the indicator values. The garden types were not all immediately recognizable or apparent in the initial field data, and the data had a wide range and large overlap of

group characteristics. The multivariate analysis indicates that the gardens may not represent discrete categories as we presumed, but rather are part of a continuum of individual gardens of gradually changing and overlapping characteristics. Patterns can be seen, but the lack of distinct groups appears to indicate that it is the landowners' practice to mix functions as well as plant species, without a strong organizational pattern. Some explanations of the observed associations are presented, the utility of the groups, and the viability of the process by which they were generated are discussed.

## INTRODUCTION

In response to shifting physical and socioeconomic conditions in the highlands of northern Thailand, Highland farmers, including ethnic minority "hill tribes," have been making a fundamental change from extensive forms of slash and burn agriculture to more intensive short rotation or permanent farming practices (Rerkasem and Rerkasem, 1994). This change has often been accompanied by a shift in emphasis from subsistence to cash crops such as soybeans, cabbage or litchi. An important element of this change in land use was the expansion of fruit cropping and fruit-based agroforestry in many highland areas as described by Poffenberger and McGean (1993), Turkelboom et al. (1996) and Withrow-Robinson et al. (1999).

There are a number of agroforestry systems used in the northern Thai Highlands (Gypmantasiri, 1993). Shifting and rotational agriculture are still important traditional systems which emphasize annual crop production and which separate trees and annual crops in time. There are also some traditional systems that include trees as crops in the production cycle, such as forest tea gardens ("*miang*"), and some sparse orchards and home gardens in limited use by different ethnic groups (Del Castillo 1990, Korsamphan, pers. comm., 1997). New practices that are part of the transition to permanent farming have also been introduced by development projects over the last two decades. Conservation farming, including alley cropping, was vigorously promoted by several development projects (Enters, 1992). Tree fruit crops were also widely introduced in many areas and trees were frequently distributed to villagers in project areas (Roth et al. 1987, Sam Mun Highland Development Project 1994). But the interest in and adoption of fruit production is not limited to project areas and the fruit system is now an important component of the broader Highland agroforestry picture (Rerkasem and Rerkasem, 1994).

The fruit-based agroforestry system in the northern Thai Highlands incorporates temperate, subtropical and tropical species (Withrow-Robinson et al. 1999). The system can be developed from many initial starting conditions and the geographic area which could potentially be converted to this use is large - extending over much of mainland mountainous Southeast Asia. The potential impacts are large.

Of the crop options available to Highland villagers, fruit cropping appears attractive. In contrast to some agroforestry practices, which focus on services such as erosion control, the fruit-based system can contribute products for market or home consumption as well (Roth et al., 1987, Enters, 1992). Planting fruit trees has generally been regarded by non-government and government agencies including the Royal Forestry Department (RFD) as an acceptable Highland cropping option (Poffenberger and McGean, 1993). Also, because of the many crop components and combinations possible, the fruit-based system is highly adaptable and applicable to a wide range of physical and social conditions, worldwide. Nair (1984) noted the potential of fruit trees as components of agroforestry systems, and the need to look beyond conventional monoculture research.

Much of what has been written describing fruit in agroforestry has appeared in the extensive literature about home gardens. These reports have documented composition, structure and production of goods for home consumption as well as sale of excess or of cash crops (see, for example, Christanty et al., 1985, Fernandes, 1984, Moreno-Black et al., 1996). There has been less work describing the role of fruit cropping practices and systems. Musvoto and Campbell (1995) described the management of mangoes (*Mangifera indica* L.) as multipurpose trees grown in association with herbaceous crops in Zimbabwe. The fruit was an important item of home consumption, but not an important source of income. In the Tanzanian highlands, deciduous fruit trees were widespread and common in both fields and homesteads (Delobel et al., 1991). Fruit trees were seen as contributing to family income, home consumption, land tenure establishment and erosion control. In West Kalimantan, Indonesia, durian (D*urio zibethinus*) were a key product produced in forest gardens and home gardens (Salafsky, 1994). In highland Java, Indonesia, Suryanata (1994) reported that fruit-based agroforestry utilizing apples (*Malus domestica* Borkh.) and oranges (*Citrus reticulata* Blanco) for commercial production was well established in localized areas. Tenure and market pressures were driving a change towards more simplified systems with less intercropping in the Javanese highlands. In northern Laos, hill farmers expressed interest in tree crops such as fruit or teak (*Tectona grandis* Linn.f.), but were restricted by market and infrastructure limitations (Roder et al., 1995). Commercial fruit plantings in northern Laos remained limited and most tree fruits raised were for home consumption.

The fruit-based system can be placed in a broader agroforestry classification structure (Nair, 1990) and described generally as an agrisilvicultural, production-oriented system used on sloping lands in a highland, moist tropical ecological zone. Although common, the fruit-based system is not uniform, but rather is made up of many different practices or subsystems. An important step in understanding the spread and possible impacts of the fruit-based cropping system is to classify and describe the subsystems in use.

The objectives of this paper were to classify gardens in the study area into fruit-based agroforestry subsystem types and investigate relationships between the subsystem types using multivariate analysis methods. The scope of the survey and classification was limited to the fruit-based system used in one watershed area in the Highlands and did not cover all agroforestry systems or all of northern Thailand.

# METHODS

## Survey and Sampling

A survey was conducted in three Highland villages to examine the nature of tree fruit-based cropping practices employed by the villagers. The study villages were located in the Royal Forest Department's Tung Jaw Watershed Management Unit, Mae Taeng Watershed Management District (formerly part of the Thai-UN Sam Mun Highland Development Project). The Tung Jaw Management Unit was located about 100 km northwest of Chiang Mai city, at approximately 98° 35' East longitude and 19° 10' North latitude in Pai District, Mae Hong Son Province, in northern Thailand.

The three sample villages were chosen to include a range of environmental, social and ethnic conditions. Khun Sa Nai (KSN) is a Hmong village of about 445 people, lower Mae Muang Luang (LMML) is a Karen village with about 380 people, and upper Mae Muang Luang (UMML) is a Lisu village of around 130 people. The three villages are located at elevations of approximately 1200, 900 and 1300 meters above sea level, respectively.

Data were collected during a series of visits in two years, primarily during the rainy seasons, from July to September, 1996 and June to August, 1998. Semi-structured interviews were conducted with key informants in each village in 1996 to develop an overview of the situation and historical events within the village. Semi-structured interviews are a part of the Rapid Rural Appraisal methodologies in which an investigator follows an outline of questions rather than a formal, structured questionnaire (Chambers, 1993). This allows more interaction and involvement with the interviewee who can then better introduce information that is of importance to him or her. Key informants interviewed in this study included the village head, village elders, public school personnel and medical personnel.

Ten households in each village were randomly selected as sample households. Semi-structured interviews were conducted with an adult member of each sample household in 1996. During the interviews, the number, location, type (paddy versus upland), approximate size and age of each parcel of land held by the family was established. If a parcel included fruit trees, then the age of planting, the type of and number of trees planted, fertilizer or pesticide input use and other cropping history details were collected.

Following the interview, each upland parcel was visited and information on location, aspect and crop type was recorded. Parcels with fruit trees were of particular interest to this study; a parcel had ten or more fruit trees was defined as a 'garden'. A garden is the sample unit for classification. Thus, sample unit area varied. Each garden was walked in an orderly manner and sketch-mapped to allow for complete census and recording of crop species composition, abundance, approximate ages and range of ages of fruit trees, and spatial arrangement of crops within the garden. Of interest were any species actively cultivated, or also any retained for some minor product or use. Weed species were not identified or counted.

Cultivated trees and shrubs were identified to genus and species when possible, and individual trees counted. These species were separated into groups by crop-type: fruit trees, other trees (generally non-cultivated wild species retained in gardens) and living fences. For the purpose of this study, some non-woody species such as bananas, bamboo and papaya, and shrubs such as tea and coffee, were considered fruit trees for cultural rather than botanical reasons.

Cultivated herbaceous crops were also identified when possible to genus and species and classified into one of two crop-type groups: herbaceous food crops (vegetables, roots or grains), and medicinal or culinary crops. The abundance of each species was estimated on a 5-step scale indicating the area occupied by or given to the crop ($<1m^2$ ; $1m^2$ - $16m^2$; $16m^2 - 80m^2$; $81m^2 - 400m^2$; $> 400\ m^2$). This was an estimate of area allocated, not of percent cover; thus a patch of peppers would receive the same abundance rating regardless of developmental stages of the crop in its growing season. Ornamental species were not identified and listed, but were simply tallied on a per garden basis. Each garden was classified for pattern and distribution of the crop species (mixed or separate; rows or disorderly), and age distribution (single or multiple ages; if multiple, approximate ages).

Garden data were revised in 1998, when each garden was revisited and another crop census made. The 1998 data serves as the basis of this analysis. There were some changes in the parcels between 1996 and 1998, resulting in three fewer parcels included in the 1998 survey. Nine were withdrawn due to abandonment, destruction (fire or livestock) or by sale, and another six were added. Cropping history and site information were gathered for the new gardens in 1998.

Classification was based on the characteristics of fruit gardens on upland parcels held by the sample households. Groupings of garden parcels became apparent during the initial survey process in 1996 and were reported in Withrow-Robinson et al. (1999). Analyses using multivariate techniques were used in this paper to separate the gardens (sample units) into clusters and examine relationships within and among these clusters. Clusters of related gardens represented different types of fruit-based agroforestry subsystems.

### Data Analysis

Multivariate analyses were used to investigate relationships and to classify types of fruit-based agroforestry gardens in the study area using 1996 background information and 1998 field survey data. Non-metric multidimensional scaling (NMS) analysis was used to assist in screening a large initial data set to select variables to be included in the smaller classification data set which was used for hierarchical cluster analysis and indicator species analysis. Data were compiled in spreadsheets and summarized in SAS (SAS Institute Inc., 1989).

NMS is an iterative ordination process for ranking locations of data points to minimize the stress in a reduced multidimensional configuration. Stress is described as the departure from monotonicity, or the difference in distances between points in the original multi-dimensional space of the data matrix and the distance in the reduced-dimensional space of the ordination matrix (McCune and Mefford, 1999). NMS is suited to data sets that are non-normal and are on arbitrary or discontinuous scales, because it replaces assumptions of linearity with a less problematic assumption of monotonicity (Gauch, 1982). The Sorensen distance measure was used to calculate distances in ordination space between the sample units.

The large, initial data set included many types of data: counts of individual trees and shrubs by species; estimates of abundance of herbaceous crops; sums of the number of species in a crop-type group; number of fruit crops with a "market unit" (crops that reached an estimated marketable threshold), number of herbaceous market units; age structure of garden (number of age classes, range in age of classes) spatial arrangement (rows, blocks, dispersed, etc.) and intercropping history. The initial data set had 129 variables (Appendix A).

The initial data matrix was adjusted before the NMS screening procedure: missing values were filled with column means and rare variables (occurring in < 6% of sample units) were deleted; data based on counts (i.e. abundance of each tree species, total number of species, abundance of all fruit trees) were relativized by sample unit totals (general procedure in PC-ORD, McCune and Mefford, 1999) to adjust for influences of variable sample unit sizes before being combined with the other continuous variables into a single matrix. All variables were then relativized by variable maximum to equalize means and variances, so all would carry equal weight in the analysis (algorithms of Mather, 1976 and Kruskal, 1964 adapted 5 for PC-ORD software, by McCune and Mefford, 1999). The initial data set was a matrix of 57 quantitative variables x 82 sample units.

The screening NMS procedure produced a three dimensional solution which minimized and stabilized stress by the 58$^{th}$ iteration. Values from Pearson correlation with the ordination axes were then used to select variables for a smaller data set for classification and other analysis: the "classification data set". An r-value of 0.45 or larger in any of the three ordination axes was used as the threshold to select variables with the greatest impact on the solution. Twenty-two variables were selected for the classification data set (Table 3.1a).

The classification data set was built for the selected 22 variables and adjusted for analysis in the same manner as for the screening NMS procedure: data based on counts were relativized by sample unit totals before being combined with other variables into a single matrix (22 variables x 82 sample units) which was then relativized by variable maximum.

Table 3.1. Variables selected for (a.) the classification data set (primary matrix) and (b.) the secondary matrix.

(a.)

| **Variable** | Unit | Type |
|---|---|---|
| Lime | tree | Quantitative |
| Japanese apricot | tree | Quantitative |
| Tamarind | tree | Quantitative |
| Pineapple | abundance | Quantitative |
| Squash | abundance | Quantitative |
| Maize | abundance | Quantitative |
| Lemon grass | abundance | Quantitative |
| Herb | abundance | Quantitative |
| Total crop diversity | species | Quantitative |
| Fruit tree | species | Quantitative |
| Living fence | species | Quantitative |
| Herbaceous food crop | species | Quantitative |
| Medicinal and culinary | species | Quantitative |
| Planting size | fruit trees | Quantitative |
| Dominant fruit | fruit trees | Quantitative |
| Number of market fruit species | species | Quantitative |
| Number of market vegetable species | species | Quantitative |
| Number of Age classes of fruit trees | years | Quantitative |
| Range of age classes for major fruits | years | Quantitative |
| Total range of age classes of fruit | years | Quantitative |
| Years intercropped | years | Quantitative |
| Ratio of years intercropped to garden age | ratio | Quantitative |

Table 3.1. Continued.

(b.)

| **Variable** | Unit | Type |
|---|---|---|
| Vegetables for market | yes/no | Catagorical |
| Fruits for market | yes/no | Catagorical |
| Market unit of coffee | yes/no | Catagorical |
| Market unit of litchi | yes/no | Catagorical |
| Market unit of mango | yes/no | Catagorical |
| Market unit of bananas | yes/no | Catagorical |
| Market unit of Japanese apricot | yes/no | Catagorical |
| Market unit of peach | yes/no | Catagorical |
| Road access to village | yes/no | Catagorical |
| Chemical fertilizer use (past 5 years) | yes/no | Catagorical |
| Herbicide use (past 5 years) | yes/no | Catagorical |
| Irrigation use (past 5 years) | yes/no | Catagorical |
| Slope | % | Quantitative |
| Log of distance to house | meters | Quantitative |
| Log of distance to road | meters | Quantitative |
| Log of distance to irrigation | meters | Quantitative |
| Log of parcel area | meters | Quantitative |
| Elevation | meters | Quantitative |

A secondary set of categorical data included environmental factors and indices of economic purpose: whether or not the garden includes any market units of fruit, or herbaceous plants (vegetables), what crops reached a "market unit" threshold, and cultural inputs such as fertilizers, pesticides and irrigation (Table 3.1b). Distance and area values were adjusted for analysis by log transformation.

The data set used in the classification procedure was then analyzed using NMS to investigate relationships among fruit-based agroforestry gardens in the study area. A three-dimensional solution was selected with a final stress of 10.63, a final instability of 0.00046 after 61 iterations.

Cluster analysis was used to classify the garden types according to characteristics represented in the classification data set. Cluster analysis defines groups based on their similarities by minimizing distances in the distance matrix. Gardens were clustered using the Euclidean (Pythagorean) distance measure and Ward's linkage method, a sequential, hierarchical, agglomerative, polythetic technique, using PC-ORD software (Ward, 1963 adapted by McCune and Mefford 1999).

Indicator species analysis (ISA) combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a species in a particular group, to produce an indicator value (McCune and Mefford 1999). Indicator values show the degree to which that species variable points to a particular group (for this data set). Indicator variables are produced for each species and expressed as a percent of perfect indication of a species for a group. PC-ORD (McCune and Mefford, 1999) uses Dufrene and Legendre's (1977) method for this procedure. ISA can also test for the significance of the maximum indicator value recorded for a given species. The Monte Carlo test produces a P-value that indicates the probability of the largest indicator value being derived from random data.

## RESULTS

The 30 households in the study reported holding a total of 149 parcels, including home sites (Table 3.2). Of these parcels, 34 (23%) were wet rice paddy and 115 (77%) were upland (hillside) sites. Of the 115 upland parcels, 82 (71%) were fruit 'gardens' (parcels with 10 or more fruit trees), another 13 parcels (11%) had one to 10 fruit trees and 20 sites (17%) had no fruit trees. Of the 82 garden parcels, 41 were located in Khun Sa Nai, 19 in Lower Mae Muang Luang, and 22 in upper Mae Muang Luang.

