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The Role of Trees in Countering Land Degradation in Cultivated Fields in Northeast Thailand

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Abstract

The paper describes characteristics of trees in cultivated fields, a familiar feature of Northeast Thailand; their origin in connection with land-use development; their ecological roles, with emphasis on soil fertility, that can restore degraded land; and ways to increase their number. Farmers make concious decision leading to the existence of these trees. They have useful functions for farmers from socio-economic and ecological viewpoints. When forest is changed to agriculture fields, soil fertility declines rapidly and soil erosion is accelerated. Much work in the Northeast has shown conclusively the soil fertility increases in the presence of trees. Leaf litter has been shown to be an important agent for nutrient cycling in tree-soil system. Leaf litter of different tree species plays different roles in improving soil fertility depending on their "quality" or chemical compositions. Trees also play important roles in nutrient capture through roots. This is particularly useful for sandy and prone-to-leaching soils of the Northeast. There are many constraints in integrating more trees into farming systems including small land holding at household level; negative impact of trees on yields of agricultural crops; and loss or damage of planted trees. Despite such constraints, some farmers have been integrating more trees into their fields. More research should be done on how to effectively integrate trees into farms.

Keywords: trees, cultivated fields, land degradation, soil fertility, Northeast Thailand

I Introduction

Trees in cultivated fields are a common feature in Northeast Thailand. They exist in both paddy fields and upland fields which are the two most prominent agricultural land uses in this region. Some are found as scattered individuals while others form larger patches of remnant forest. Scientists have shown interest in explaining this unique characteristic of northeastern land use for decades. For example, Pendleton [1943], who surveyed soils through out the Northeast during the 1930s, stated that farmers knew that trees fertilize the paddies so they did not cut more native trees than strictly necessary. Following Pendleton many scientists have conducted further studies on trees in cultivated fields, especially those in paddy fields, including Grandstaff *et al.* [1986], Prachaiyo [1993; 2000], Sae-Lee *et al.* [1992], Takaya and Tomosugi [1972], Vityakon [1993; 1995a], Vityakon *et al.* [1988; 1993a; 1993b; 1996], and Watanabe *et al.*

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[1990]. These studies over the years have shown that trees in fields serve two useful roles: 1) they provide resources used by rural inhabitants for their self-reliance livelihood, and 2) they provide ecological services to the agroecosystems. The socioeconomic role is more obvious than the ecological role. Farmers make conscious decisions to retain trees when the net benefits are perceived as exceeding the costs. Trees are retained for such future uses as lumber, food, medicine and fodder [Grandstaff *et al.* 1986]. This paper aims to describe features of trees in fields and their connection to land-use development in Northeast Thailand; their ecological roles with emphasis on soil fertility and nutrient cycling; and their possible effectiveness in restoring degraded land. In addition it discusses ways to increase the number of trees in fields in order to more effectively restore degraded land.

II Features of Trees in Fields and Land-use Development in Northeast Thailand

In this section, I first analyze the relations of land-use development in the region to features of trees in fields. A case study of a representative village is used as an example to this effect. The locations of trees in fields and the types of trees growing there are then presented.

II–1 *Relations of Land-use Development to the Feature of Trees in Fields*

The presence of trees in fields in the Northeast is related to the history of land-use development of this region. The region used to be densely covered with forest before it was gradually cleared for subsistence agriculture. In 1939, most of the Northeast was covered by mature forest, and only 6.9% of the area was under cultivation, of which 99% was devoted to rice. Upland crops (tobacco, maize, cotton, and legumes) accounted for the remainder [Pendleton 1943 cited by Rambo 1991]. At an early stage of village establishment upland rice was cultivated [Theerasasawat *et al.* 1990]. This is a transitional stage to wet rice. The main reason for the transitional stage is that forest land clearing does not allow immediate establishment of paddy rice, which requires more intensive land preparation processes than upland rice cultivation. Paddy rice also requires the building of paddy bunds. However, upland rice cultivation was unsustainable as it brought about the destruction of forests and the loss of soil through erosion and fertility decline [Hattori and Kyuma 1978]. In addition, upland rice produce lower yield than paddy rice. Thus, paddy (wet) rice came to gradually replace the upland rice. The history of Kham Muang Village, Khao Suan Kwang District 50 km north of Khon Kaen, which is considered a representative village for the undulating terrain of the Khorat basin and the study site of our on-going land degradation project, has shown that wet rice was first cultivated in the depression of the undulating land and on both sides of streams. These low-lying areas had shallow groundwater [*ibid.*]. Water was easily controlled in these low-lying areas, and relative simple operations of bund building and terrace construction enabled people to stabilize their cropping [*ibid.*]. However, by the mid-1960s population increase led to expansion of wet rice production into the lower part of upland area in the undulating terrain. This corresponds to the finding of Hattori and Kyuma [*ibid.*] that by 1960 most low-lying areas with a shallow water table had been used to their limits and further expansion of wet rice cultivation had to be on upland areas. In the undulating terrain, therefore, two kinds of paddy fields exist. The first kind of paddy fields in the low-lying areas are called lower paddies, while the second kind in the upland areas are called upper paddies. In general, more trees are found in upper paddies than in lower paddies, partly because the former have been developed for a shorter time so the forest trees still remain to a larger extent.