### Characteristics of Gardens

Crop diversity (number of cultivated species counted) totaled 96 species in the 82 gardens surveyed in 1998 (Appendix A shows full species list). Of the 96 cultivated species, 31 were considered fruit trees. There were also 15 other trees, mostly indigenous tree (or shrub) species found in the gardens which were retained for minor fruit, nut, or

Table 3.2. Abundance of parcels held by sample households in 1998 by the presence of fruit trees and whether upland or paddy, in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (ALL), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| | ALL | KSN | LMML | UMML |
| Gardens | 82 | 41 | 22 | 19 |
| Uplands with few trees | 13 | 4 | 3 | 6 |
| Uplands with no trees | 20 | 9 | 1 | 10 |
| Paddy fields | 34 | 6 | 24 | 4 |
| Total | 149 | 60 | 50 | 39 |

Table 3.3. Crop diversity by mean number of species per garden in each crop-type group, planting size and dominant tree abundance for garden parcels in 1998 in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (ALL), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| Variable (units) | ALL | KSN | LMML | UMML |
| Total crop diveirsity (species) | 12.0 | 11.7 | 15.0 | 9.4 |
| Fruit tree (species) | 6.7 | 7.2 | 7.6 | 4.7 |
| Other tree (species) | 0.6 | 0.3 | 1.3 | 0.3 |
| Living fence (species) | 0.3 | 0.2 | 0.7 | 0.1 |
| Herbaceous food (species) | 3.5 | 3.2 | 4.0 | 3.5 |
| Medicinal and culinary herb (species) | 1.0 | 0.8 | 1.4 | 0.7 |
| Planting size (trees) | 82.8 | 115.2 | 50.1 | 51.1 |
| Dominant fruit species (trees) | 48.9 | 69.7 | 23.6 | 33.2 |
| Number of market vegetables (species) | 0.5 | 0.8 | 0.1 | 0.1 |

other products and also 3 species used as living fences. There were 30 herbaceous food crops and 17 herbaceous medicinal or culinary herbs identified. Ornamental species were also quite common, with as many as 14 in a garden.

Total crop diversity at the garden level averaged 12.0 cultivated crop species per parcel, with an overall range from 1 to 33 species per garden. There was an average of 6.7 fruit tree species (range 1-17) and less than one other tree (mean = 0.6, range 0 to 4) or living fence species (mean = 0.3, range 0 to 3 species) per garden. There was an average of 3.5 herbaceous food crop species (range 0 to 11), and 1.0 medicinal and culinary species (range 0 to 7). Crop diversity by mean number of species in each crop-type group, by village unit is shown in Table 3.3.

Planting size of the average garden was 82.8 individual fruit trees (range 11 to 484) per garden (Table 3.3). Combined, there were a total of 6793 fruit trees in the garden parcels. The degree with which a garden was dominated by a single tree species ranged from 17% to 100% (average 58.8). The abundance of the single most abundant (dominant) fruit tree species averaged 48.9 trees per parcel (range 3 to 327). Gardens were situated from 800 m to 1500 m elevation above sea level, and were located from immediately adjacent to the home to 7.5 km away. Garden size averaged 0.56 ha (ranged 0.06 ha to 2.9 ha). Tree planting density averaged 208 trees/ha (range13 to710 t/ha). This density reflects that all species, including shrubs such as coffee and tea were included.

The five most abundant tree fruit species in all the gardens overall were peach, litchi, Japanese apricot, coffee and mango (1528, 1322, 794, 772 and 632 combined trees each, respectively). Mean abundance of fruit tree species overall and by village are shown in Table 3.4. The most frequently planted tree fruit species, by the percentages of all gardens in which they are growing, were mangos, jackfruit, banana, peach, Japanese apricot and litchi (73.1%, 57.3%, 57.3%, 53.7%, 53.7 and 52.4% respectively, Table 3.5). Six fruit species were present in more than 50% of the gardens while eight species were present in 5% or less of the gardens.

There was a wide range in age of fruit trees within gardens. The number of age classes of the fruit trees in a garden averaged 2.9 age classes (range 1 to 11). The range from the youngest trees to the oldest averaged 5.6 years but ranged from 1 to 30 years.

## Non-metric Multidimensional Scaling

An NMS analysis using the classification data set (of 22 selected variables) as the primary matrix revealed many strong correlations with the ordination axes (Appendix B). The strongest correlation appeared along axis 1(Figure 3.1) with the variable for total crop diversity ($r = 0.84$). Axis 1 was also correlated with the total number of fruit tree species ($r = 0.83$), the abundance of the dominant fruit species ($r = -0.80$), the number of age classes ($r = 0.59$), the number of herbaceous medicinal and culinary species ($r = 0.55$), the number or years of intercropping ($r = 0.55$), the number of living fence

Table 3.4. Abundance (1998 mean values) of important fruit species for garden parcels in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (ALL), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| Species (units) | ALL | KSN | LMML | UMML |
| Jack fruit *A. heterophyllus* (trees) | 2.6 | 2.8 | 3.2 | 1.3 |
| Lime *citrus aurantifolia* (trees) | 0.5 | 0.2 | 1.3 | 0.3 |
| Coffee *C. arabica* (trees) | 9.4 | 12.0 | 4.6 | 9.5 |
| Litchi *L. chinensis* (trees) | 16.1 | 30.0 | 2.5 | 2.1 |
| Mango *M. indica* (trees) | 7.7 | 9.6 | 7.1 | 4.5 |
| Banana *Musa* cvs (clumps) | 6.4 | 2.4 | 15.6 | 4.5 |
| Japanese apricot *P. mume* (trees) | 9.7 | 10.2 | 4.3 | 14.8 |
| Peach *P. persica* (trees) | 18.6 | 31.3 | 1.8 | 10.7 |
| Guava *P. guajava* (trees) | 0.9 | 0.5 | 2.0 | 0.5 |
| Pear *P. pyrifolia* (trees) | 2.5 | 4.5 | 0.4 | 0.7 |
| Tamarind *T. indica* (trees) | 0.8 | 2.9 | 2.1 | 0.2 |

Table 3.5. Frequency of some characteristic crop species (as % of gardens in which they were present in 1998) in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (ALL), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | | Village | | |
|---|---|---|---|---|
| Species (units) | ALL | KSN | LMML | UMML |
| (n) | (82) | (41) | (19) | (22) |
| Jack fruit *A. heterophyllus* (%) | 57.3 | 63.4 | 63.6 | 36.8 |
| Lime *C. aurantifolia* (trees) | 24.4 | 14.6 | 45.5 | 21.1 |
| Coffee *C. arabica* (%) | 20.7 | 14.6 | 31.8 | 21.1 |
| Litchi *L. chinensis* (%) | 52.4 | 63.4 | 50.0 | 31.6 |
| Mango *M. indica* (%) | 73.2 | 73.2 | 86.4 | 57.9 |
| Banana *Musa* cvs (%) | 57.3 | 53.7 | 77.3 | 42.1 |
| Japanese apricot *P. mume* (%) | 53.7 | 56.1 | 27.3 | 78.9 |
| Peach *P. persica* (%) | 53.7 | 75.6 | 22.7 | 42.1 |
| Guava *P. guajava* (%) | 25.6 | 12.2 | 54.5 | 21.1 |
| Pear *P. pyrifolia* (%) | 28.0 | 34.1 | 18.2 | 26.3 |
| Tamarind *T. indica* (%) | 29.3 | 19.5 | 63.6 | 10.5 |
| Pineapple (%) | 23.2 | 19.5 | 45.1 | 0.0 |
| Squash *Cucurbita sp.* (%) | 46.3 | 46.3 | 40.9 | 52.6 |
| Maize *Z. mays* (%) | 43.9 | 43.9 | 36.4 | 52.6 |
| Lemon grass (%) | 24.4 | 22.0 | 36.4 | 15.8 |
| *Z. cassumnar* (%) | 11.0 | 4.9 | 31.8 | 0.0 |

species (r = 0.53), the range in ages of fruit trees (r = 0.51), the species variable for tamarind (r = 0.50), and the number of Japanese apricot trees (r = -0.50). Axis 1 can be interpreted as reflecting the overall crop diversity of the gardens, and particularly the diversity of the fruit tree component. Along this axis there are correlations suggesting a pattern of low crop diversity and high numbers of the dominant fruit tree species on the left hand side, and high crop diversity and low numbers of the dominant tree species on the right.

Fewer variables had strong correlation values with axis 2. Axis 2 was correlated with the number of herbaceous food crops (r = 0.80, Figure 3.2), the abundance of squash (r = 0.77), maize (r = 0.69), the total crop diversity (r = 0.60) and negatively with planting size (r = -0.52). Thus, axis 2 appears to reflect the importance of herbaceous food crops, and particularly those used in the household, as might be found in the smaller gardens.

Of the three, axis 3 had the weakest correlation with the variables. This axis was correlated with planting size (i.e. the number of fruit trees planted, r = - 0.67, Figure 3.3), the number of market fruit species (r = - 0.54), the range of age classes of major fruits (r = 0.55), the years of herbaceous intercropping (r = 0.54) and number of age classes (r = 0.52) and ratio of years of intercropping to age of planting (r = 0.52). Axis 3 seems to reflect an inverse relationship with the increasing size of the fruit planting, which may relate in part to the interest in or potential market production of the fruit component.

Figure 3.1. NMS graph of sample units in ordination space along the first and second axes, with a graphic overlay of the variable for total crop diversity. The size of the triangle is proportional to the size of the variable.

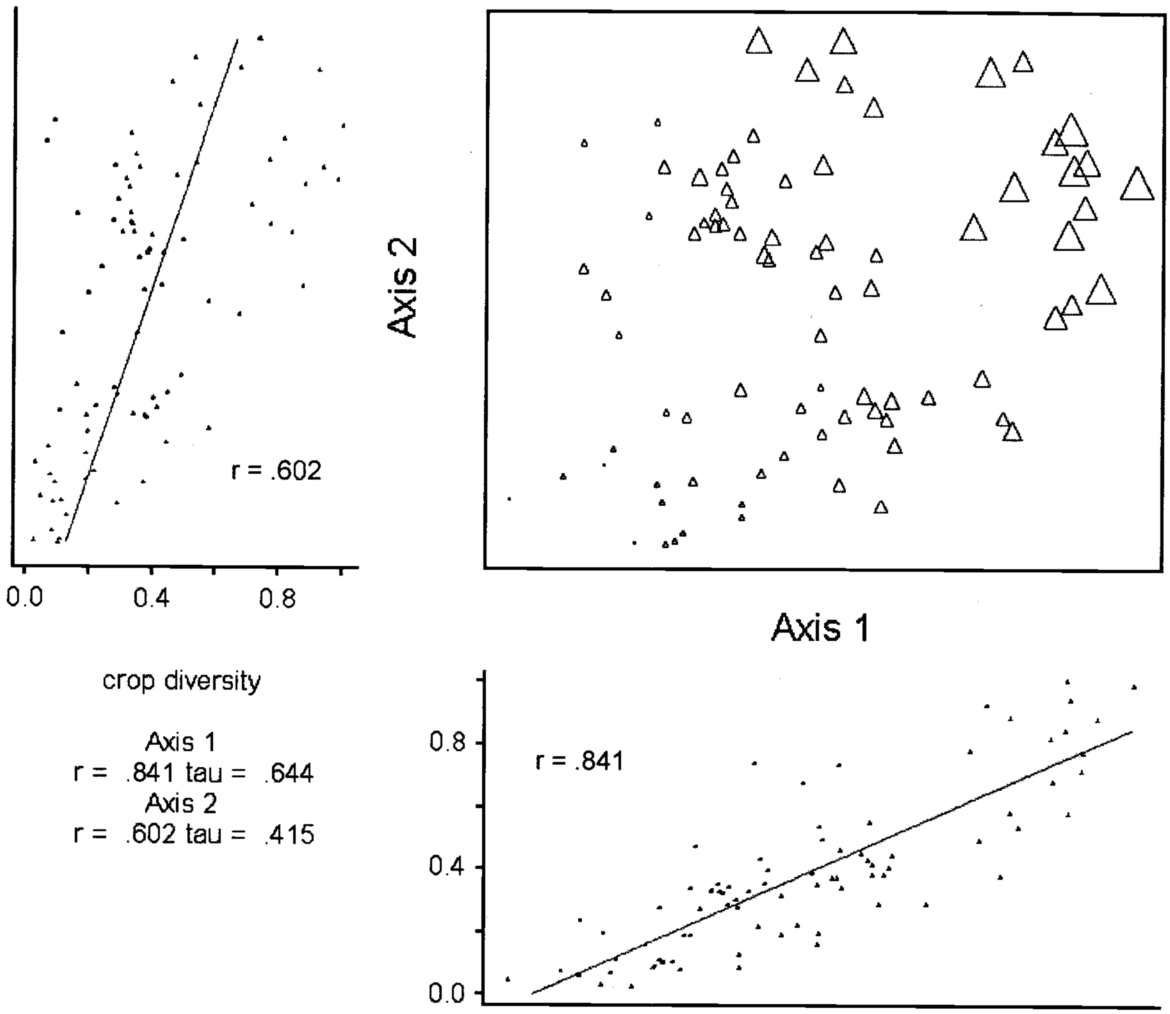
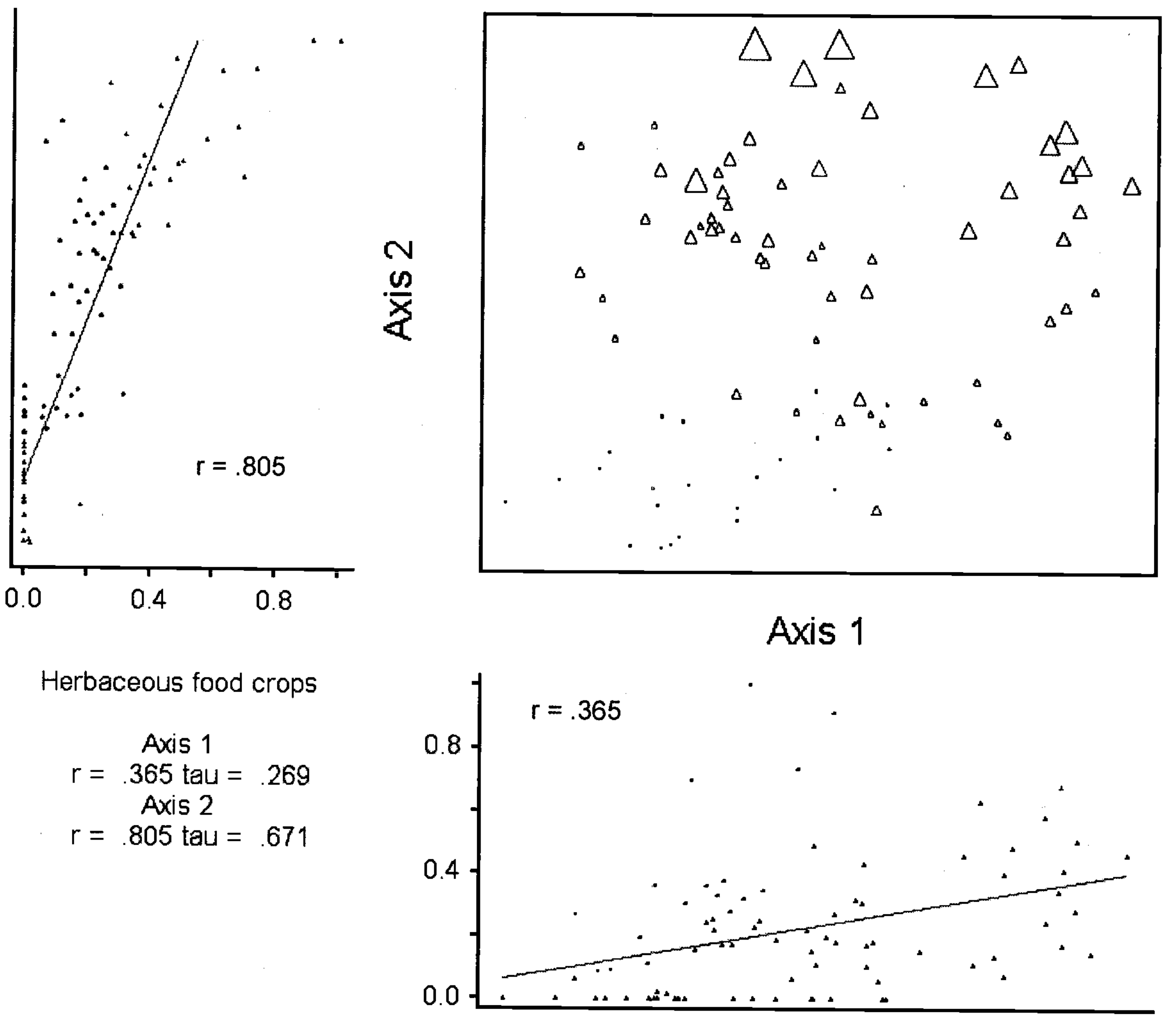


Figure 3.2. NMS graph of sample units in ordination space along the first and second axes, with a graphic overlay of the variable for herbaceous food crops. The size of the triangle is proportional to the size of the variable.



To summarize the interpretations of variable correlations, axis 1 can be interpreted as reflecting the overall crop diversity of the gardens and particularly the diversity of the fruit tree component. Axis 2 appears to reflect an increasing importance of herbaceous food crops, particularly those used in the home. Axis 3 seems to reflect an inverse relationship with the increasing size of the fruit tree planting, which may relate in part to the interest or potential for market production.

There were only three environmental variables from the secondary matrix with significant correlations with the ordination axes, none of which were very strong. All of these correlations are negative and along the first axis. The variables are the log of distance to house ($r = -0.64$), log of parcel size in hectares ($r = -0.64$) and slope ($r = -0.51$). These correlations suggest that crop species diversity increases as distance from the garden to the house and parcel size and slope all diminish.

## Cluster Analysis of Gardens

The Cluster Analysis developed linkages between the 82 sample gardens (from 22 variables in the classification data set). Individual sample units were progressively joined with other sample units or clusters of units according to similarities in their characteristics. These relationships are illustrated by the hierarchical dendrogram, (Figure 3.4) which has a low 2.4 percent chaining. Chaining is the sequential addition of small groups to a larger group. A division was made to produce seven clusters. Each cluster represents a different

Figure 3.3. NMS graph of sample units in ordination space with a graphic overlay of variable for planting size (number of fruit trees). The size of the triangle is proportional to the size of the variable.

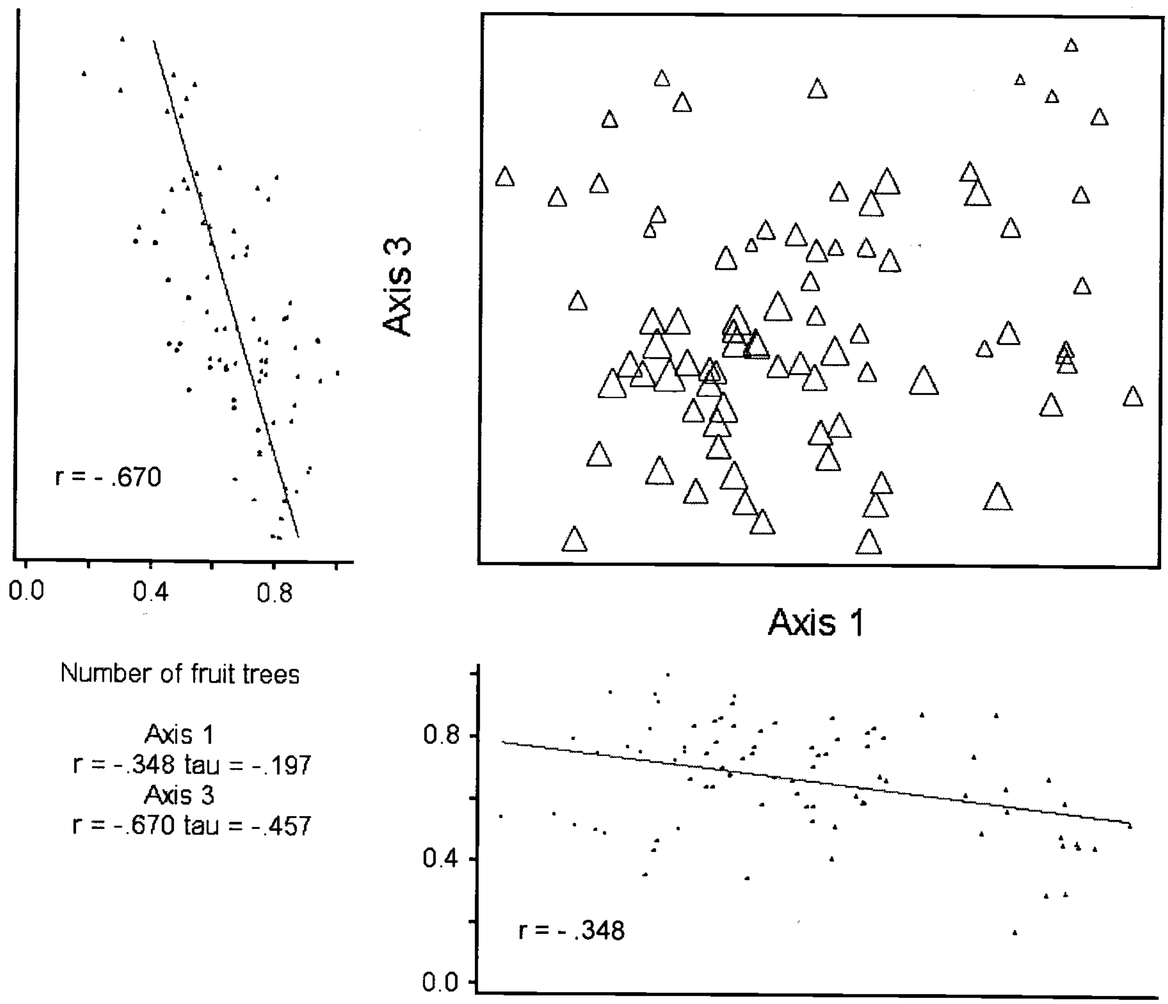
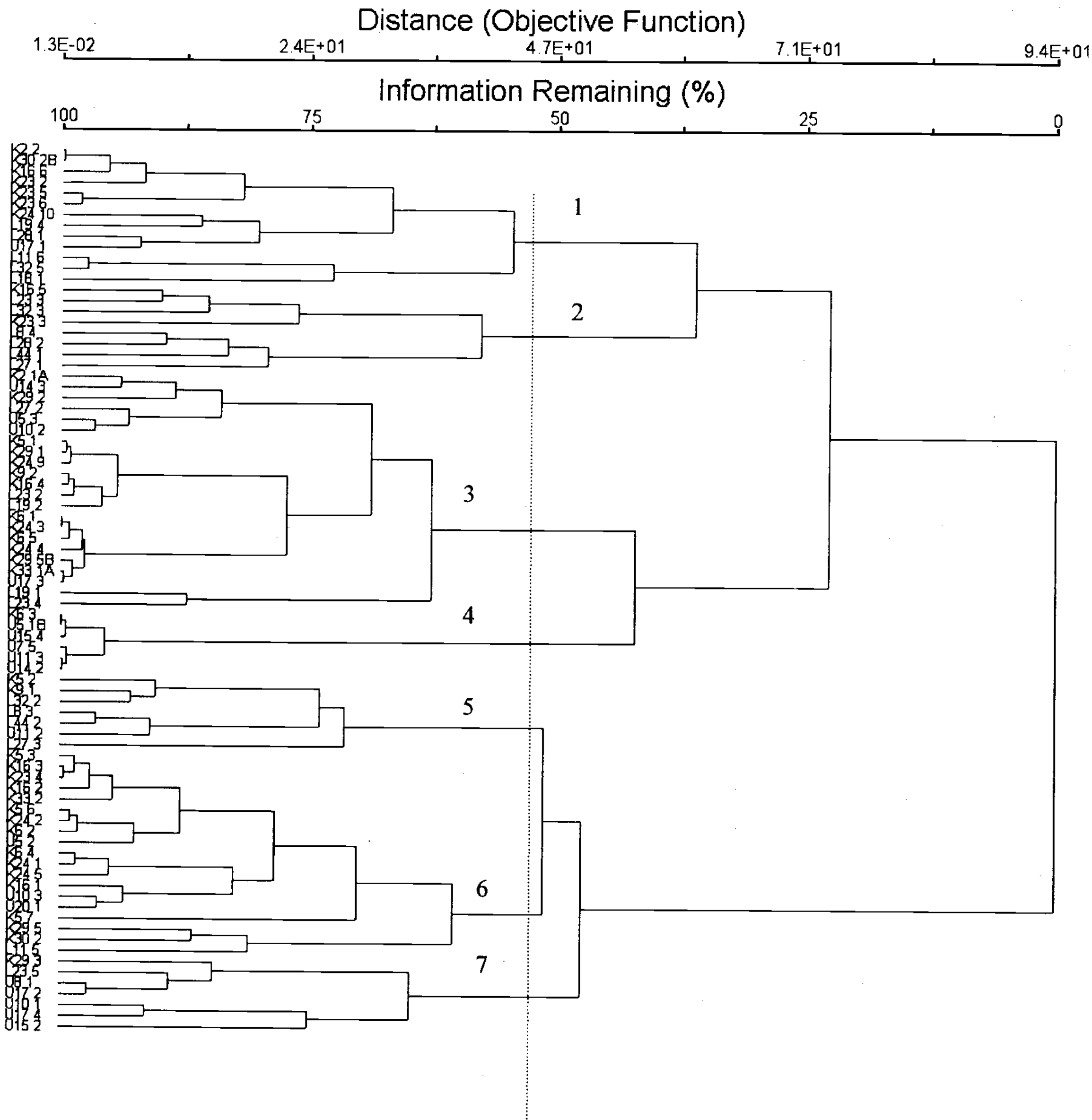


Figure 3.4. Dendrogram showing hierarchical linkage of gardens, and their division into seven fruit-based agroforestry subsystems (vertical dashed lines and numbers indicate the garden type). This is a graphical result of cluster analysis of the 82 gardens (indicated by the numbers on left) according to the 22 variables of garden characteristics in the classification data set.



type of fruit-based agroforestry subsystem or 'garden type.' Membership in clusters ranged from 6 to 22 garden parcels. Garden types are numbered 1, 2, 3, 4, 5, 6 and 7 (with a membership of 13, 8, 22, 6, 6, 19 and 7 gardens, respectively).

### Indicator Species Analysis

Indicator species analysis (ISA) was used to combine information on the relative abundance of a variable in a particular group and the relative frequency of a variable in a particular group, to produce an indicator value for each variable in each of the 7 garden types (Table 3.6). The indicator value shows the degree to which that variable points to a particular group. Maximum indicator values for a variable ranged from a low of 18% for planting size (in garden type 3) to a high of 60% for medicinal and culinary herb crop diversity (in garden type 2). The Monte Carlo test of significance for largest indicator value for each variable was significant for 13 variables ($P < 0.01$).

### Garden Types

Characteristics of the seven garden types can be seen in summary values for crop diversity variables (Table 3.7) abundance of important fruit species (Table 3.8) and frequency of some woody and herbaceous crop species (Table 3.9). Garden type characteristics were also expressed in the graphic arrangement of the seven garden types in

Table 3.6. Indicator values (% of perfect indication) for variable and garden type with the maximum indicator value for each variable indicated in bold. P-values are for the Monte Carlo test of significance of observed maximum indicator value for each variable.

| | Garden Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Mote Carlo |
| (n) | (13) | (8) | (22) | (6) | (7) | (19) | (7) | p |
| Lime (trees) | 0 | **44** | 3 | 0 | 16 | 0 | 0 | 0.001 |
| Japanese apricot (trees) | 1 | 1 | 2 | **50** | 2 | 3 | 30 | 0.001 |
| Tamarind (trees) | 10 | **30** | 8 | 0 | 2 | 1 | 0 | 0.016 |
| Pineapple (abundance) | 0 | **56** | 2 | 0 | 6 | 1 | 0 | 0.001 |
| Squash (abundance) | 5 | 10 | 0 | 0 | 0 | **38** | 29 | 0.001 |
| Maize (abundance) | 0 | 1 | 0 | 0 | 31 | 31 | **32** | 0.002 |
| Lemon grass (abundance) | 1 | **22** | 2 | 0 | 10 | 7 | 0 | 0.048 |
| *Z. cassumnar* (abundance) | 0 | **59** | 1 | 0 | 2 | 0 | 0 | 0.001 |
| Total crop diversity (species) | 21 | **27** | 9 | 3 | 13 | 12 | 15 | 0.001 |
| Fruit tree (species) | **26** | 23 | 11 | 5 | 14 | 10 | 9 | 0.001 |
| Living fence (species) | 15 | **29** | 2 | 0 | 4 | 0 | 0 | 0.270 |
| Herbaceous food (species) | 13 | 24 | 2 | 0 | 11 | 18 | **28** | 0.018 |
| Medicinal and culinary herb (species) | 2 | **60** | 2 | 0 | 5 | 7 | 2 | 0.001 |
| Planting size (trees) | 12 | 13 | **18** | 12 | 17 | 17 | 11 | 0.001 |
| Dominant fruit (trees) | 9 | 7 | **19** | **19** | 17 | 18 | 12 | 0.060 |
| Number of market fruit (species) | 1 | 7 | 26 | 3 | **27** | 17 | 2 | 0.002 |
| Number of market vegetable (species) | 1 | 0 | 0 | 0 | 9 | **36** | 4 | 0.007 |
| Number of Age classes of fruit trees (years) | **23** | 19 | 10 | 9 | 12 | 10 | 18 | 0.650 |
| Range of age classes for major fruits (years) | **27** | 16 | 8 | 8 | 12 | 10 | 19 | 0.003 |
| Total range of age classes of fruit (years) | **28** | 20 | 11 | 6 | 10 | 8 | 17 | 0.043 |
| Years intercropped (years) | **28** | 21 | 8 | 8 | 9 | 9 | 17 | 0.025 |
| Ratio of years intercropped to garden age | 20 | 12 | 7 | 15 | 9 | 9 | **26** | 0.050 |

Table 3.7. Crop diversity by mean number of species in each crop-type group, planting size and dominant tree abundance for garden parcels in 1998 in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (ALL) and by garden type. Maximum values in bold.

| | | Garden Type | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | All | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| (n) | (82) | (13) | (8) | (22) | (6) | (7) | (19) | (7) |
| Total crop diversity (species) | 12.0 | 9.6 | **24.1** | 10.9 | 2.5 | 13.3 | 14.0 | 8.0 |
| Fruit tree (species) | 6.7 | 6.5 | **11.1** | 7.6 | 2.2 | 7.6 | 6.5 | 2.9 |
| Other tree (species) | 0.6 | 0.8 | **1.5** | 0.7 | 0.3 | 1.1 | 0.3 | 0.3 |
| Living fence (species) | 0.3 | 0.5 | **1.4** | 0.3 | 0.0 | 0.4 | 0.1 | 0.0 |
| Herbaceous food (species) | 3.5 | 2.2 | **6.1** | 1.6 | 0.0 | 3.3 | **6.1** | 4.6 |
| Medicinal and culinary herb (species) | 1.0 | 0.3 | **4.0** | 0.6 | 0.0 | 0.9 | 1.1 | 0.3 |
| Planting size (trees) | 82.8 | 28.4 | 61.6 | **124.6** | 56.0 | 77.3 | 110.8 | 29.5 |
| Dominant fruit (trees) | 48.9 | 12.5 | 16.6 | **72.8** | 52.8 | 45.1 | 70.5 | 19.7 |
| | | | | | | | | |
| Parcel size (ha) | 0.56 | 0.22 | 0.18 | 0.46 | 0.62 | 0.47 | **1.1** | 0.59 |
| Total crop diversity (species/ha) | 50.5 | 68.9 | **177.6** | 46.1 | 5.0 | 31.1 | 21.8 | 20.8 |
| Fruit tree (species/ha) | 27.5 | 45.6 | **79.9** | 29.0 | 4.5 | 17.9 | 9.5 | 7.0 |
| Herbaceous food (species/ha) | 13.3 | 16.5 | **47.1** | 7.2 | 0.0 | 8.2 | 10.2 | 12.7 |
| Medicinal and culinary herb (species/ha) | 4.8 | 1.6 | **31.3** | 3.5 | 0.0 | 1.6 | 1.3 | 0.8 |
| Density (trees/ha) | 208.0 | 149.4 | 339.8 | **340.5** | 102.9 | 167.0 | 134.8 | 79.5 |
| Percent dominant fruit (%) | 58.8 | 39.2 | 31.4 | 61.3 | **94.6** | 59.5 | 64.1 | 72.7 |
| Distance to house (m) | 1228 | 981 | 134 | 1496 | 1566 | 592 | **1973** | 421 |

Table 3.8. Mean abundance of important fruit species for garden parcels in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. Mean values for the three villages overall (ALL) and by garden type. Maximum values in bold.

| | | Garden Type | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | All | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| (n) | (82) | (13) | (8) | (22) | (6) | (7) | (19) | (7) |
| Jack fruit *A. heterophyllus* (trees) | 2.6 | 2.4 | **6.5** | 2.0 | 0.5 | 4.7 | 2.7 | 0.0 |
| Lime *C. aurantifolia* (trees) | 0.5 | 0.1 | **2.1** | 0.5 | 0.0 | 2.0 | 0.1 | 0.0 |
| Coffee *C. arabica* (trees) | 9.4 | 0.2 | 5.1 | **33.0** | 0.0 | 0.0 | 0.1 | 0.0 |
| Litchi *L. chinensis* (trees) | 16.1 | 2.5 | 6.8 | 20.2 | 0.0 | 3.1 | **40.5** | 0.0 |
| Mango *M. indica* (trees) | 7.7 | 4.7 | 11.3 | 7.0 | 0.7 | **31.7** | 4.1 | 3.3 |
| Banana *Musa* cvs (clumps) | 6.4 | 2.3 | 3.1 | 7.8 | 0.2 | **23.3** | 5.9 | 3.4 |
| Japanese apricot *P. mume* (trees) | 9.7 | 2.0 | 5.3 | 5.8 | **52.8** | 4.6 | 6.4 | 18.3 |
| Peach *P. persica* (trees) | 18.6 | 8.2 | 3.1 | 32.2 | 1.5 | 0.3 | **34.6** | 2.9 |
| Guava *P. guajava* (trees) | 0.9 | 1.7 | **4.4** | 0.6 | 0.0 | 0.4 | 0.1 | 0.0 |
| Pear *P. pyrifolia* (trees) | 2.5 | 0.8 | 1.5 | **5.2** | 0.0 | 0.1 | 3.6 | 0.1 |
| Tamarind *T. indica* (trees) | 0.8 | 0.5 | 1.5 | **1.6** | 0.0 | 0.3 | 0.4 | 0.0 |

Table 3.9. Frequency (% of gardens) of some crop species in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. Values are for the three villages overall (ALL) and by garden type. Maximum values in bold.