In hilly marginal zones which occupy much less area of the Northeast than the undulating zones, Takaya and Tomosugi [1972] identified two kinds of paddy fields, i.e. those in the valley bottoms and those on the hill slopes. The former are flat irrigated fields and treeless, while the latter are sloping and still heavily wooded since they are more recently established. Takaya and Tomosugi [*ibid.*] have aptly named the rice paddies on the slopes “rice producing forest.”

Upland fields are used mainly for field crop cultivation. In early stages of village establishment cotton grown for subsistence use was the main field crop. Later kenaf was the first cash crop to be planted. Kenaf was later replaced by cassava and more recently sugarcane. Trees in upland fields used to be more dense at the early stages of crop cultivation, but they were gradually cut down to make way for the field crops and to reduce the shading effect that negatively affected the field crops. The number of trees in the upland fields, therefore, rapidly decreases with time.

This pattern is shown in detail by a study of land use change in Kham Muang Village of Khon Kaen done as part of the Khon Kaen University (KKU) Land Degradation Project (Fig. 1). During the “subsistence period,” which is the first 78 years since the village was established in 1889, rice was cultivated for home consumption while cotton was the most important field crop. Cattle were raised in large numbers as there was ample of forest vegetation for their grazing. In the early 1950s, kenaf, another fiber crop, was introduced and planted on the uplands. It was sold for making rope and sacking. By 1967, a much larger area was planted to kenaf as cotton rapidly disappeared. The planting of kenaf as a cash crop led to rapid reduction of forested area. However, forest was cleared in a gradual fashion so that remnants of forest trees remained scattered in the upland fields for many years. Over time, however, as more trees were cut down for various use during later years, the density of trees gradually decreased.

The next period of land-use development is termed the “subsistence-commercial” period (1968–94). Wet rice continued to be cultivated in lower and upper paddies. In 1971, cassava started to replace kenaf as a cash crop on the uplands. Cassava products were exported to the European Community (EC) market for use as animal feed. The cultivated area of cassava was rapidly expanded during 1973–74. In 1987, sugarcane cultivation started in response to the establishment of a sugar refinery nearby. During the last part of this period (1987–94), cassava and sugarcane were predominant on the uplands. The forest area gradually decreased in the “subsistence-commercial” period due to the encroachment of cassava and sugarcane. Scattered trees in fields were gradually cut down for various uses. In addition, sugarcane has relatively little tolerance to shading compared to rice and cassava so its cultivation has led to the clearing of trees in fields at an accelerating rate.

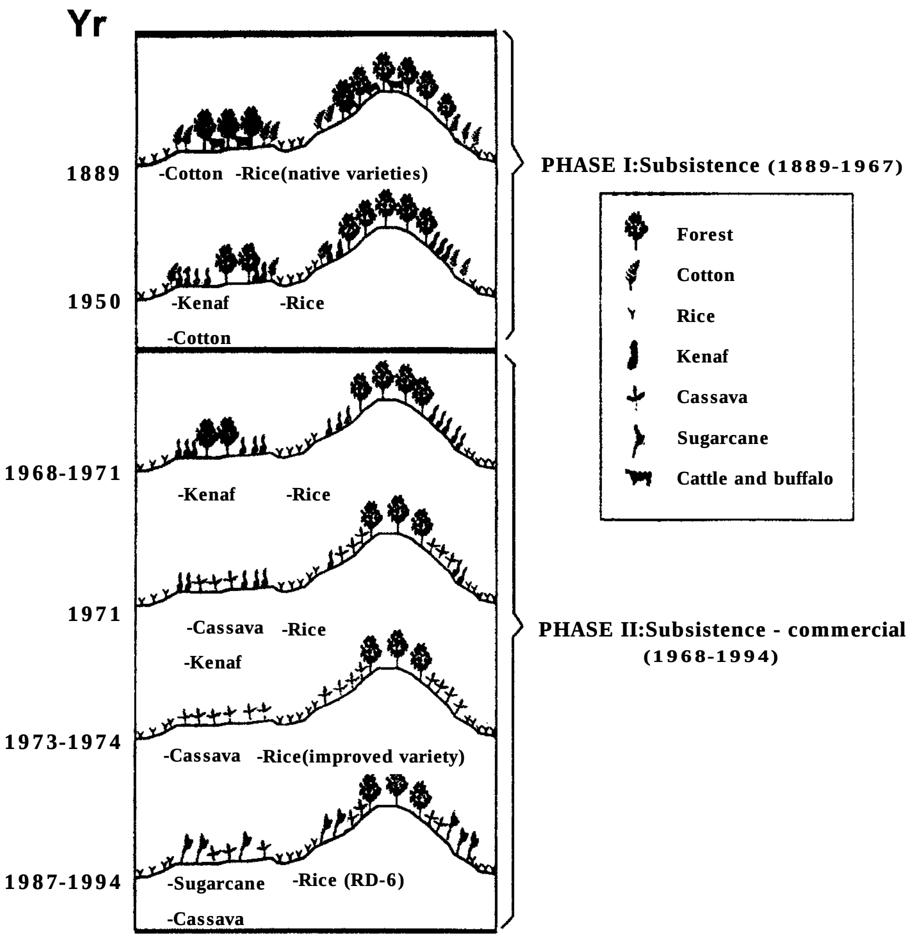

Fig. 1 Cross Section of a Transect of Land Form in Kham Muang Village, Khao Suan Kwang district of Khon Kaen illustrating land-use change over 100 years in this village (unpublished data of KKU Land Degradation Project).

II–2 *Locations of Trees in Fields*

The cultivated fields as described in the previous sections consist of paddy fields and upland fields. The locations of trees in the paddy field agroecosystem can be classified as follows: paddy floor, paddy bunds, and field hut area on the higher ground. The higher ground in the paddy field agroecosystem is the place where farmers build their field hut and grow some kitchen vegetables, mulberry for silk raising, and sometimes have a fish pond, fruit trees and some multipurpose trees (Fig. 2). In the upland fields agroecosystem, forest trees are found scattered without definite pattern, but planted trees are usually found at the boundaries of the fields partly to indicate land ownership. A study in one representative village in Kranuan district of Khon Kaen [Vityakon *et al.* 1996] has revealed the preferred location of tree planting. In the paddy agroecosystem, farmers preferred to plant trees in field hut area on the

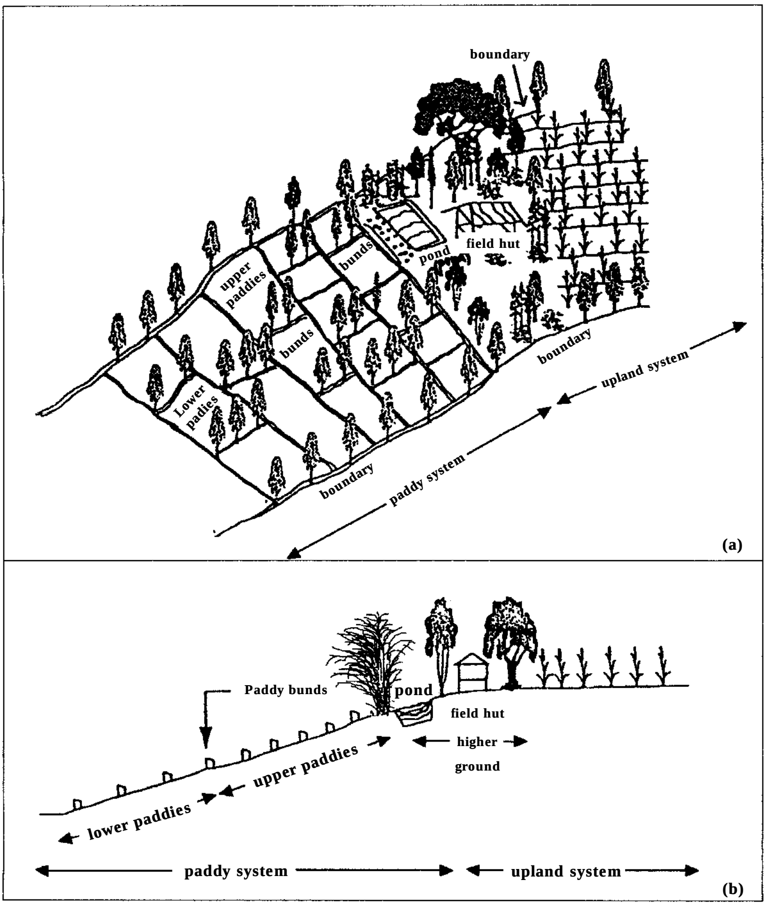

Fig. 2 Locations of Trees in Cultivated Fields of Northeast Thailand
(a) top view, (b) cross section.

upper grounds followed by paddy bunds, while in the upland agroecosystem the boundaries of the upland fields are most preferred. The preferred planting areas are those that least affect the associated crops and least obstruct the cultural practices, notably ploughing.

II–3 *Types of Trees in Fields*

The trees in fields presented up to this point are mainly those that originated from the forest or "forest survivors" [Vityakon 1993]. Forest survivors are mainly species from the dry dipterocarp forest that once densely covered the surface of the undulating terrain of the Northeast. *Dipterocarp* spp. are dominant. The density of trees in paddy fields in Khon Kaen as separately surveyed by 2 research teams was found to be 30–149 trees ha^{-1} [Watanabe *et al.* 1990] and 6 to more than 31 trees ha^{-1} [Prachaiyo 1993] as compared to 468 trees ha^{-1} of the original forest [Wacharakitti 1979 cited in Watanabe *et al.* 1990]. In addition to the forest survivors, other species of trees have been introduced after the forest system was changed into an agroecosystem. For example, in the case of the wet rice agroecosystem, these species have been introduced only after the establishment of the paddies. They are termed "domesticated trees" [Vityakon 1993]. They are less common in paddies and upland fields than the forest survivors. These trees either are volunteers that naturally generated from seeds brought into the system through various accidental means, or were intentionally planted by the farmers. Domesticated trees are more commonly found in paddy fields than in the upland agroecosystem. The reason is likely the fact that rice is more tolerant of shading by trees than field crops (cassava and sugarcane). *Samanea saman* (commonly known as rain tree or Indian walnut and in Thai, *chamcha*, *kampuu*, or *chamchuree*) is the most common domesticated tree that is naturally generated from seeds. Its pods and leaves are eaten by cattle, which spread the seeds in their dung. Farmers choose to keep this tree on the bunds or upper ground of the paddy system because of its multiple uses. Other introduced trees include *Azadirachta indica* (*sadao* or neem tree) and *Tamarindus indica* (tamarind); they provide both shade and food [*ibid.*]. In some cases forest species are planted by farmers in paddies or upland fields. One of the most popular species found is *Pterocarpus macrocarpus* (*pradu* in Thai). *Pradu* is planted because it yields excellent timber and is relatively fast growing. The author has found them planted in both paddy and upland field agroecosystems. It is first in the list of the most favoured tree for planting by farmers followed by multipurpose trees, eucalyptus, and fruit trees, such as mangoes [Vityakon *et al.* 1996].