| Variable | All | Garden Type 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| (n) | (82) | (13) | (8) | (22) | (6) | (7) | (19) | (7) |
| Jack fruit *A. heterophyllus* (%) | 57.3 | 69.2 | **87.5** | 59.1 | 33.3 | 85.7 | 52.6 | 0.0 |
| Lime *C. aurantifolia* (trees) | 24.4 | 7.7 | **87.5** | 36.4 | 0.0 | 42.9 | 5.3 | 0.0 |
| Coffee *C. arabica* (%) | 20.7 | 7.7 | **62.5** | 45.5 | 0.0 | 0.0 | 5.3 | 0.0 |
| Litchi *L. chinensis* (%) | 52.4 | 46.2 | 62.5 | 68.2 | 0.0 | 42.9 | **73.7** | 0.0 |
| Mango *M. indica* (%) | 73.2 | 84.6 | 87.5 | 77.3 | 16.7 | **100.0** | 73.7 | 42.9 |
| Banana *Musa* cvs (%) | 57.3 | 61.5 | **87.5** | 50.0 | 16.7 | 85.7 | 57.9 | 42.9 |
| Japanese apricot *P. mume* (%) | 53.7 | 30.8 | 25.0 | 50.0 | **100.0** | 42.9 | 57.9 | **100.0** |
| Peach *P. persica* (%) | 53.7 | **76.9** | 37.5 | 59.1 | 16.7 | 14.3 | 73.7 | 28.6 |
| Guava *P. guajava* (%) | 25.6 | 38.5 | **100.0** | 22.7 | 0.0 | 28.6 | 5.3 | 0.0 |
| Pear *P. pyrifolia* (%) | 28.0 | 30.8 | **37.5** | 31.8 | 0.0 | 14.3 | 36.8 | 14.3 |
| Tamarind *T. indica* (%) | 29.3 | 38.5 | **75.0** | 36.4 | 0.0 | 28.6 | 15.8 | 0.0 |
| Pineapple *A. comosus* (%) | 23.2 | 7.7 | **100.0** | 22.7 | 0.0 | 28.6 | 15.8 | 0.0 |
| Squash *Cucurbita sp.* (%) | 46.3 | 46.2 | 62.5 | 9.1 | 0.0 | 0.0 | **100.0** | 85.7 |
| Maize *Z. mays* (%) | 43.9 | 0.0 | 25.0 | 4.5 | 0.0 | **100.0** | **100.0** | **100.0** |
| Lemon grass (%) | 24.4 | 15.4 | **62.5** | 18.2 | 0.0 | 42.9 | 31.6 | 0.0 |
| *Z. cassumnar* (%) | 11.0 | 0.0 | **75.0** | 9.1 | 0.0 | 14.3 | 0.0 | 0.0 |

ordination space (Figures 3.5 and 3.6), where the garden types tended to form recognizable groups, although some spread widely along the axes. There was considerable overlap among garden types in one or two dimensions. Separation was better in the axis 1 and 2 graph than in the graph of axis 2 and 3 (or axes 1 and 3, not shown). Overlap tended to be strongest among related groups on the same cluster string.

Garden type 1 is made up of gardens with moderate total crop diversity (9.6 species per parcel, Table 3.7). Other crop diversity values are also moderate. Parcels are small (0.23ha) and the planting size is small (28 trees per parcel). The dominance of the most abundant tree species is low (39% of all fruit trees) and the number of trees of individual species per parcel is low (Table 3.8). In ordination space (Figures 3.5 and 3.6), garden type 1 lies in a space of moderate to high species diversity (axis 1), a moderate to high number of herbaceous food crops (axis 2), and a small planting size (axis 3). The indicator species analysis shows the importance and complexity of the tree fruit component. Indicator values for garden type 1 are the highest of any group for tree fruit diversity (26%), range of age classes of major fruits (27%) and total range of age classes (28%). Thus, Garden type 1 can be characterized as small gardens generally close to the home, relatively high in total diversity, fruit crop diversity, with many age classes and no one fruit in great abundance. Although there is a long history of intercropping, market crops are rare and herbaceous crop species diversity is moderate. Note that the multivariate methods show different relative positions and a greater importance of the crop species diversity in this garden type than is

Figure 3.5. NMS graph of all sample units in "garden characteristic" ordination space along axes 1 and 2. Group membership and boundaries are indicated.

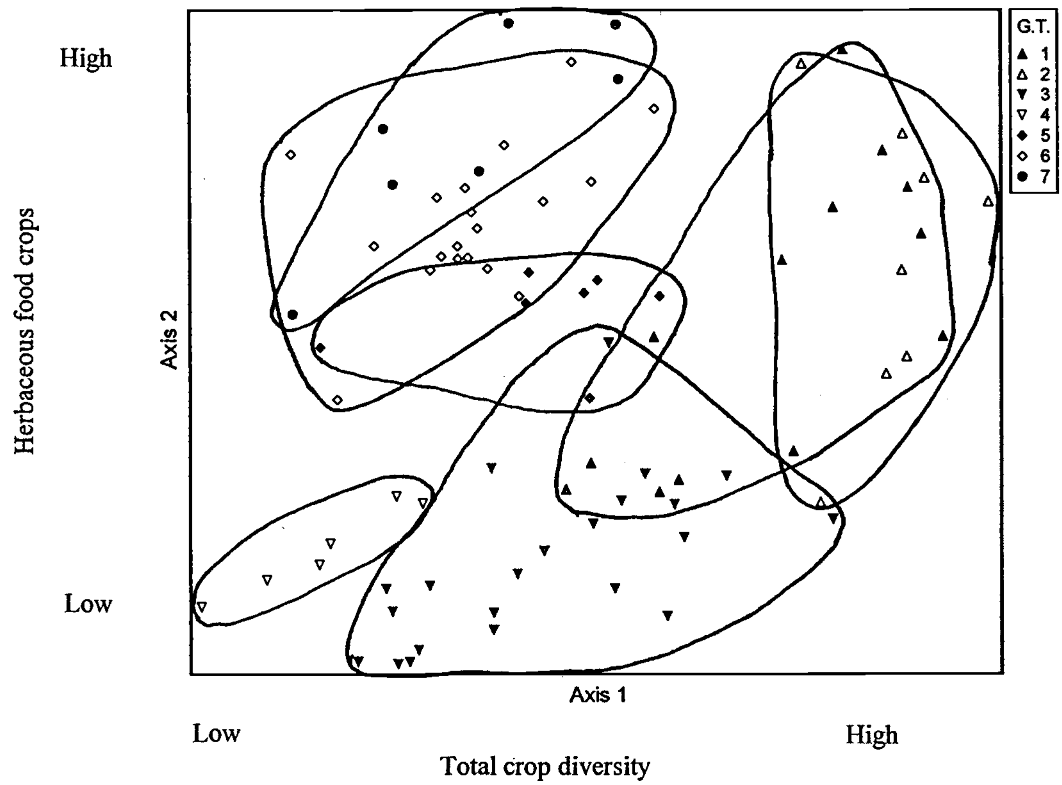
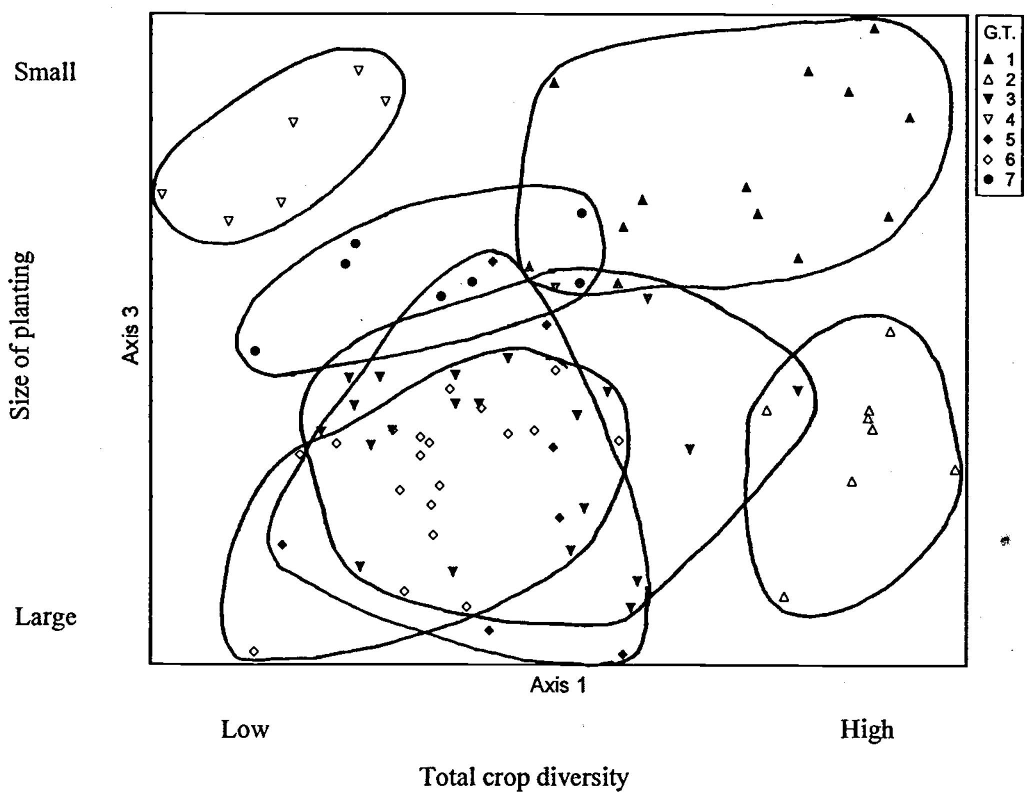


Figure 3.6. NMS graph of all sample units in "garden characteristic" ordination space along axes 1 and 3. Group membership and boundaries are indicated.



seen in the summary statistics. This apparent disagreement likely relates to garden size. Crop diversity measures expressed on a per area basis are more consistent with the multivariate results, which were adjusted for parcel size through the general relativization procedure.

Garden type 2 has the greatest total crop diversity and highest number of species in each crop type category. The abundance of the dominant tree species is low (31.4% of all fruit trees). The number of trees of individual species is generally low, although jackfruit, lime and guava (fruits of low average abundance but of domestic value) are most abundant in this garden type. Garden parcels are very small (0.18 ha) but planting size is not (61 trees per parcel). The frequency of most tree species is high, which may reflect that special or new species are collected and tried here. In ordination space, garden type 2 lies in an area of high species diversity and low abundance of the dominant fruit (axis 1), moderate to high herbaceous food crop diversity (axis 2), and moderate to large plantings (axis 3) (in this case, relative to parcel size). Indicator species analysis shows the importance of crop diversity values and some domestic crops in defining this garden type. Indicator values are the highest group value for total crop diversity (27%) and, medicinal and culinary herbs (60%). The importance of some individual species used domestically is also shown. Indicator values for pineapple (56%), tamarind (30%), lemon grass (22%) and *Z. cassumnar* (59%) are each the highest group value for that species. Thus, this garden type is made up of small, fenced gardens, very close to the home, which are diverse both in fruit crop and herbaceous crop species, particularly culinary and medicinal herbs. No one fruit in great abundance. Fruit trees are in are many age classes, and no one species is in great abundance. The emphasis on household crops is high and market crops are rare.

Garden type 3 is made up of moderate total crop diversity and tree fruit diversity (10.9 and 7.6 species/parcel respectively). Diversity of other crop categories is low. Garden parcels are medium-sized (0.46 ha) but have the largest mean planting size (124 trees) and so a high density (340.5 trees/ha). The most abundant tree crop makes up more than half (61%) of the planting. Peach, coffee and litchi are all abundant. Garden type 3 lies in an ordination space that stretches broadly from moderate to low species diversity (axis 1), a low number of herbaceous food crops (axis 2) and moderate to large planting size (axis 3). Indicator values suggest the importance of large plantings, with a high dominance of one or more crops grown for market, in characterizing this type. Thus this garden type tends to be mid-sized parcels with many fruit trees. The tree component of the gardens is mixed, with several abundant species for market, there is moderate tree diversity. There are no market vegetables grown and herbaceous crop diversity is low.

In Garden type 4, mean total diversity and fruit diversity are both very low. These are medium-sized plantings dominated by Japanese apricot (95 % of trees in garden). There are no herbaceous intercrops. This garden type lies in an ordination space of low species diversity and high abundance of the dominant fruit (axis 1); low herbaceous food crops (axis 2); and small planting size (axis 3). The indicator values also show the importance of Japanese apricot (50%) in distinguishing this group. Thus, these gardens are basically simple orchards of Japanese apricot with little active herbaceous intercropping, few herbaceous crops of any kind and no market vegetables. Diversity is very low.

Garden type 5 is a rather non-descript group gardens with moderate total diversity (13.5 species) and fruit tree diversity (7.6 species). Over half the trees in the garden (59.5%) are on average of one species. Mangos and bananas are abundant and frequent, and maize is raised in all the gardens. Garden type 5 lies in an indistinct location near the middle of ordination space for total diversity (axis 1) and herbaceous food crops (axis 2). It spreads across the third ordination axis from mid to large planting sizes (axis 3). Indicator species analysis shows that this group is characterized by a high number of market fruit species, which implies mixed gardens of several relatively abundant species, as well as some minor species. Thus these are mid-sized, moderately diverse gardens, fairly close to home, with moderate numbers of the dominant fruit trees, and several fruit species being grown in market quantities. Maize is grown, along with some other herbaceous crops, mostly for home consumption.

In garden type 6, total diversity (14 species) and tree fruit diversity (6.5 species) are moderate, but the number of herbaceous food crops is high (6.1 species). The most abundant fruit accounts for 64.1 % of the trees in the garden. Parcel size (1.1 ha) and fruit tree planting size (110.8 trees) are both large. Both peaches and litchi have high mean abundances and frequencies. There are some plantings where both are present, but generally just one or the other is abundant. Maize and squash are both always planted. Garden type 6 lies in an ordinations space of moderate to low species diversity (axis 1), moderate to high numbers of herbaceous food crop species (axis 2), and a broad, mid to large planting size (axis 3). Indicator species analysis shows the importance of herbaceous food crops in distinguishing this group, with high indicator values for squash (38%), maize (31%) and the number of market vegetable species (36%). Thus, type 6 can be characterized as large, moderately diverse gardens far from the home, with high numbers of the dominant fruit but several fruit in marketable quantities. These gardens are actively intercropped and maize is grown along with other herbaceous crops. They are similar to type 5 gardens, but have more marketable fruit crops and are further distinguished by the presence of squash and a high number of market vegetable crops.

Gardens in type 7 are generally small plantings (29.5 trees) with low total crop diversity (8.0 species) and fruit diversity (2.9). Herbaceous food crop diversity is fairly high (4.6 species). The most abundant tree species is quite dominant (72 % of all trees). Japanese apricot and corn are always present and squash is very common. Garden type 7 lies in an ordination space of moderate to low species diversity, moderate to high abundance of the dominant fruit (axis 1), moderate to high herbaceous food crop diversity (axis 2), and moderate planting size (axis 3). Indicator species analysis shows the importance of herbaceous crops in this group, with the top indicator values for maize (32%) and herbaceous food crop diversity (28%). So, gardens in type 7 are mid-sized and moderately diverse, though more so in herbaceous crops than tree crops. Like garden types 5 and 6, they are intercropped with corn and other food crops, but are smaller and closer to home. Garden type 7 is clearly distinguished from 5 and 6 by the tree crop component, which due to the dominance of Japanese apricots more closely resembles garden type 4 (although distinguished from type 4 by the importance of herbaceous crops). Maize is grown along with squash but few vegetables are grown for market.

## DISCUSSION

Description, classification and cataloging agroforestry systems and practices have been core elements of agroforestry research. It has been an important initial step towards recognizing existing traditional as well as new and emerging systems. Nair (1990) proposed a broad classification framework based on structural, functional, socioeconomic and ecological bases. This approach to classification served general academic needs of communication among researchers quite well, and has been widely applied. Nonetheless, alternative classification schemes continue to be proposed to meet more specific needs and interests (see, for example Punam et al. 1991, Sinclair 1999). An important reason for classification is to help organize our collective thinking and discussion of systems, but it can also assist in the analysis and evaluation of systems.

Because of their complexity, the quantification of agroforestry systems is difficult. Many ecologists seeking to describe and understand patterns in other complex plant communities now commonly use multivariate analysis methodologies in their research. Multivariate analysis lends itself well to ecological studies because it helps to uncover structure in the data, and it provides relatively objective summarization of the data (Gauch, 1982). These methods, including cluster analysis and numerous ordination techniques, are widely applied to describe the composition of natural plant communities and their relationships to environmental factors. Cluster analysis can be a useful aid in dividing large and diverse data sets and ordination can help explain the patterns of relatedness of different communities. Both methods are finding some, although limited, applications to agroforestry situations (see, for example, Millat-E-Mustafa et al., 1996, Lauriks et al., 1999).

Multivariate analysis is an appropriate approach to explore in this study. As an approach to classification, it offers a means of introducing more objective rigor to the process of relating the different Highland gardens to one another. Beyond providing a means of distinguishing the groups, multivariate analysis also provides methods to explore the relationships among those groups and the factors that influence their formation. Nonetheless, it must be remembered that NMS is an iterative process that groups sample units that are the most similar. It is not inferential or causal. The scope of inference is limited to explanations of the observed associations rather than descriptions of causal relationships.