III Land Degradation Caused by Land-use Change

Once forest is changed to agriculture fields, soil fertility declines rapidly and soil loss due to erosion is accelerated. An on-going study of land-use patterns and associated land degradation in the undulating terrain of the Northeast (KKU Land Degradation Project) has shown that soil loss (measured on a field plot basis) due to rainfall erosion in sandy soil area is much more severe under cultivated conditions (cassava and sugarcane) than forest (Table 1). Cultivating practices also have significant bearing on the seriousness of soil loss, for example soil disturbance such as ploughing in the rainy season when the crop canopy cover is not full can increase the severity of soil erosion (Table 1). The decline in soil fertility is partly the consequence of loss of soil and associated nutrients. Other factors include nutrients removed through harvesting, and those lost through leaching, and burning (as practised in sugarcane).

The decline in soil fertility is characterized by decreases in nutrients and soil organic matter. A most vivid indicator of declining soil fertility is yield loss. Numerous studies have shown declines in yield in continuous cassava cultivation due to decreasing soil fertility. Sittibusaya *et al.* [1988 as cited by Howeler 1991] reported cassava yield declines in unfertilized plots in three soil series, i.e. Sattahip (a Quartzipsamment), and Huai Pong and Khorat (Paleustults), found extensively in the Northeast. The decline was >40% of the initial yields during 20–25 years of continuous cassava production, i.e. from 27–29 t ha^{-1} to 16–17 t ha^{-1}. Other systems of

Table 1 Quantities of Soil Erosion and Runoff Water during the Rainy Seasons of the Year 2000 in Forest and Cassava Land of Kham Muang Village, Khao Suan Kwang District of Khon Kaen

Month	Rainfall (mm)	Natural Events/ Cultivation Practices		Quantities of Soil Eroded (kg ha^{-1})		Quantities of Runoff (mm)	
		Forest	Cassava	Forest[1)]	Cassava[2)]	Forest[1)]	Cassava[2)]
Apr	137.2	Leaf shed	Ploughing/planting	774	9,199	11.9	49.7
May	166.6			545	8,420	9.5	53.4
Jun	131.2		Weeding/fertilizing	111	646	2.7	15.2
Jul	212.8			90	355	4.7	19.1
Aug	373.0			206	3,324	7.8	92.4
Sep	138.6			13	107	3.6	11.2
Oct	64.4			11	3	2.2	0.6
Total	1,246.0			1,750	22,054	42.3	241.6

Sources: P. Vityakon in connection with KKU Land Degradation Project (unpublished data).
1) Dimension and area of the plot = $4.7 \times 21.0 = 99.4$ m^2.　Slope was 3.3%.
2) Dimension and area of the plot = $4.5 \times 57.4 = 256.5$ m^2.　Slope was 5.2%.

land use are less subject to degradation after clearing of the forest, however. In the paddy rice agroecosystem, low but sustainable yield seems to be the case in the Northeast. An investigation into the supply of a major nutrient, potassium (K), has shown that various sources of K in the paddy can supply adequate K for rice requirement at the low yield of not more than 2 t ha^{-1}. One source of K found is in the paddy water that is partly supplied from runoff water from the uplands [Vityakon 1989].

Soil organic matter (SOM) decline is also reported when forest is converted to cultivated land. Vityakon [1991] compared the soil organic matter content of topsoils of the same soil (Warin–Oxic Paleustult) in 3 plots situated adjacent to each other in Phu Wiang district of Khon Kaen. They were under forest, 10-year continuous cassava and paddy rice. The SOM was reduced by 40% (from 1.32% under forest to 0.79 under cassava and 0.72% in the rice paddy). A similar trend was found in highly sandy Khorat soil in Khao Suan Kwang district of Khon Kaen, i.e. 0.81% under dry dipterocarp forest and 0.19, 0.34, and 0.60% under cassava and sugarcane and paddy rice cultivation, respectively (S. Tangtrakarnpong and P. Vityakon in connection with KKU Land Degradation Project, unpublished data). The same workers also found lower microbial biomass carbon and nitrogen in cultivated soils as compared to forested soil at the same study site.

Leaching loss of nutrients is a serious problem when forest is converted to field crops, especially in sandy soils. Roots of diverse forest vegetation capture nutrients at various depths which greatly decreases losses through leaching whereas field crops only take up nutrients effectively at one depth. Thus, those nutrients that are leached below the root zone of the crops are likely to be lost. SOM can enhance nutrient retention capacity of the soils. Cation exchange capacity (CEC) of soils are used to measure the cationic nutrient retention capacity. Some work has found significant positive correlations between CEC and SOM content. An increase in SOM by 1% led to an increase in CEC of 2 cmol kg^{-1} [Kapland and Estes 1985] and

7 cmol kg^{-1} [Vityakon 1991].

Reduced soil fertility under field crop cultivation can also be caused partly by export of soil nutrients contained in harvested materials. For example, cassava removes large amounts of nitrogen, phosphorus and potassium in the harvested tubers. Howeler [1991] used data of cassava grown in a dry zone of Sri Lanka produced by Amarasiri and Perera [1975]. He showed that nutrients removed at the yield of 13.5 t DM ha^{-1} of harvested tuber were (in kg t^{-1} DM of harvested product) 4.6 for N, 0.74 for P, and 12.1 for K which amount to the nutrient loss (in kg ha^{-1}) of 62.1 for N, 10.0 for P, and 163.4 for K. Potassium is the nutrient most heavily removed. Howeler [1991], who comprehensively reviewed much work done on long-term soil fertility trials in many countries, has concluded that continuous cassava production leads to K exhaustion in most soils. This necessarily results in declining yields unless the lost K is replaced with chemical fertilizers which is only done to a small extent in the Northeast. The situation appears to be different for rice than for cassava. Figures from IRRI show that IR8 variety yielding 8.7 ton ha^{-1} removes in harvested panicle (in kg t^{-1} of grain) 13.3 for N, 4.4 for P, and 7.1 for K [Yoshida 1981] which amount to nutrient removed in harvested product of 115.7, 38.3, and 61.8 kg ha^{-1} of N, P and K, respectively. However, in the Northeast, the average rice yield is much lower (2 t ha^{-1}). Consequently, the rice crop tends to remove much lower quantities of nutrients than those high yielding varieties employed by IRRI. Vityakon [1989] found that K removed in grains of RD6 glutinous rice grown by three farmers in a village in Khon Kaen Province was on the average 4.4 kg K ha^{-1}. The study shows that rice production appears to be sustainable as far as potassium is concerned.

IV Roles of Trees in Fields in Mitigating Land Degradation

There is a lot of evidence from various agroecosystems showing that the presence of trees can maintain or improve soil fertility. For example, in shifting cultivation systems, the fertility of degraded soil resulting from a 2-or-3-year cropping phase can be improved through a fallow phase of 5–10 years of natural vegetation. This demonstrates the power of trees in restoring fertility lost during cultivation. This section discusses studies on roles of trees in increasing soil fertility in cultivated fields with special emphasis on paddy fields through tree litter. Studies on litter decomposition and nutrient release are presented to probe deeper into mechanism by which trees can restore and maintain soil fertility. Finally other mechanism by which trees can maintain soil fertility through reducing nutrient loss is presented.

IV–1 *Soil Fertility Enhancement under Trees' Influence*

Studies by the author of the roles of trees in maintaining soil fertility in paddy fields in Northeast Thailand have shown conclusively that trees enhance soil fertility in areas where their influence can reach. An earlier study comparing soil fertility of paddy fields on a sandy soil having low and high tree densities (9 and 20 trees per 400 m^2, or 225 and 500 trees ha^{-1}, respectively) of forest survivors, *Dipterocarpus obtusifolius*, has shown that soil fertility as measured by various fertility parameters including contents of major nutrients (N, P, K), SOM, and cation exchange capacity (CEC) is much higher in the high density plot as compared to the low density one (Table 2) [Vityakon *et al.* 1988]. This was believed to be due in part to the higher quantity of litter fall from trees in the high density plot. It was concluded that trees contributed to high SOM which act as nutrient reserves. In addition, organic matter contributed by tree leaves led to high CEC which retains cationic nutrients. The workers pointed out that measures to increase organic matter in the Northeast sandy soils are very desirable due to low CEC and high susceptibilty of soil nutrients to leaching. The total amount of nutrients (N, P, K, Ca, and Mg) in litter fall in the high-density plot during the 6-month period in the 1987 dry season (Table 3) was comparable to the amount of nutrients supplied by 16–16–8 fertilizer applied at the recommended rate of 125 kg ha^{-1}.

More intensive studies were later conducted to investigate the role of trees growing on paddy bunds on paddy soil fertility [Sae-Lee *et al.* 1992]. Four kinds of trees commonly found in the paddies were included in the study: *Parinarium anamense, D. obtusifolius, D. intricatus,* and *Samanea saman*. The first 3 species are survivors from the forest, and the last one is a naturally generated domesticated tree. A number of soil fertility parameters (including SOM,

Table 2 Comparative Fertility of Topsoils (0–20 cm) (Great Group Quartzipsamment) of Paddy Fields with High and Low Density of *Dipterocarpus obtusifolius* Trees

Soil Fertility Parameter	No-tree Plot[1)]	High Tree Density (20 trees/400 m^2)	Low Tree Density (9 trees/400 m^2)
CEC (cmol kg^{-1})	6.3	2.7	1.3
Soil organic matter (%)	0.47	0.81	0.37
Total N (%)	0.03	0.04	0.02
Bray II extractable P (ppm)	0.7	8.3	2.0
Exchangeable K (cmol kg^{-1})	0.04	0.03	0.02

Source: Adapted from Vityakon *et al.* [1988]

1) The authors pointed out that the soil in the no-tree plot appeared to be finer textured and, hence, had higher clay content resulting in higher CEC than those plots with trees even if it was situated adjacent to each other.

Table 3 Quantities of Litter Fall and Nutrients in the Litter Sampled from Paddy Fields of High and Low Density of *Dipterocarpus obtusifolius* Trees in the 1987 and 1988 Seasons

Parameter	High Tree Density		Low Tree Density	
	1987[a]	1988[b]	1987[a]	1988[b]
Litter fall (t ha^{-1})	7.0	11.0	2.8	4.1
N (kg ha^{-1})	46.3	72.5	16.3	23.3
P (kg ha^{-1})	15.0	23.1	3.8	5.7
K (kg ha^{-1})	12.4	20.5	3.8	5.0
Ca (kg ha^{-1})	41.3	64.2	18.3	26.7
Mg (kg ha^{-1})	10.6	16.5	5.0	6.8

Source: [Vityakon *et al.* 1988 as cited after Vityakon 1993]

a Values are for 6-month period in the dry season.

b Values are for the entire year period.