We took two very different approaches to classification and analysis in this study, so a review and comparison of the methods and results is useful and interesting. In this chapter's analysis, classification was determined by cluster analysis, NMS was then used to define gradients of garden characteristics and determine the position of gardens along gradients, and ISA helped further identify the key factors important in distinguishing separate groups. We identified and described seven garden types from this multivariate classification. Crop species diversity, abundance of herbaceous food crops and size of tree planting were the key characteristics driving the separation of the different garden types, which are reviewed and compared below.

Garden types 1 and 2 are closely linked on the cluster analysis dendrogram and so show many similarities. Both are small and diverse, and are characterized by the wide variety of woody and herbaceous species, whose composition and abundance seems to reflect a domestic use focus. Living fences frequently enclose the gardens. Garden type 1 parcels seem less intensively managed, with a larger parcel size but smaller and less diverse fruit tree component. Garden type 2 parcels tend to be the smallest and very diverse with a high abundance and/or frequency of both tree and herbaceous crops of domestic importance. Medicinal and culinary herb species are very much more important in this garden type than in any other. Both types fit the general concept of home gardens.

Garden types 3 and 4 also lie together on another stem of the dendrogram. Both these garden types are characterized and separated from the other gardens by very low herbaceous crop diversity. There is not much similarity in the tree component. Garden type 4 is set apart from type 3 by the abundance and dominance of Japanese apricot trees. Garden type 3 is a larger group than type 4 (22 vs. 6 gardens) and shows more variability in the tree component and the make up of the gardens overall, as illustrated by the wider distribution of the gardens along all three axes in ordination space.

Garden types 5, 6 and 7 are also branches on a common stem of the dendrogram. These garden types again appear to be characterized and related by their herbaceous crop component. Maize appears with 100% frequency in these garden types. The herbaceous crop component tends to be diverse and includes multiple species raised for market. The fruit crop component again seems to help distinguish between these groups rather than be part of their similarities. Garden type 7 is characterized by high frequency (100%), abundance and dominance of Japanese apricot.

In Chapter 2, we presented a preliminary classification that was developed through a conventional approach (Withrow-Robinson et al., 1999). Gardens were subjectively separated into four general groups and 11 fruit-based agroforestry subsystems. The four groups were: A. Home Gardens, B. Home Garden-Like Agroforestry, C. Trees in Fields and D. Conventional Commercial Orchards. Groups were organized largely along a spectrum of economic (domestic or commercial) function, with home gardens at one end and a large group of commercial orchards at the other. Subsystems were further distinguished by composition and structure. The classification emerged directly from field observations and so subsystems were readily recognizable.

The home gardens identified in the preliminary classification reflected a functional orientation towards crops for home consumption, which was often expressed in plantings of small amounts of many things and often in a small area. The two home garden subsystems were distinguished from one another by the relative lack or presence of herbaceous crops. Conventional commercial orchards identified in the preliminary classification reflected commercial orientation in the choice and abundance of the tree species, and were generally large with little diversity in the tree component. The three subsystems were again distinguished by the presence and nature of the intercrops. The Home Garden-Like Agroforestry group identified in the preliminary classification showed mixed functional objectives of home consumption (and the frequently associated total and tree crop diversity) with commercial economic objectives. Within the group were four subsystems in 2 pairs, with distinctions within those pairs again being made by the lack of, or presence and nature of intercrops.

Looking at the results of the two classification processes used in this study, we find some interesting similarities and differences. One similarity is the emergence of patterns common to both classifications. Specifically, both classifications identified groups recognizable as home gardens and also groups identifiable as commercial orchards. In this chapter, garden types 1 and 2 can be readily described as home gardens. These two closely linked garden types are similar to the home gardens described in Chapter 2 (group A), with which they are quite consistent in composition, structure and purpose. The two sets of home gardens are not identical, as there is considerable drift in membership in the home garden groups from one analysis to the next, yet it is interesting that such similar groups emerged from the classifications.

Another similarity is the identification of groups that are commercial orchards. Chapter 2 identified a broad group of Conventional Commercial Orchards (group D). Two Garden types from this chapter's analysis (types 4 and 7) certainly fit in that broad group, although more narrowly defined. Each is a Japanese apricot orchard that, on the basis of their herbaceous crop component, are on separate stems of the classification dendrogram. Each of these two garden types also has a simple, low diversity tree fruit component, which distinguishes each from the other branches on their dendrogram stem as well as in ordination space. Garden type 4 is dominated by Japanese apricot (95%) with little active herbaceous intercropping, few herbaceous crops of any kind and no market vegetables. Garden type 7 has a little more tree fruit diversity, but it is intercropped with maize and other herbaceous crops.

There are also some important differences that emerge when looking at the results and particularly the two sets of conventional orchards from the different classification methods. The conventional commercial orchards in Chapter 2 fit a broad functional description and were characterized by low fruit-crop diversity, with a high abundance and/or dominance of one or more commercial tree species. The composition of individual species was not considered. In this chapter's analysis, the two commercial orchard garden types were more narrowly defined and a single species was a key part of the characterization. No umbrella category emerged to include low diversity plantings of market species. Garden types 4 and 7 appear to separate from gardens more related by their herbaceous components only because of the additional distinction of the dominant fruit tree species, Japanese apricot. No other species-specific orchard groups appeared, as no other commercial fruit species was selected as a variable through the screening process.

These observations lead us to question the structural nature of the fruit-based agroforestry system. We clearly made an assumption at the outset of the study that there are separate and distinct garden types that had emerged as a result of the local farmers organizing of their gardens in response to a group of physical and socioeconomic environmental conditions. In particular, it appeared as if people were organizing their gardens by function, which became central to the structure of our first classification system. But the multivariate analysis seems to indicate that these gardens do not represent discrete categories as we presumed, but rather are part of a continuum of individual gardens of gradually changing and overlapping characteristics. It is possible to draw lines of separation to form groups and impose a structure. Yes, there are clear patterns among them, and some patterns that are familiar from the functional classification, but the bulk are not. Function was not borne out as a strong organizing factor. So in practice it appears that people in this Highland area appear to be mixing all components and functions, either by design and in response to changing situations and events.

It may still be useful to classify or categorize garden types even if, as it seems to be in this case, they are more continuous than distinct. Classification can be an important tool to understanding and communication. Each approach we tried has individual limitations. The functional (abstract) classification of Chapter 2 is appealing in its ease of use and intuitive structure, and particularly the ability to weight the influence of variables to reflect management issues. By looking at function and management we may be able to generalize our observations for application in other places and different species. Although this may be an academically useful approach, it must be recognized that it may not very closely reflect how gardens are actually organized.

The multivariate analysis (MVA) used in this chapter worked well to show patterns in the data and illustrate relationships and structure of the characteristics and gardens. Its effectiveness however, was limited in several ways. One characteristic of the MVA classification was the tendency to organize around one or more individual species (such as Japanese apricots or maize). This is not surprising, as that is often the objective of MVA of community data. In this case it can be seen as a drawback, as we were not very interested in a separation of groups on the basis of one or two species only (i.e. apricot and corn, mango and rice, etc.) and was something we tried to avoid. Another hindrance was the inability to weight variables that are most relevant to our focus. The perennial crop component, which helped define the garden as a sample unit, was of central interest. Herbaceous crops were of secondary interest. Yet in this analysis, herbaceous crops and particularly maize turned out to be variables by which some related groups (types 3, 4 and 5,6,7) were formed. As a result, the groupings may not reflect questions of interest, which relate to function and management rather than strict species composition. The reason for our focus on function and management was to try to generalize practices to other places and different suites of species.

It might also be possible to combine the two approaches to gain some of the strengths from each. In particular, it would be helpful to be able to choose and weight the variables around which the classification is organized, as we did in the approach taken in

Chapter 2, but also have a quantitative method to relate the many variables, as we did in this chapter. It might be effective to choose a set of variables that reflected characteristics of interest (a set of calculated characteristics of community composition and diversity), and then use the multivariate methods to relate the selected variables quantitatively. In this approach we would select a small group of variables reflecting *a priori* interests, rather than using strength of correlation to screen them out of the larger data set. Selected variables would likely include calculated characteristics of community composition and diversity such as the number of species by crop types, abundance and frequency and also functional characteristics, but exclude individual species community data. Weighting the factors' influence would be more difficult, but might be accomplished by including several variables relating to an important characteristic. Such an approach would focus on questions of function and management and allow a test of whether these issues play an important role in the design of agroforestry activities by farmers.

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# Chapter 4

# An Approach to Quantifying Performance Factors in Fruit-Based Agroforestry

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# ABSTRACT

A study of fruit-based agroforestry systems was conducted in three villages in a Highland watershed of northern Thailand. Objectives were to develop a better understanding of the biophysical and socio-economic performance of the fruit-based agroforestry system and assess potential for an evaluation mechanism. Data were collected in 1998 through field surveys and a series of regular interviews with the gardens' owners. We examined economic, environmental and social factors relating to composition, cover, inputs of labor and agricultural chemicals, and the distribution and yield of economic and domestic crops by garden and household units. The average household managed 2.3 ha of land, 80% of were uplands, and 20% irrigated paddy fields. Of the upland parcels, about 85% were gardens. 93% of the sample households had garden parcels. A total of 96 crop species were recorded in the sample gardens, with an average of 12 crop species per garden parcel, and 23.5 raised per household. There were a total of 31 fruit species, an average of 12 were raised per household. A limited number of fruit species were raised in large numbers. Only 12 fruit species reached a household-level abundance of 20 trees or more. Only six exceeded 20 trees in 5 or more households. Households in Khun Sa Nai had the highest level of input use in their gardens and also received higher cash returns and profit from garden activities than did households in Upper Mae Muang Luang or Lower Mea Muang Luang. Fruit crop production was very low in the study area and throughout northern Thailand in 1998. As a result, most of the economic activity in gardens reported in 1998 was from herbaceous crops, particularly cabbage. Difficulties in data collection are identified, examined and discussed.

# INTRODUCTION

Highland farmers including ethnic minority "hill tribes" in northern Thailand, have been making a fundamental change from traditional slash and burn agriculture to more intensive short rotation or permanent farming practices in response to shifting physical and socioeconomic conditions (Rerkasem and Rerkasem, 1994). An important element of this change in land use has been the expansion of fruit cropping and fruit-based agroforestry in many highland areas as described by Poffenberger and McGean (1993), Turkelboom et al. (1996) and Withrow-Robinson et al. (1999).

Faced with problems such as rising demand for crop lands, forest destruction in important watershed areas, opium production, rural poverty and other problems, the Thai government, through development projects such as the Royal Project, Sam Mun Highland Development Project, and the Thai-German Highland Development Programme looked to introductions of new cropping practices and new crops to help resolve some these problems. A common objective was to replace shifting cultivation with permanent agriculture and to develop commercial cash crops (SMHDP 1994). New cropping practices have been introduced over the last two decades as part of the transition to permanent farming. Conservation Farming practices, including terraces and alley cropping, were vigorously promoted in several development projects (Enters, 1992, Amaruckachoke and Gypmantasiri, 1995). Although popular among Highland farmers, some new cash crops such as cabbages have attracted criticism for having negative impacts on the environment due to practices such as high fertilizer and insecticide use and dry season irrigation (Rendard, 1994Bangkok Post, July 27, 1997).

Tree fruit crops were also widely introduced and promoted for both commercial and domestic purposes and trees were frequently distributed to villagers in project areas (Roth et al., 1987, SM-HDP 1994, Bourne, 1990). The interest in and adoption of fruit production was not limited to project areas, however, and the fruit-based system is now an important component of the broader Highland agroforestry system (Rerkasem and Rerkasem, 1994). Fruit cropping appears attractive. In contrast to agroforestry practices that focus solely on services such as erosion control, the fruit-based system can contribute products for market or home consumption as well (Bourne 1990, Enters, 1992). Planting fruit has generally been regarded as an environmentally acceptable Highland cropping option by non-government and government agencies alike, including the Royal Forestry Department (RFD), (Poffenberger and McGean, 1993, SM-HDP 1994) although chemical use and dry-season irrigation have been identified as potential problem issues for fruit cropping as well (Rerkasem and Rerkasem 1994).

The fruit-based agroforestry system in the northern Thai Highlands incorporates temperate, subtropical and tropical species (Withrow-Robinson et al. 1999). Because of the many crop components and combinations possible, the fruit-based system is adaptable and applicable to a wide range of physical and social conditions, worldwide. Nair (1984) noted the potential of fruit trees as components of agroforestry systems, and the need to look beyond conventional monoculture research.

Much of what has been written describing fruit in agroforestry has appeared in the extensive literature about home gardens. These reports have documented composition, structure and production of goods for home consumption as well as sale of excess or some cash crops (see, for example, Christanty et al., 1985, Fernandes, 1984, Moreno-Black et al., 1996). Although much less extensive, there has been some work describing the role of other fruit cropping practices and systems. Examples include the use of mangoes as multipurpose trees in Zimbabwe (Musvoto and Campbell, 1995), deciduous fruits in the Tanzanian highlands (Delobel et al., 1991), and durian (*Durio zibethinus*) in forest gardens and home gardens (Salafsky, 1994).

There is also an extensive horticultural literature on eco-physiological and cultural requirements for the commercial plantation production of fruit crops of both temperate and tropical origin in tropical and subtropical highlands (see for example Lin, 1992, Menini, 1990). This work is important to the development of viable commercial industries, yet successful transfer and application of that information often lags far behind the dissemination of the crops in developing rural areas.

In highland Java, Indonesia, Suryanata (1994) reported that fruit-based agroforestry utilizing apples (*Malus domestica* Borkh.) and oranges (*Citrus reticulata* Blanco) for commercial production was well established in localized areas. Land tenure and market pressures were driving a change towards more simplified systems with less intercropping in the Javanese highlands. She later reported that, as fruit became a commercial commodity rather than part of a subsistence economy, fruit culture has become a force of change to the local social and land tenure structure (Suryanata, 1999).

In two earlier papers, the authors described fruit-based agroforestry gardens in northern Thailand, proposed two different approaches to classification of these gardens and examined the relationship of crop species composition, abundance, category of use, age structure and spatial arrangement to the classification (Withrow-Robinson et al., 1999, Withrow-Robinson and Hibbs, Chapter 3). The objective of this paper is to further develop our understanding of the socio-economic, biological and environmental performance of the fruit based agroforestry system in the study area, and to quantify vegetative cover, inputs of labor and agricultural chemicals, and the yield of economic and domestic crops by garden and household units.

## METHODS

### Survey and Sampling

The study was conducted in three Highland villages, located about 100 km northwest of Chiang Mai city, at approximately 98° 35' East longitude and 19° 10' North latitude in Pai District, Mae Hong Son Province, northern Thailand. The villages were within the Royal Forest Department's Thung Jaw Watershed Management Unit, Mae Taeng Watershed Management District.

Three sample villages were chosen to include a range of environmental, social and ethnic conditions. Khun Sa Nai (KSN) is a Hmong village of about 445 people, lower Mae Muang Luang (LMML) is a Karen village with about 380 people, and upper Mae Muang Luang (UMML) is a Lisu village of around 130 people. The three villages are located at elevations of approximately 1200, 900 and 1300 meters above sea level, respectively.

Data were collected during a series of visits over two years. Background data was collected during the rainy season from July to September 1996. Classification and other field data were collected during the rainy season from June to August 1998. Data on crop management activities, labor, and economic inputs and outputs for each garden were collected throughout 1998.

Ten households in each village were randomly selected as sample households. Semi-structured interviews were conducted with an adult member of each sample household in 1996. In semi-structured interviews, an investigator follows an outline of questions rather than a formal, structured questionnaire (Chambers, 1993). This allows more interaction and involvement with the interviewee who can then better introduce information that is of importance to him or her. For gardens (parcels with 10 or more trees), we collected information on the age of planting, the type of and number of trees planted, and other cropping history details. A garden was the sample unit for classification. Thus sample unit area varied.

*Classification Data*

Each garden parcel was walked in an orderly manner and sketch-mapped to allow for complete census and recording of crop species composition, abundance, approximate tree ages and spatial arrangement of crops within the garden. Of interest were species actively cultivated, or retained for some product or use. Weed species were not identified or counted. Cultivated trees and shrubs were identified to genus and species when possible, and individual trees counted. These species were separated into groups by crop-type: fruits trees, other trees (generally non-cultivated wild species retained in gardens) and living fences. Cultivated herbaceous crops were also identified when possible to genus and species and classified into one of two crop-type groups: herbaceous food crops (including vegetables, roots and grains), and medicinal or culinary herb crops. The abundance of herbaceous species was estimated according to the area occupied by the crop.

Garden data was revised in 1998, when each garden was revisited and another crop census made. The 1998 data serves as the basis of this analysis. There were some changes in the parcels between 1996 and 1998, resulting in three fewer parcels included in the survey in 1998 than were in 1999.

*Transect Data*

Concurrent with the 1998 classification field survey, we also collected transect information on area cropped and vegetation cover in each garden. Transects were established in a systematic manner. Spacing between transect lines and so sampling intensity varied with parcel size. For parcels estimated to be less than 0.8 ha, transect lines were spaced 20 meters apart, larger than 0.8 ha and up to 1.6 ha transects were spaced 30 meters apart, and if greater than 1.6 ha transects were spaced 40 meters apart. The initial transect was established at a distance from the garden's edge equal to1/2 the between-transect distance (i.e. 10, 15, 20 meters). Transect lines were established to follow the dominant contour of a parcel and/or to follow a straight boundary rather than along a predetermined bearing.