CEC, and nutrients) were measured at various distances from the tree trunk employing the tree-soil transect technique (which compares the soil properties found in areas under the canopy of individual trees with surrounding areas). Trees were found to have significant effects on soil fertility, as indicated by the lower fertility of soil samples taken at greater distances from the trees. The only leguminous tree studied, *Samanea saman,* was associated with higher soil fertility levels than the other trees. This probably reflects the quality of leaf litter from *Samanea*: a leaf litter decomposition experiment indicated that *Samanea* leaves tended to be easily decomposable and had higher nutrient concentrations, especially of N, than the leaves of the other species [Sae-Lee 1990 as cited by Vityakon 1993]. This result highlights the importance of tree leaf litter decomposition as a mechanism which brings about restoration and enhancement of soil fertility.

IV–2 *Leaf Litter Decomposition and Nutrient Release*

Subsequent work has put emphasis on the aspect of tree leaf litter decomposition and nutrient release to probe deeper into one of the mechanisms by which trees can restore and maintain soil fertility. One study investigated leaf litter of 5 common multipurpose trees found locally in the Northeast farming systems: mango (*Mangifera indica*), eucalyptus (*Eucalyptus camaldulensis*), *pradu* (*Pterocarpus macrocarpus*), neem (*Azadirachta indica*), and sesbania (*Sesbania grandiflora*). The quality, decomposition rates, and nutrient release rates of these tree leaf litter (under field condition) are shown in Table 4.

The results show that different types of tree leaf litter have different decomposition and nutrient release rates depending on their qualities as determined by their C/N ratio, and lignin content. *Pradu* has the lowest C/N ratio but the highest lignin content which might lead to its having the lowest decomposition and nutrient release rates. Sesbania has a relatively low C/N ratio and it has lower concentration of lignin than *pradu*. It exhibits the highest decomposition and nutrient release rates. On the other hand, mango, eucalyptus and neem have higher C/N

Table 4 Carbon/nitrogen Ratios, Lignin Contents, Field-condition Decomposition, and Nutrient Release Rates of Leaf Litter from 5 Multipurpose Tree Species

Parameter	Trees				
	Mango	Eucalyptus	*Pradu*	Neem	Sesbania
C/N ratio	37.3	40.6	15.3	41.4	27.3
Lignin (%)	10.4	7.7	11.8	9.7	11.0
Decomposition rates (k – yr^{-1})	4.58	4.65	3.21	5.20	9.22
Nutrient release rate (yr^{-1}) :					
N	2.03	3.73	3.33	3.80	7.87
P	5.18	5.45	2.83	8.55	11.58
K	2.29	2.56	1.62	5.75	5.89
Ca	4.05	0.94	2.61	5.18	8.36
Mg	3.71	3.81	2.75	6.15	8.77

Source: Vityakon [1995a] with exception of lignin data, which is from Vityakon (unpublished) ratios but relatively lower lignin contents with relatively higher decomposition rates than the *pradu* (Table 4). Availability of a major nutrient phosphorus (P) (water soluble P) from various leaf litter sources in submerged condition, has been found to be independent of P content in the leaf litter [Ruaysoongnern *et al.* 1993]. It has been found that rapidly decomposed organic materials bring about higher P solubility than slowly decomposed counterparts [Willet and Intrawech 1988 as cited by Ruaysoongnern *et al.* 1993]. Potassium (K), on the other hand, is leached readily from various leaf litter and does not depend on decomposition as do phosphorus and nigrogen as found by Ruaysoongnern *et al.* [1996]. The workers also discussed the implication of their findings on management of leaf litter from trees in fields to achieve the goal of nutrient conservation for wet rice which include collection, processing, and application of organic materials. The collection should be done prior to heavy rains and composting process should avoid excessive watering to prevent nutrient loss through leaching, while application of the organic materials is to be done in a spatially uniform fashion for better distribution of nutrients.

Subsequent study has investigated the effect of different-quality tree leaf litter on soil organic matter (humus) characteristics [Adulprasertsuk *et al.* 1997]. The species investigated were those forest survivors found commonly in upland and paddy fields. Their leaf litters have different qualities (Table 5). The decomposition study was conducted under controlled- or pot-experiment condition. The species posessing high C/N ratios and lignin, i.e. *D. tuberculatus*, exhibit the lowest decomposition rate (k). However, those that have either high C/N or high lignin, i.e. *S. obtusa* and *X. xylocarpa*, respectively, have the second lowest k. The two species exhibiting highest k are those that have relatively lower lignin contents (9.6% *I. malayana*, and 13% *T. indica*). As regards the E4/E6 ratio, it is a spectral characteristic of humic substance which is used as an indicator of degree of humification. The lower the E4/E6 ratios, the higher the degree of humification. The lowest E4/E6 ratios (4.58 and 4.76) are found in *S. obtusa* and *D. tuberculatus*, respectively. On the other hand, the highest E4/E6 ratio (6.10) is found in *T. indica*. These results tend to show that leaf litters which have a high content of materials resistant to decomposition such as lignin or have high C/N ratio tend to produce highly-humified

Table 5 Carbon/nitrogen Ratios, Lignin Contents, Controlled-condition Decomposition Rates of Leaf Litter from Various Forest Survivor Trees and Their Derived Humic Substance Characteristics

Parameter	Trees (scientific name/common name or Thai name)					
	Dipterocarpus tuberculatus (*Pluang*)	*Irwingia malayana* (*Krabok*)	*Samanea saman* (Raintree)	*Shorea obtusa* (*Teng*)	*Tamarindus indica* (Tamarind)	*Xylia xylocarpa* (*Daeng*)
C/N ratio	71.8	67.1	25.8	90.9	51.7	38.1
Lignin (%)	22.0	9.6	16.4	16.0	13.0	21.0
Decomposition rate (k – yr^{-1})	0.50	1.58	1.02	0.74	1.93	0.71
Humic acid characteristics						
E4/E6 ratio	4.76	5.20	5.82	4.58	6.10	5.23

Source: Adulprasertsuk *et al.* [1997] with exception of lignin data, which is from Vityakon (unpublished).

soil organic matter and vice versa. In the low fertility, low organic matter soil of the Northeast, both organic materials that decompose and release nutrients quickly (termed high-quality organic materials), and those that are resistant to decomposition (termed low-quality organic materials) but lead to accumulation of SOM (humus) are required to restore and maintain soil fertility and reduce soil degradation.

Much less research has been done on the role of trees in soil fertility maintenance in upland fields in the Northeast. However, upland fields planted with field crops usually have fewer trees than are found in paddy fields because field crops, notably cassava and sugarcane, are less tolerant of shading than rice. However, it is common knowledge among farmers that a patch of trees on relatively higher grounds of the undulating terrain is beneficial for soil fertility and crop productivity on lower ground. This is due to nutrients and organic matter transferred from the upper ground to the lower ground through runoff water.

IV–3 *Other Processes by Which Trees Restore and Enhance Soil Fertility*

Trees enhance soil fertility through many processes as categorized by Young [1989] as processes that "augment additions" to the soil and those that "reduce losses" from the soil. These processes are components of the overall "nutrient cycling" services provided to the ecosystem by the trees. Nutrient cycling in forest ecosystems is nearly closed. However, the system becomes more "open" as the proportion of trees-to-agricultural crop plants decreases, as in the case of an agroforestry system.

The processes of augment additions to the soil include addition of SOM and nutrients to the soil as described earlier. The process which leads to reduced loss is nutrient capturing by tree root systems. One vivid example of this process occurs in tropical rain forest where it has been shown that the thick root mat (15–40 cm) in the soil surface plays important roles in nutrient cycling and conservation through nutrient retention (physical adsorption) and uptake (through active feeder roots) [Jordan and Herrera 1981; Stark and Jordan 1978]. Furthermore, it has been demonstrated that trees or perennial plants can take up nutrients from deeper soil layers than those used by annual crops. A study done in alley cropping system in Sumatra, Indonesia employing ^{15}N has shown that while *Gliricidia sepium*, a widely grown alley tree crop with its predominantly shallow root system, takes up little ^{15}N from lower soil depths, *Peltophorum dasyrrachis* with its deep root system, takes up ^{15}N actively from 55 cm soil layer [Cadisch *et al.* 1997]. The popular concept that trees act as "nutrient pumps" (i.e. trees are visualized as being able to take up nutrients from a considerable soil depth, greater than that reached by the root zones of herbaceous crop plants), is supported by the above study.

Trees should prove to be beneficial to sandy soils of Northeast Thailand through their nutrient capturing mechanism. Nutrient leaching studies in the Northeast sandy soils, although relatively rare, have shown that various nutrients are leached readily in these soils. Some lysimeter studies conducted by the Department of Agriculture have shown that in sandy loam soils, such as Warin and Khorat series (Oxic Paleustult), N (nitrate and ammonium) is leached beyond top soils (15 cm) after 100 mm of rain [Paisalcharoen *et al.* 1987]. In Warin sandy loam soil, the amount of N collected in percolation water at 1 m depth increased with increasing fertilizer rates [Vibulsukh *et al.* 1987]. Sulfate (S) is another nutrient shown to be readily leached from the top 30 cm soil depth in Yasothon sandy loam soil (Oxic Paleustult) and Nam Phong loamy sand (Quartzipsamment) after receiving 465 and 225 mm of rains, respectively [Aitken 1981].

V Integration of Trees into Farming Systems of the Northeast

The number of trees in fields in farming systems of the Northeast is declining over time as more trees are cut down to be used and some of them die naturally after their natural habitats are transformed. Finding ways to increase the number of trees in fields by integrating new trees into farming systems is, therefore, a major concern. Farmers' motivations and factors influencing their incorporation of trees in fields were examined by Vityakon *et al.* [1996]. These studies confirmed what had been found earlier by Vityakon *et al.* [1993a] that in Northeast Thailand the size of land holding is the most important criterion for farmers in deciding whether or not to grow trees on agricultural land. Large land holders, i.e. richer farmers, tend to be more ready to integrate trees into their farms than small land holders. Large land holders can afford to have a certain degree of productivity decline per unit area because they still have adequate total production. The productivity decline is due to space lost when trees take up space of crops and trees' negative effect, e.g. shading, on the associated crops. On the other hand, small land holders have to use their limited land totally for production of both subsistence and cash crops. As generally observed, they are less likely to take risks of experimenting on new introduced technologies. Constraints on tree planting are identified as follows:

1. Small area available for agricultural production as shown in the case of the small land holders who cannot afford to use their land for activities other than their crop production.
2. Negative impacts of trees on yields of agricultural crops. Trees grown in association with crops can reduce yields by shading the crops. Vityakon *et al.* [1993b] found that shading resulted in decreased rice yields due to the decrease in various yield components including tillering, number of panicles and number of grains per panicle. On the other hand, it brought about an increase in unfilled grains. Shading was also found to increase rice plant height that can subject the plants to lodging. However, crops have different tolerance to shading. Rice is more tolerant than field crops and among the major field crops cassava is more tolerant than sugarcane.