Each change in overstory and ground cover condition was recorded along the transect. For the overstory, each point along the transect was recorded when passing under or out from under the crown of a tree, as were changes from one tree species to another. Where crowns were mixed in a given canopy layer, no overlap was allowed but one or the other chosen. Overlap was allowed for separate canopies, but this condition was rare. For ground cover conditions, recorded changes included if and how the area was prepared for planting (tilled, slashed, slashed and burned, sprayed or scalped) and if planted, what crop was in that cover area (i.e. tilled, maize). If not currently cropped or prepared for cropping, the period or age of the weeds or fallow were estimated or the other condition or use occupying that area was recorded (rock, road, building etc.). In addition to the ground condition, the percent cover of the herbaceous layer was systematically recorded along the transect line. Sample points were located at the same interval along the transect as the distance between transects (20, 30 or 40 meters). A visual estimate of percent cover of a $1m^2$ area was made at each point.

*Input and Output Data*

Information on crop management activities and crop production were collected for each garden for one year. Of interest were the tasks done, labor used, the type, amount and cost of material inputs used (such as fertilizer or pesticides), as well as the production of economic crops or household goods. This input and output data collection began with a visit, made together with one of the local field assistants, in March 1998. In that first visit, we explained what we were interested in learning, and collected the input and output data for January, February and March (a period of low field activities at the end of the dry season). Following this joint visit, the assistant for that village returned each month from April through December to briefly interview the landowner regarding field activities, inputs and production for the month. These interviews were conducted in their native (minority) language and recorded on data sheets. All monetary values are reported in the Thai Baht (about 35 B/$US).

Labor was recorded by individual tasks such as burning, planting, weeding, spraying, pruning, harvesting and marketing. This separation was meant to aid in recalling and estimating activities, and were later summed as a composite value for the month. The time spent on each activity was recorded for the garden as a whole and by major crop. Labor supplied by family members or through traditional mechanisms of labor exchange were recorded together. Tasks performed by hired labor were recorded separately and as an economic cost (Baht) rather than time. Likewise, we kept track of the amounts, costs and number of applications of fertilizers, pesticides, seeds and other cash inputs.

Crops sold were recorded when possible by the amount, unit price and total value. However, crops were harvested and sold under a variety of arrangements. It was quite common for crops such as cabbage or fruit to be sold standing in the field or orchard and harvested for the buyer by his hired crew. In these cases, the farmer had no measure of the yield, and just the sale price was available. Crops such as maize and rice, which were used in the home, were recorded by estimate of volume or weight.

Household consumption of fruits and vegetables can be an important part of garden output, but was difficult to quantify. Recording weights and measures of all fruits and vegetables consumed in the home although possible, seemed difficult and overly intrusive for the purposes of this study. We recorded the number and frequency of crops harvested for home use each month instead.

## Analysis

Input and output data were compiled and summarized by garden in monthly spreadsheets. Material inputs such as fertilizer were recorded and summed by amount used, number of times applied and as a cost. All costs and economic returns were summed and used to calculate monthly economic measures such as marginal gains. Annual values were calculated from monthly figures, and then summarized by garden and household in SAS (SAS Institute Inc., 1989).

Transect and composition data were compiled in spreadsheets and summarized in SAS. Cover types were calculated as a percent of garden area. Parcel size was determined using transect lengths and spacings, and then subsequently used as the denominator in all per unit-area calculations.

# RESULTS AND DISCUSSION

In Chapters 2 and 3, our survey and analysis focused on the description and characterization of individual gardens (defined as upland parcels with 10 or more fruit trees). These characteristics were used to relate gardens by composition and function, and to develop a classification system. The survey also provides information illustrating the prominence of gardens and their importance in the allocation of land and resources, crops and management activities of households.

Land Use Patterns

The thirty sample households together reported total land holdings of 68.4 ha (Table 4.1). Thus, the average household managed a little over 2 ha of land. Upland parcels (gardens, parcels with fewer than 10 tree and parcels with no trees) together accounted for nearly 80% of the overall cropland area available to households, and paddy (wet rice) fields accounted for about 20% (Table 4.2). Gardens were the most frequent and extensive use for upland parcels in the three villages and accounted for 85 % of the upland cropping area, or 46 ha, overall (Table 4.3).

The villagers in Khun Sa Nai (KSN) had the largest total crop area, with 37.3 ha, an average of 3.7 ha per household. Most of the sample households' total crop area was uplands (nearly 90%), although paddy fields have been developed below the village in the last three decades (Cooper 1984, Tan-Kim-Yong et al. 1994). They also had the greatest number of gardens parcels (41), which together accounted for 30.7 ha, or 92 % of the total upland cropping area of the sample households. The sample households in Lower Mae Muang Luang (LMML) had the smallest total crop area, with just 14.4 ha all together, an average of 1.4 ha per household. Wet rice production was emphasized, and nearly 60% of their cropping area was paddy fields and about 40% uplands. Their 22 garden parcels accounted for the lowest total area (5.2 ha) in gardens, which was 86.7 % of their total upland cropping area (Table 4.3). LMML had highest proportion (84%) of upland parcels in gardens. The sample households in Upper Mae Muang Luang (UMML)

Table 4.1. Total crop area (in hectares) held by sample households in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| | All (n=30) | KSN (n=10) | LMML (n=10) | UMML (n=10) |
| Gardens | 46.0 | 30.7 | 5.2 | 10.1 |
| Uplands with few trees | 3.1 | 0.3 | 0.6 | 2.2 |
| Uplands with no trees | 5.2 | 2.5 | 0.2 | 2.6 |
| Paddy fields | 14.0 | 3.8 | 8.4 | 1.8 |
| Total | 68.4 | 37.3 | 14.4 | 16.6 |

Table 4.2. Percent of total cropping area held by sample households in upland or paddy (wet-rice) fields in Thung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| | All | KSN | LMML | UMML |
| | % | % | % | % |
| Upland parcels | 79.5 | 89.7 | 41.7 | 89.4 |
| Paddy fields | 20.5 | 10.3 | 58.3 | 10.6 |

had a crop area of 16.6 ha overall, or 1.6 ha per household. Most of the total cropland area was upland (nearly 90%), as paddy development was limited. The 19 garden parcels in UMML totaled 10.1 ha, or 67.8 % of the total upland cropping area (table 4.3).

The importance of gardens in upland parcel land use was also reflected in the distribution of parcel types among households. Twenty-eight of the 30 sample households (93%) had garden parcels (Table 4.4). All households in KSN had garden parcels (with a range of 2 to 7 gardens per household), and nine of the ten households in each LMML and UMML had garden parcels (ranging from 0 to 4 gardens per household in each village). In contrast, only 53% of households overall owned paddy fields. Nearly half the families in LMML had paddy, while only a third of the sample households in UMML had paddy land.

Theses land use patterns in each of the three villages reflect the different cultural and agricultural traditions, establishment histories and political situations of each village. KSN, a Hmong village, and the UMML a Lisu village, were each established at high elevations, in areas suited to production of their traditional upland crops: upland rice, maize and particularly, opium (Sabhasri, 1978). Both villages were actively involved in and benefited from the opium trade of northern Thailand, and both raised the crop in large areas on the mountain slopes around and above each village. The national and international opium eradication efforts of the late 1980s and 1990s (such as undertaken by UNHDP) affected the two villages differently, as have the eradication-associated

Table 4.3. Percent of total upland cropping area by parcel type (garden parcels, parcels with few trees (<10) and parcels with no trees). All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| | All | KSN | LMML | UMML |
| | % | % | % | % |
| Gardens | 84.6 | 91.6 | 86.7 | 67.8 |
| Uplands with few trees | 5.8 | 1.0 | 10.7 | 14.6 |
| Uplands with no trees | 9.6 | 7.4 | 2.7 | 17.5 |

Table 4.4. The percentage of sample households with gardens, other upland parcel types or paddy fields. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | Village | | | |
|---|---|---|---|---|
| | All (n=30) | KSN (n=10) | LMML (n=10) | UMML (n=10) |
| | % | % | % | % |
| Gardens | 93.3 | 100.0 | 90.0 | 90.0 |
| Uplands with few trees | 36.7 | 40.0 | 20.0 | 50.0 |
| Uplands with no trees | 40.0 | 60.0 | 10.0 | 50.0 |
| Paddy fields | 53.3 | 50.0 | 80.0 | 30.0 |

development efforts such as the SMHDP, other development projects, and the RFD's watershed protection policies. Linked to the opium eradication and development activities, the RFD's watershed protection efforts emphasized designation of protected areas, restriction of cropping areas and relocation of cropping areas from ridge tops and headwater areas to positions lower in the landscape. Because of KSN's location in the upper part of a large sub-basin idstant from other villages, villagers had the room and the opportunity to relocate production areas down-slope. This included opportunity to develop paddy field. Thus, of the three villages, KSN appears to have been the least impacted by land use restrictions. Large extended family units and income from cash crops also helped give many KSN households the capacity to shift or expand production areas. Because of UMML's location on a mountain flank and just a short distance above LMML, villagers had much less opportunity to relocate production areas, which resulted in a greater impact and loss of crop production area.

KSN and UMML also differ significantly in other resources that have influenced adjustments to a post-opium economy. The Huai Pong Sa sub-basin where KSN is located has many small streams. The small streams and steep slopes of the basin are suited for use of gravity-fed irrigation, a recently evolved practice and, important to a number of alternative cash crops such as cabbage and litchi. Also, a reasonably good road, passable most of the year, serves KSN. Together, these have helped facilitate profitability and development of new cash crops, particularly cabbage. The landscape of UMML was less well disposed to transition to the post-opium economy. There was less water available (in fewer streams) needed to serve both domestic and agricultural demand of both UMML and LMML (resulting in some conflict of water rights). Also UMML is located farther from paved roads on a very poor road, which is often not passable during the rainy season.

The cultural traditions, agricultural practices and establishment history of LMML differ from the other two villages in significant ways. The traditional Karen agroeconomic strategy favored production of domestic subsistence crops over cash crops, and wet rice cultivation when possible (Kunstadter 1978). LMML was established low in the watershed, where more gently sloping ground suited paddy field development. The villagers reported that the village was established and paddies were first developed more than 100 years ago. The low number and small total area of upland parcels reflects not only the traditional emphasis on paddy rice production, but also changes in land use patterns, particularly rotation practices, brought about through watershed protection and planning by the RFD (SMHDP, 1994). Until recently, LMML practiced rotational swidden cultivation and most families managed many parcels in rotation and larger upland areas than now. RFD watershed protection policies that restricted the location and area of farming activities resulted in a loss of land available to the villagers for cropping.

## Crop Species Frequency and Abundance

A total of 96 crop species were recorded in the sample gardens in 1998, with an average of 12 crop species per garden parcel (range 1-33 species, Chapter 3). At the household-level, sample households raised an average of 23.5 different crop species in their gardens, with a range of 1 to 44 species recorded in the survey. Households raised a greater variety of crops in KSN (28 crop species per household) and LMML (26 crop species) than in UMML (16 crop species per household). A total of 31 fruit species were recorded overall in 1998, with 27 species in both KSN and LMML, and 17 species in UMML. The average household raised about 12 fruit species overall (14.9, 12.4, 7.8 species for KSN, LMML and UMML respectively), 8 herbaceous food crops and 2.3 medicinal and culinary herb species per household overall. That the household crop species diversity was highest in KSN was due largely to the greater number and larger size of garden parcels in KSN than in LMML. Gardens in LMML had higher numbers of crop species on a per hectare basis than did gardens in KSN. This fits with the observation that more gardens in LMML were of the home garden types where emphasis may have been to grow a large number of crops to meet a wide range of needs in a small space.

More households in the study raised mangos (87 %) than any other fruit. Mango was followed in popularity by banana (83%) jackfruit, Japanese apricot and litchi (73% each). Mango, banana and jackfruit were among the 5 most frequently grown fruit species in each of the three individual villages (Table 4.5). These household-level frequencies of the most common fruit species were higher than at the garden-level, where mango was again the most frequent (73%) followed by banana, jackfruit, Japanese apricot, and peach (all at 57%, see Chapter 3). Together, thirteen fruit species (of 31 recorded overall) were raised by 50% or more of the households overall, 14 species in

Table 4.5. Frequency of fruit crop species as a % of households in whose gardens each species were present in 1998 in the Tung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | All | | KSN | | LMML | | UMML | |
|---|---|---|---|---|---|---|---|---|
| Rank | crop | % hh | crop | % hh | crop | % hh | crop | % hh |
| 1 | mango | 86.7 | mango | 100 | mango | 90 | J. apricot | 90 |
| 2 | banana | 83.3 | banana | 100 | banana | 90 | mango | 70 |
| 3 | jack fruit | 73.3 | jack fruit | 100 | guava | 90 | banana | 60 |
| 4 | litchi | 73.3 | litchi | 100 | tamarind | 80 | jack fruit | 50 |
| 5 | J. apricot | 73.3 | peach | 100 | jack fruit | 70 | litchi | 50 |
| 6 | papaya | 63.3 | pumelo | 100 | litchi | 70 | peach | 50 |
| 7 | pumelo | 63.3 | J. apricot | 90 | papaya | 70 | pear | 50 |
| 8 | peach | 63.3 | papaya | 90 | pumelo | 60 | guava | 40 |
| 9 | bamboo | 53.3 | persimmon | 90 | lime | 60 | lime | 40 |
| 10 | lime | 53.3 | pear | 70 | coffee | 60 | coffee | 40 |
| 11 | guava | 53.3 | bamboo | 70 | bamboo | 50 | bamboo | 40 |
| 12 | tamarind | 53.3 | lime | 60 | peach | 40 | papaya | 30 |
| 13 | pear | 50.0 | tamarind | 60 | J. apricot | 40 | pumelo | 30 |
| 14 | coffee | 46.7 | tangerine | 60 | coconut | 40 | tamarind | 20 |
| 15 | persimmon | 33.3 | coffee | 40 | pear | 30 | tea | 20 |

KSN, 11 species in LMML and 7 in UMML. There were 6 species that were grown by all households in KSN. Households in KSN showed a lot of consistency in raising certain popular fruits. There was less consistency in LMML, which in turn was more consistent than in UMML.

Among the fruit crop species, Peach, litchi, Japanese apricot, coffee and mango had the highest overall abundance of fruit crop species (Chapter 3). Households had 243 fruit trees on average (472, 112, 108 trees for KSN, LMML and UMML respectively). However, few species were abundant in large, potentially economically-significant numbers, even when looking at the a household's gardens collectively. There were only 12 fruit species which reached a household-level abundance of 20 trees or more. Only six of these species exceeded 20 trees in 5 or more households (mango, 15 households; peach, 15 households; J. apricot, 10 households; coffee, 7 households, litchi, 7 households; and banana, 5 households).

Of herbaceous crop species, squash and maize were the most frequent species per household (77 %) followed by cucumber (63%) and pepper (57%, see Table 4.6). There were a higher number of herbaceous species than fruit species grown, with 47 overall, (and 34, 31 and 26 recorded in gardens in KSN, LMML and UMML respectively). At the time of the survey early in the rainy season, there were 7 herbaceous crop species present in 50% or more of families' gardens overall, with 11 in KSN, 10 in LMML and 3 in UMML. Although squash, maize and cucumbers appeared with high frequency in all

Table 4.6. Frequency of herbaceous crop species as a % of households in whose gardens each species were present in 1998 in the Tung Jaw Watershed Management Unit, Mea Hong Son Province, Thailand. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| | All | | KSN | | LMML | | UMML | |
|---|---|---|---|---|---|---|---|---|
| Rank | crop | % hh | crop | % hh | crop | % hh | crop | % hh |
| 1 | squash | 76.7 | squash | 90 | pineapple | 80 | maize | 80 |
| 2 | maize | 76.7 | maize | 90 | squash | 70 | squash | 70 |
| 3 | cucumber | 63.3 | pepper | 80 | pepper | 70 | cucumber | 60 |
| 4 | pepper | 56.7 | cucumber | 70 | maize | 60 | eggplant | 40 |
| 5 | pineapple | 50.0 | cassava | 70 | cucumber | 60 | bean | 40 |
| 6 | cassava | 50.0 | pineapple | 60 | cassava | 60 | unknown herb | 40 |
| 7 | lemongrass | 50.0 | lemongrass | 60 | lemongrass | 60 | lemongrass | 30 |
| 8 | eggplant | 43.3 | sugarcane | 60 | taro | 60 | sugarcane | 30 |
| 9 | taro | 36.7 | ginger | 60 | eggplant | 60 | potato | 30 |
| 10 | sweet potato | 36.7 | taro | 50 | sweet potato | 50 | bitter melon | 30 |
| 11 | bean | 30.0 | cabbage | 50 | *Zingiber c.* | 40 | pepper | 20 |
| 12 | sugarcane | 30.0 | sweet potato | 40 | galangal | 40 | cassava | 20 |
| 13 | rice | 23.3 | bean | 40 | rice | 30 | sweet potato | 20 |
| 14 | ginger | 23.3 | onion | 40 | eggplant | 30 | eggplant | 20 |
| 15 | cabbage | 20.0 | eggplant | 30 | eggplant | 30 | tobacco | 20 |

villages, there was less consistency in the herbaceous makeup of gardens than there was with perennial fruits. These common herbaceous crops were raised predominantly for household use, although maize and squash were also sold. Cabbage, the dominant herbaceous crop of economic importance, was under-represented in this rainy season survey because much of it is grown under irrigation in the dry period.

Crop Cover

Total tree cover at the garden level averaged 21.2 % per parcel, with an overall range by garden of 0.1% to 67.4%. Tree cover for the individual garden types varied from 11.1% to 38.3%. Mean crown cover for any individual species was low; for example, litchi had a mean cover of 2.2 % and a maximum of 29%, mango 3.3% (max 63.8%), banana 2.3% (max 30.6%), Japanese apricot 2.9% (max 31.4%) and peach 3.9% (35 max). Mean percent herbaceous cover for each garden was 60.7%.

An average of 28% of garden area (range 0 to 100%) was planted or prepared for planting of herbaceous crops. Of this, maize was allotted the greatest area (12.6%). Another 15.8% was recently slashed, which could be either the first step in site preparation or simply weed control. Nearly half of the garden area, 49.2% (range 0 to 100%), had been left in weeds or fallow at the time of sampling early in the rainy season. Estimated fallow ages observed ranged from the previous season (35%), weeds of 2 or 3 years old (13.5%), and weedy fallow of 4 years or longer (0.7%) which indicates fallows were short and that the gardens were frequently cropped. Irrigated dry-season crops were not evident at the time of the survey in the rainy season. Planting of most rain-fed crops had been done or was in progress. The area of gardens in other covers which included buildings, roads, packed earth yards and rock was just 7% (range 0 to 87.8%).

## Management Activities

In addition to the physical data collected by field surveys, information on crop management activities and crop production were collected for each garden for one year. The average annual production inputs and outputs are presented in Table 4.7 and indicate different management activity levels in gardens in the three villages. Data were collected at a garden level to allow for comparisons between garden types. A garden represents a management unit at one scale of management of interest. A household's group of gardens represents another management unit and scale of management activity, as many cropping decisions and daily activities for individual parcels relate to the group overall. There were clear and different patterns between villages in what households did with and got from their garden parcels (Table 4.8). Households in KSN had the highest level of input use in their gardens and also received higher cash returns and profit from garden activities than did households in UMML or LMML. Fruit crop production was very low in the study area and throughout northern Thailand in 1998. Most of the economic activity in gardens in reported in 1998 was from herbaceous crops, particularly cabbage.

Table 4.7. Garden parcel average of production inputs and outputs for gardens. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| **Factor Name** | **Units** | **All** n=82 | **KSN** n=41 | **LMML** n=22 | **UMML** n=19 |
|---|---|---|---|---|---|
| **Chemical inputs** | | | | | |
| Fertilizer | Kg/yr | 100.2 | 193.4 | 0.0 | 15.0 |
| Fertilizer applications | times/yr | 0.6 | 1.0 | 0.0 | 0.3 |
| Insecticide | l/yr | 1.2 | 2.4 | 0.0 | 0.1 |
| Insecticide applications | times/yr | 0.9 | 1.4 | 0.0 | 0.9 |
| Herbicide | l/yr | 0.6 | 1.1 | 0.0 | 0.5 |
| Herbicide applications | times/yr | 0.3 | 0.2 | 0.1 | 0.6 |
| **Labor inputs** | | | | | |
| Labor | days/yr | 31 | 49 | 12 | 15 |
| **Costs** | | | | | |
| Labor (hired) | B/yr | 765 | 1224 | 316 | 295 |
| Chemical costs | B/yr | 1198 | 2220 | 18 | 359 |
| Seed costs | B/yr | 600 | 1188 | 5 | 19 |
| Other costs | B/yr | 441 | 865 | 2 | 33 |
| Total costs | B/yr | 2996 | 5481 | 341 | 706 |
| **Returns** | | | | | |
| Total economic return | B/yr | 10178 | 19679 | 45 | 1407 |
| **Profit** | | | | | |
| Marginal gain (profit) | B/yr | 7182 | 14198 | -297 | 701 |

Table 4.8. Household average production inputs and outputs for garden parcels. All three villages combined (All), Khun Sa Nai (KSN), lower Mae Muang Luang (LMML) and upper Mae Muang Luang (UMML).

| **Factor Name** | **Units** | **All** n=30 | **KSN** n=10 | **LMML** n=10 | **UMML** n=10 |
|---|---|---|---|---|---|
| **Chemical inputs** | | | | | |
| Fertilizer | Kg/yr | 274 | 793 | 0 | 29 |
| Fertilizer applications | times/yr | 1.6 | 4.2 | 0.0 | 0.6 |
| Insecticide | l/yr | 3.4 | 9.9 | 0.0 | 0.2 |
| Insecticide applications | times/yr | 2.5 | 5.7 | 0.0 | 1.7 |
| Herbicide | l/yr | 1.8 | 4.4 | 0.1 | 0.9 |
| Herbicide applications | times/yr | 0.8 | 1.0 | 0.2 | 1.1 |
| **Labor inputs** | | | | | |
| Labor | days/yr | 85 | 203 | 25 | 28 |
| **Costs** | | | | | |
| Labor (hired) | B/yr | 2091 | 5019 | 695 | 560 |
| Chemical costs | B/yr | 3275 | 9104 | 39 | 682 |
| Seed costs | B/yr | 1639 | 4870 | 12 | 36 |
| Other costs | B/yr | 1204 | 3545 | 5 | 63 |
| Total costs | B/yr | 8188 | 22474 | 751 | 1341 |
| **Returns** | | | | | |
| Total economic return | B/yr | 27819 | 80685 | 98 | 2673 |
| **Profit** | | | | | |
| Marginal gain (profit) | B/yr | 19630 | 58211 | -653 | 1332 |

Fertilizers, insecticides and herbicides were all commonly used in KSN. Average annual household expenses for garden activities were 22,474 Baht (B), of which chemicals made up the highest average input cost, followed by labor and then seed costs. Households saw average returns of about 80,685 B and marginal gains of 58,211 B (ranging from –3,055 B to 163,845 B, see Table 4.9) from their garden parcels. Most cash inputs and returns were related to cabbage production. 60 % of the households in KSN raised and sold cabbage in 1998, the year studied. Households reported sales of cabbage from garden parcels ranging from 1350 B to 205500 B, which represented contributions of from 26% to 100% of the cash households earned from their gardens. Landowners reported low and sporadic yields for all the fruit crops. Nonetheless, seven households reported harvest and sale of one or more fruit crops from their gardens in 1998 (apricot, banana, coffee litchi and peach). Fruit crops accounted for from <1% to 100 % cash production from a household's gardens. Many households in KSN were actively involved as producers in the cash crop economy. Others participated indirectly as laborers.

The economic activities in gardens in LMML were very different. In contrast to KSN, no fertilizers or insecticides were used in LMML, and only one household applied herbicides (Table 4.10). Average annual household expenses for garden activities were only 751 B, most of which were labor costs. Most households (90%) saw no returns. Only one household reported marketing any crop from a garden, in this case bananas and coffee. All households saw a net cash loss or zero gain for garden activities (average

Table 4.9. Total production inputs and outputs for garden parcels, by household in Khun Sa Nai.

| **Factor Name** | **Units** | **Household Number** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2** | **5** | **6** | **9** | **16** | **23** | **24** | **29** | **30** | **33** |
| **Chemical inputs** | | | | | | | | | | | |
| Fertilizer | Kg/yr | 100 | 1805 | 2289 | 250 | 0 | 0 | 2235 | 1150 | 100 | 0 |
| Fertilizer applications | times/yr | 2 | 9 | 10 | 1 | 0 | 0 | 12 | 6 | 2 | 0 |
| Insecticide | l/yr | 1.5 | 28.3 | 10 | 15 | 0 | 0 | 25.2 | 18 | 1 | 0 |
| Insecticide applications | times/yr | 1 | 22 | 8 | 4 | 0 | 0 | 12 | 9 | 1 | 0 |
| Herbicide | l/yr | 0 | 10 | 23 | 0 | 5.5 | 0 | 5 | 0 | 0 | 0 |
| Herbicide applications | times/yr | 0 | 3 | 4 | 0 | 2 | 0 | 1 | 0 | 0 | 0 |
| **Labor inputs** | | | | | | | | | | | |
| Labor | days/yr | 130.5 | 402.3 | 454.8 | 43.5 | 38.5 | 16.5 | 448.8 | 349.0 | 117.7 | 24.0 |
| **Costs** | | | | | | | | | | | |
| Labor (hired) | B/yr | 400 | 5220 | 19700 | 1200 | 650 | 0 | 18920 | 3000 | 1100 | 0 |
| Chemical costs | B/yr | 1135 | 20200 | 24070 | 5730 | 885 | 0 | 26570 | 11360 | 1085 | 0 |
| Seed costs | B/yr | 660 | 3980 | 16260 | 0 | 1900 | 1300 | 17513 | 7080 | 3 | 0 |
| Other costs | B/yr | 0 | 5700 | 10600 | 0 | 0 | 0 | 18050 | 200 | 900 | 0 |
| Total costs | B/yr | 2195 | 35100 | 70630 | 6930 | 3435 | 1300 | 80417 | 21640 | 3088 | 0 |
| **Returns** | | | | | | | | | | | |
| Total economic return | B/yr | 5250 | 163880 | 234475 | 70000 | 3000 | 2530 | 156325 | 166538 | 0 | 4848 |
| **Profit** | | | | | | | | | | | |
| Marginal gain (profit) | B/yr | 3055 | 128780 | 163845 | 63070 | -435 | 1230 | 75908 | 144898 | -3088 | 4848 |

Table 4.10. Total production inputs and outputs for garden parcels, by household in Lower Mea Muang Luang.

| Factor Name | Units | Househol**c** Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **8** | **11** | **18** | **19** | **23** | **27** | **28** | **32** | **44** |
| **Chemical inputs** | | | | | | | | | | |
| Fertilizer | Kg/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fertilizer applications | times/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Insecticide | l/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Insecticide applications | times/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Herbicide | l/yr | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Herbicide applications | times/yr | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| **Labor inputs** | | | | | | | | | | |
| Labor | days/yr | 41.5 | 23 | 1.5 | 13.25 | 59.5 | 31.75 | 18.5 | 47.5 | 16.75 |
| **Costs** | | | | | | | | | | |
| Labor (hired) | B/yr | 0 | 0 | 0 | 970 | 4180 | 0 | 200 | 0 | 1600 |
| Chemical costs | B/yr | 0 | 0 | 0 | 0 | 0 | 0 | 385 | 0 | 0 |
| Seed costs | B/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 60 |
| Other costs | B/yr | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total costs | B/yr | 0 | 50 | 0 | 970 | 4180 | 0 | 585 | 60 | 1660 |
| **Returns** | | | | | | | | | | |
| Total economic return | B/yr | 0 | 0 | 0 | 0 | 980 | 0 | 0 | 0 | 0 |
| **Profit** | | | | | | | | | | |
| Marginal gain (profit) | B/yr | 0 | -50 | 0 | -970 | -3200 | 0 | -585 | -60 | -1660 |

marginal gain -653 B, with a range from –3200 B to 0 B). Most tasks and labor inputs were reported collectively for the garden, and not separated by crop, reflecting the tendency towards highly mixed gardens, and a focus on many rather than just a few commodities. It also appears that many activities took place in small incremental steps and so were likely not always fully reported. Households in LMML wre not very well positioned, nor does it seem, very inclined to participate in cash crop market production.

Input use in UMML was moderate, and fertilizers, insecticides and herbicides were all used. Only 30% of households used fertilizers and insecticides in their gardens, and they used less than did households in KSN. 60% of households used herbicides. Average annual household expenses for garden activities were 1,341 B, of which chemicals made up the highest average input cost, followed by labor and then seed costs (Table 4.11). Households saw average returns of about 2,673 B and marginal gains of 1332 B (ranging from –1,958 B to 2,380 B) from their garden parcels. Most cash inputs and returns were related to annual crop production. One household in UMML raised and sold cabbage in garden parcels in 1998, for a return of 13200 B. Landowners reported very low yields for all the fruit crops. Only 3 households reported harvest and sale of a fruit crop, all less than 1,000 B, from their gardens in 1998. Fruit crops accounted for from 25% to 100 % cash production from the household's gardens. Like neighboring LMML, households in UMML were not very well positioned to participate in cash crop market production. Annual cash crop production has been hindered by both the lack of irrigation water for dry season crop production, and the poor road, which has made

Table 4.11. Total production inputs and outputs for garden parcels, by household in Upper Mea Muang Luang.

| **Factor Name** | **Units** | **Household Number** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **5** | **7** | **8** | **10** | **11** | **14** | **15** | **17** | **20** |
| **Chemical inputs** | | | | | | | | | | |
| Fertilizer | Kg/yr | 0 | 0 | 0 | 85 | 0 | 0 | 0 | 100 | 100 |
| Fertilizer applications | times/yr | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 |
| Insecticide | l/yr | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0.25 | 1 |
| Insecticide applications | times/yr | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 1 | 8 |
| Herbicide | l/yr | 0.5 | 0 | 0.5 | 2.5 | 0 | 0 | 1.75 | 2 | 1.5 |
| Herbicide applications | times/yr | 1 | 0 | 1 | 3 | 0 | 0 | 2 | 3 | 1 |
| **Labor inputs** | | | | | | | | | | |
| Labor | days/yr | 11.5 | 0 | 11.25 | 63.5 | 14.5 | 20.5 | 26.75 | 56.75 | 72.75 |
| **Costs** | | | | | | | | | | |
| Labor (hired) | B/yr | 600 | 0 | 0 | 1000 | 1000 | 1500 | 1200 | 300 | 0 |
| Chemical costs | B/yr | 190 | 0 | 190 | 2065 | 0 | 0 | 658 | 1870 | 1850 |
| Seed costs | B/yr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 360 | 0 |
| Other costs | B/yr | 60 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 470 |
| Total costs | B/yr | 850 | 0 | 190 | 3065 | 1000 | 1500 | 1958 | 2530 | 2320 |
| **Returns** | | | | | | | | | | |
| Total economic return | B/yr | 800 | 0 | 0 | 15680 | 0 | 850 | 0 | 4700 | 4700 |
| **Profit** | | | | | | | | | | |
| Marginal gain (profit) | B/yr | -50 | 0.000 | -190 | 12615 | -1000 | -650 | -1958 | 2170 | 2380 |

marketing of crops during the rainy season difficult and uncertain. Villages reported that fruit production was lower than expected, and although interested, were not enthusiastic about economic prospects. There were difficulties finding cultivars that fit the environmental conditions of the village for some of the temperate fruits. Production problems have been exacerbated by lack of skills and attention needed for good management.

## Evaluation of Subsystems

An objective at the start of this project was to develop a methodology for the evaluation and comparison of agroforestry subsystems. We saw the need to be able to assess and compare Highland fruit-based agroforestry systems to be able select among them to better meet different objectives. Ideally, such an evaluation tool would incorporate environmental, economic and social considerations and would allow for an evaluation and comparison of different agroforestry subsystems in the study area as well as be adaptable to a larger area.

Our evaluation tool was simple in concept: a matrix, much as has been used to compare the characteristics of different multipurpose trees (see Rocheleau et al., 1988). For this matrix, values would be calculated for each of a number of different criteria for each garden. A mean or a range of values could be presented in this matrix for each type of garden. The evaluation criteria chosen would reflect the garden's economic, environmental and social performance. The premise was to make a comparison between garden types, using garden-level field data. There were three steps in the process towards this evaluation tool: 1.) developing a classification of garden types; 2.) building a database of garden traits, management activities, inputs and other factors, and; 3.) putting the pieces together in a matrix.

The first step, developing a classification, was explored in the two previous chapters. We were working on the assumption that there were distinct garden types that had emerged as a result of the local farmers organizing of their gardens in response to a group of physical and socioeconomic environmental conditions. In particular, it appeared as if people were organizing their gardens by function. But in Chapter 3, the multivariate analysis indicated that the gardens did not represent discrete categories as hypothesized, but rather are part of a continuum of individual gardens of gradually changing and overlapping characteristics. We were able to draw lines of separation to form groups, but function was not borne out as a strong organizing factor. This created a dilemma. The premise of evaluating gardens by type was wed to the assumption that types could be identified, and that they would have unifying similarities relating to management practices. Although we could impose a structure on the sample gardens, the strength of such a classification as a management tool would be diminished.

In the second step, we tried to develop a set of factors that could be used to compare the performance of different garden types. These factors ought to allow comparison on an environmentally, socially and ecologically relevant basis. For instance, some factors of economic interest would be the profitability of gardens, and seasonal cash flows in and out of them; factors of environmental interest relate to potential soil and water conservation and water quality issues, such as soil cover, irrigation water use and the use of fertilizers or pesticides. Factors of social interest certainly include water issues, as well as labor use and patterns. Some of this information was developed as part of the classification step, most of the rest was developed in a separate but related step in the monthly input and output interviews, or the transects.

In the third step, we assembled the matrix of evaluation factors and garden types. Each value in the matrix was taken from observed values in the study area. We found that value ranges were too broad and variable to be very helpful and so chose not to present the matrix of evaluation factores and garden types, but instead to present information on some of these factors separately in this chapter (above).

The evaluation matrix we developed fell short of our hopes of producing an effective evaluation tool. The idea, simple as we tried to keep it, turned out to be overly ambitious or too complicated for the level of resources we had to apply. There are several important issues relating to the concept and data that remain problematic. First, there were problems choosing and developing relevant, yet appropriately simple factors for evaluating many important properties, such as soil erosion (we measured soil cover instead). Within the narrower boundaries that we determined were achievable, we also encountered serious challenges and difficulties in data collection, for example, estimating water use with gravity-fed sprinkler irrigation. I underestimated the difficulty of collecting this and other production-related data. Finally, there were great difficulties in quantifying performance measures for perennial crops. These occur because management activities and production patterns associated with perennial crops change with time, as do the values associated with the activities and production (see Monke and Peason, 1989 for approaches to this problem). This was further complicated by the nature of the gardens which often included not only a mix of species, but also a large range of crop tree ages within individual gardens and from garden to garden. Some of these data issues stem from the premise that the most relevant information for each subsystem (assuming it can be defined) was available through on-farm assessments, and our choice to evaluate these systems with on-farm data. Trying to touch on so many aspects of the fruit-based agroforestry system may have been overly ambitious for the complexity and variability of the situation.

## Conclusions

Gardens were a very popular land use for upland parcels in all three study villages, and 93% of sample households had at least one garden parcel. Gardens accounted for 85% of upland cropping area. However, trees did not necessarily dominate the garden parcels, and tree cover was only 21.2% on average. Many gardens were not densely or uniformly planted. Also, many gardens were still young, and had not reached mature crown sizes. Both of these patterns allowed for intercropping with herbaceous crops, a common practice.

Households in all the communities tended to grow a many woody and herbaceous species in their gardens to meet a variety needs. The number of crop species raised (96 overall and an average of 23 per household) and fruit species (31 overall, 12 per household) are low compared to figures reported for other gardens in the tropical lowlands. Hocking et al. (1996) reported 37 species of tree species on Bangladeshi homesteads from across a wide region. The most popular species were bamboo, jackfruit, mango, betel nut and Jujube. Rico-Gray et al., (1990) found 135 tree and shrub species in a 20 garden sample the Yucatan of Mexico. Finally, Gajaseni and Gajaseni (1999) reported crop species grown in individual gardens in central Thailand to range from 26 to 53 species. Nonetheless, the tendency for all households to have at the least small numbers of many fruit species suggests that domestic use was a priority.

Some aspects of gardens tended to vary between villages, which likely reflected the different social, agricultural and historical situations of each. Households in KNS tended to have more, larger sized gardens and plantings, reflecting their better opportunity to participate in the cash economy than the other villages. Most households derived some income from their gardens. Fertilizers, insecticides and herbicides were all commonly used in KSN. Most gardens in LMML were small, diverse and with a domestic orientation, and no fertilizers or insecticides and very few herbicides were used. Very few households gained income from their gardens. Villagers in UMML had limited area for crop production, and the smallest portion of upland in gardens. Half the households derived some income from their gardens, and most showed some interest and intent at commercial fruit production, but market opportunities were poor.

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# Chapter 5

# Summary

Brad Withrow-Robinson

This project has contributed to recognizing the scope and diversity of fruit based agroforestry in northern Thailand, as well as some understanding about its development and functions. The agroforestry systems described and investigated in this study include a wide spectrum of species and practices. These systems developed in response to changing socio-political conditions and to meet a variety of landowner objectives. In this study, we began by describing and classifying fruit-based agroforestry by two different approaches. We also quantified a group of economic, social and environmental factors to explore a methodological process by which fruit-based agroforestry could be evaluated.

In Chapter 2, we presented a preliminary classification developed from the initial survey of gardens. The classification is a straightforward and conventional approach. Gardens were subjectively separated into four general groups and 11 fruit-based agroforestry subsystems. Groups were organized largely along a spectrum of economic (domestic or commercial) function. Subsystems were further distinguished by composition and structure. Home gardens and commercial orchards were at opposite ends of the spectrum. There was also a prominent group of gardens with clearly and strongly mixed functions, both commercial and home use. It was apparent that fruit-based gardens were very dynamic and tended to develop over time. Individual garden characteristics seemed to evolve and reflect changes in plans as well as by chance such as tree loss and survival. Subsystems were readily recognizable from field observations. The classification was subjective and emerged directly from field.

In Chapter 3, we took a different approach to a similar, updated data set from the 1998 survey and explored the use of multivariate analysis methods of description and classification. Multivariate analysis offered a more objective method of handling and relating a large number of variables. It also offered additional insights as to how the different groups related to each other and to their environment. Crop species diversity, abundance of herbaceous food crops and the size of the tree planting were the key garden characteristics distinguishing the different garden types. Multivariate analysis methods are appropriate for this sort of complex and variable data. Seven garden types emerge as subsystems from this process. Our observations led us to question the structural nature of the fruit-based agroforestry system. We began with the hypothesis that there were separate and distinct garden types that had emerged in response to a group of physical and socioeconomic environmental conditions. In particular, it appeared as if people were organizing their gardens by function. But the multivariate analysis seems to indicate that these gardens do not represent discrete categories as presumed, but rather are part of a continuum of individual gardens of gradually changing and overlapping characteristics. Function was not borne out as a strong organizing factor. So in practice, it seems that people in this Highland area appear to be mixing all components and functions, either by design or in response to changing situations and events.

The secondary data set developed and described in Chapter 4 quantified many variables relating to production outputs, inputs of materials, labor and cash, as well as other physical and socio-economic factors. These factors were examined on both a garden and household level. Gardens were a very popular land use for upland parcels in all three study villages, and 93% of sample households had at least one garden parcel. Some aspects of gardens tended to vary between villages, which likely reflected the different social, agricultural and historical situations of each. The effort to incorporate different social, economic and ecological performance factors in a matrix for comparing and evaluating different systems was not practical. There remains a need for tools that can help us compare and evaluate the performance of the different systems described by the classification. The utility of this data set, first seen as contributing to that need, was restricted by limitations in the data which arose from problems in choosing relevant factors, collecting data for highly variable factors and quantifying performance of perennial crops.

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# APPENDICES

Appendix A. Variables in initial data set screened for inclusion in classification data sets and list of species identified in garden surveys. An * indicates a species noted in 1996 only, ** indicates a species noted in 1998 only. Variable types are continuous quantitative (Q) and categorical (C).

| **Variable** | | Unit | Type |
|---|---|---|---|
| *plant species* | | | |
| Fruit tree species | *Scientific name* | | |
| Custard apple | *Anona squamosa* | tree | Q |
| Jack fruit | *Artocarpus heterophyllus* | tree | Q |
| Bamboo | *sp1* | clump | Q |
| Bamboo | *sp2* | clump | Q |
| Bamboo | *sp3** | clump | Q |
| Tea | *Camilia sinensis* | tree | Q |
| Papaya | *Carica papaya* | tree | Q |
| Lime | *Citrus aurantifolia* | tree | Q |
| Kiefer lime | *Citrus hystrix*** | tree | Q |
| Pumelo | *Citrus maxima* | tree | Q |
| Sweet orange | *Citrus reticulata* | tree | Q |
| Coffee | *Coffea arabica* | tree | Q |
| Coconut | *Cocos nucifera* | tree | Q |
| Persimon | *Diospyros kaki* | tree | Q |
| Wild persimmon | *Diospyros sp.* | tree | Q |
| Loquat | *Eriobotrya japonica* | tree | Q |
| Langsad | *Euphoria longana* | tree | Q |
| Litchi | *Litchi chinensis* | tree | Q |
| Apple | *Malus domestica* | tree | Q |
| Mango | *Mangifera indica* | tree | Q |
| Mulberry | *Morus sp.* | tree | Q |
| Banana | *Musa* edible cultivars | clump | Q |
| Passionfruit | *Passiflora edulis* | tree | Q |
| Avacado | *Persea americana* | tree | Q |
| Japanese apricot | *Prunus mume* | tree | Q |
| Peach | *Prunus persica* | tree | Q |
| Plum | *Prunus salicina*** | tree | Q |
| Guava | *Psidium guajava* | tree | Q |
| Pear | *Pyrus pyrifolia* | tree | Q |
| Water apple | *Sysygium sp.*** | tree | Q |
| Tamarind | *Tamarindus indica* | tree | Q |
| *Makwaen* | *Xanthozylem sp.*** | tree | Q |

Appendix A. Continued

| | | | |
|---|---|---|---|
| <u>Other Tree species</u> | | | |
| *Cha Om* | *Acacia sp.* | tree | Q |
| Betel palm | *Areca catechu* | tree | Q |
| | *Bauhinia sp.** | tree | Q |
| | *Cassia sp.* | tree | Q |
| False chestnut | *Castanopsis sp. 1* | tree | Q |
| False chestnut | *Castanopsis sp. 2* | tree | Q |
| False chestnut | *Castanopsis sp. 3* | tree | Q |
| Wild langsad | *Euphoria sp.* | tree | Q |
| Wild fig | *Ficus sp. 1** | tree | Q |
| Wild fig | *Ficus sp. 2* | tree | Q |
| | *Flactoria indica* | tree | Q |
| Leucaena | *Leucaena leucocephala* | tree | Q |
| | *Oroxylum indicum* | tree | Q |
| | *Protium serratum* | tree | Q |
| False chestnut | *Quercus sp.* | tree | Q |
| | *Spondias bipinnata* | tree | Q |
| Teak | *Tectona grandis* | tree | Q |
| | *Thernstroemia gymnanthera* | tree | Q |
| Maidenhair palm | | tree | Q |
| Prickly pear cactus | | tree | Q |
| Unknown tree | | tree | Q |
| Unknown tree | | tree | Q |
| <u>Living Fence species</u> | | | |
| | *Erythrina sp.* | presence or absent | C |
| *("SaBooDam")* | *Jatropha curcus* | tree | C |
| | *Sambucus sp.* | tree | C |
| <u>Herbaceous food crop species</u> | | | |
| Garlic | *Allium sativum** | abundance | Q |
| Japanese onion | *Allium sp. 1* | abundance | Q |
| chives | *Allium sp. 2* | abundance | Q |
| Onion | *Allium tuberosum* | abundance | Q |
| Amaranthus | *Amaranthus sp.* | abundance | Q |
| Pineapple | *Ananas comosus* | abundance | Q |
| Peanut | *Arachis hypogaea* | abundance | Q |
| Cabbage | *Brassica oleracea v.c.* | abundance | Q |

Appendix A. Continued

| | | | |
|---|---|---|---|
| Mustards | *Brassica sp.*** | abundance | Q |
| Pepper | *Capsicum annum* | abundance | Q |
| Pepper | *Capsicum frutescens** | abundance | Q |
| Taro | *Colocasia esculenta* | abundance | Q |
| Cucumber | *Cucumis sativus* | abundance | Q |
| Squash | *Cucurbita sp.* | abundance | Q |
| Carrot | *Daucus carota* | abundance | Q |
| Tree cotton | *Gossypium arboreum* | abundance | Q |
| Sunflower | *Helianthus sp.* | abundance | Q |
| Roselle | *Hibiscus sabdariffa* | abundance | Q |
| sweet potato | *Ipomoea batatas* | abundance | Q |
| Tomato | *Lycopersicon esculentum* | abundance | Q |
| Cassava | *Manihot esculenta* | abundance | Q |
| Bitter melon | *Momordica charantia* | abundance | Q |
| Rice | *Oryza sativa* | abundance | Q |
| Bean | *Phaseolus vulgaris* | abundance | Q |
| Pepper leaf | *Piper sarmentosum* | abundance | Q |
| Sugar cane | *Saccharum officianarum* | abundance | Q |
| Chayote | *Sechium edule* | abundance | Q |
| Eggplant | *Solanum melongena* | abundance | Q |
| Eggplant | *Solanum sp.1* | abundance | Q |
| Eggplant | *Solanum sp.2*** | abundance | Q |
| Eggplant | *Solanum sp.3*** | abundance | Q |
| Potato | *Solanum tuberosum* ** | abundance | Q |
| Bean | *Vigna unguiculata* | abundance | Q |
| Maize | *Zea mays* | abundance | Q |

Medicinal and culinaryspecies

| | | | |
|---|---|---|---|
| | *Artemesia sp.** | abundance | Q |
| Turmeric | *Curcuma domestica* | abundance | Q |
| Lemon grass | *Cymbopogon ciratus* | abundance | Q |
| Galangal | *Langus galangal* ** | abundance | Q |
| Mint | *Mentha sp. 1* | abundance | Q |
| Mint | *Mentha sp. 2*** | abundance | Q |
| Tobacco | *Nicotiana tobaccum* | abundance | Q |
| Basil | *Ocimum sp.* | abundance | Q |
| Opium poppy | *Papaver somniferum* | abundance | Q |
| Betel pepper | *Piper betel* | abundance | Q |
| Sesame | *Sesamum indicum** | abundance | Q |
| | *Zingiber cassumnar* | abundance | Q |
| Ginger | *Zingiber officinale* | abundance | Q |

Appendix A. Continued

| | | |
|---|---|---|
| *Bai Pho* | abundance | Q |
| *Ruesee Fasom* | abundance | Q |
| *Phak Bam* | abundance | Q |
| Unknown herb species * | abundance | Q |
| Unknown herb species * | abundance | Q |
| Unknown herb species * | abundance | Q |
| Unknown herb species | abundance | Q |
| Unknown herb species ** | abundance | Q |
| Unknown herb species ** | abundance | Q |
| Unknown herb species | abundance | Q |
| | | |
| *Crop type group* | | |
| Total crop diversity | species | Q |
| Fruit tree | species | Q |
| Other tree | species | Q |
| Living fence | species | Q |
| Herbaceous food crop | species | Q |
| Medicinal and culinary | species | Q |
| Planting size | fruit trees | Q |
| Dominant fruit (abundance of) | fruit trees | Q |
| | | |
| *Indices of economic purpose* | | |
| Number of market vegetable species | species | Q |
| Number of market fruit species | species | Q |
| Years intercropped | years | Q |
| Ratio of years intercropped to garden age | raio | Q |
| | | |
| *Age class structure* | | |
| Number of Age classes of fruit trees | classes | Q |
| Range of age classes for major fruits | years | Q |
| Total range of age classes of fruit | years | Q |

Appendix A. Continued

***Catagorical variables in secondary matrix***

*Indices of economic purpose*

| | | |
|---|---|---|
| A market unit of jack fruit | yes/no | C |
| A market unit of sweet orange | yes/no | C |
| A market unit of coffee | yes/no | C |
| A market unit of litchi | yes/no | C |
| A market unit of mango | yes/no | C |
| A market unit of banana | (seasonal, year-round) | C |
| A market unit of J. apricot | yes/no | C |
| A market unit of peach | yes/no | C |
| A market unit of pear | yes/no | C |
| A market unit of tamarind | yes/no | C |
| A market unit of *Xanthozylum sp.* | yes/no | C |
| Market vegetables | (present/absent) | C |
| Market fruit | (present/absent) | C |
| Road access to village | (seasonal, year-round) | C |

*Cultural inputs*

| | | |
|---|---|---|
| Chemical fertilizer use (past 5 years) | yes/no | C |
| Insecticide use (past 5 years) | yes/no | C |
| Herbicide use (past 5 years) | yes/no | C |
| Irrigation use (past 5 years) | yes/no | C |

Appendix B. NMS correlation matrix showing correlations of variables in classification data set with the three ordination axes.

| **Variable** | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| Lime | 0.436 | 0.121 | -0.175 |
| Japanese apricot | -0.499 | -0.100 | 0.385 |
| Tamarind | 0.500 | 0.055 | -0.031 |
| Pineapple | 0.403 | 0.090 | -0.409 |
| Squash | -0.051 | 0.765 | -0.145 |
| Maize | -0.324 | 0.686 | -0.355 |
| Lemon grass | 0.237 | 0.257 | -0.447 |
| herb | 0.424 | -0.025 | -0.336 |
| Total crop diversity | 0.841 | 0.602 | 0.156 |
| Fruit tree | 0.838 | 0.262 | 0.282 |
| Living fence | 0.530 | 0.184 | 0.265 |
| Herbaceous food crop | 0.365 | 0.805 | 0.045 |
| Medicinal and culinary | 0.547 | 0.311 | -0.266 |
| Planting size | -0.348 | -0.523 | -0.670 |
| Dominant fruit | -0.795 | -0.435 | -0.398 |
| Number of market fruit species | -0.124 | -0.382 | -0.543 |
| Number of market vegetable species | -0.123 | 0.380 | -0.312 |
| Number of Age classes of fruit trees | 0.590 | 0.371 | 0.516 |
| Range of age classes for major fruits | 0.509 | 0.337 | 0.551 |
| Total range of age classes of fruit | 0.499 | 0.301 | 0.478 |
| Years intercropped | 0.548 | 0.333 | 0.540 |
| Ratio of years intercropped to garden age | 0.323 | 0.359 | 0.522 |