   Despite these negative effects of tree shading, some positive effect has been observed. Some farmers in the Northeast have pointed out that in dry years rice seems to grow better under tree canopies. The same observation was reported in upland rice in north central region of Vietnam. In localities usually suffering drought, if dry rice is sown under shade it can produce more stable production. Therefore, rice is sown under shade of lacquer trees in north central Vietnam [Bui Huy Dap 1978]. This might point out effect of shading on reducing evapotranspiration resulting in soil moisture and plant water conservation that can be of benefit in rainfed rice of the Northeast.

3. Difficulties in planting and maintaining trees because of damage caused by cattle; lack of water; wild fire and poor soils.

Cattle and buffaloes in the Northeast are raised on naturally available fodder. Even if they are watched by herders, to some extent they are allowed to roam freely. It frequently occurs that the cattle graze on some of the planted trees or trample on some of the newly planted small seedlings. Lack of water is the problem in the dry seasons as over 90% of the Northeast agriculture is rainfed. Although tree planting is done in the rainy season, if the seedlings fail to become well-established before the rainy season ends, they can suffer water shortage in the dry season. Wild fire has become a more serious problem since the Northeast farmers, due to labor shortage, have increasingly adopted direct seeded rice as opposed to the transplanted rice as was traditionally practised. Paddy fields with direct-seeded rice usually have more weeds than the transplanted rice. After harvesting in the dry season the weedy fields can catch fire much more easily. In addition, sugarcane culture involves burning before harvesting in the dry season (October–April). It is not uncommon for these fires to get out of control. The fires from these various sources often damage trees planted in paddy and upland fields. Poor soil is another reason frequently cited by the farmers for not planting trees in their fields because it inhibits seedling establishment. Some farmers apply cattle manure when planting, however once seedlings are established application of soil amendments is rare.

Despite such constraints, Northeastern farmers still attempt to retain and plant new trees in their agroecosystems. Farmers who are relatively large land holders have on their own accord plant trees on their land, such as on paddy bunds, in areas around field huts and as borders in the uplands. The author has encountered some farmers who even retain patches of forest tree remnants in some of their paddy fields despite severe rice yield loss in those fields.

Integrating trees in cultivated fields, both paddy and upland, was found to be successfully adopted as reported by Rathakette [1993]. *Eucalyptus camaldulensis*, a multipurpose tree, was grown by 20 farmers on their available land (some vacant patches in the uplands or paddy bunds) in a village in Khon Kaen. The worker involved the farmers in a long-term experiment (1985–92) that entailed all stages of tree growing from planting to final cutting and marketing of the wood. As growing eucalyptus was not labor intensive and did not incur much cost (free seedlings were provided), the farmers integrated it as parts of their farm activities. Some yield loss of cassava grown in rows immediately next to eucalyptus in an adjacent field was reported. However, the farmers were the ones who made decisions on how to manage the trees and solve the problem of trees' negative effects. This example shows that farmers adopted tree growing introduced by researchers because the activity does not interfere with various existing farm operations and their livelihoods. Moreover the activity gave opportunity for the farmers to increase their income. This should be taken as a criterion bringing about successful tree integration into farms.

Some farmers demonstrate their keen enthusiasm for tree integration. They have gone so far as conducting experiments related to tree integration into their farms [Polthanee *et al.* 1996]. One farmer studied planting materials for a most favoured tree for planting in farms, i.e. *pradu* (*Pterocarpus macrocarpus*). He found that cuttings from main roots of mature seedlings were better planting materials than seedlings raised from seeds in plastic bags. Another farmer worked on planting teak (*Tectona grandis*), a popular species for tree plantations, on paddy bunds. He found that size of the bunds should be 2.50 meters wide, for teak to grow well. A smaller bund, i.e. 1 meter, did not support good growth of teak.

Testing performance of multipurpose tree species grown on paddy bunds, a preferred location for tree integration by farmers as found by Vityakon *et al.* [1996], is one way to promote tree planting in fields. Subsequent work concentrating particularly on integrating trees on paddy bunds was conducted as an on-farm trial employing 5 multipurpose trees: *Pterocarpus macrocarpus* (*pradu*), *Mangifera indica* (mango), *Sesbania grandiflora*, *Azadirachta indica* (neem), and *Leucaena leucochphala* [Vityakon 1995b]. The farm selected belonged to a large land-holding farmer in Kranuan District of Khon Kaen. The farmer was willing and enthusiastic in integrating trees on the paddy bunds. The choice of the tree species was made by researchers in consultation with the farmer. They were planted on the bunds in east-west direction in the rainy season of 1993. The growth evaluation after 29 months of growing showed that leucaena made the most rapid growth reaching the height of 2.9 meters with the growth rate of 102.2 cm year^{-1}. Sesbania came second with the growth rate 46.1 cm year^{-1}, followed by *pradu* 35.4 cm year^{-1} and neem 21.6 cm year^{-1}. One of the great obstacles to growing trees on paddy bunds was found to be wild fire in dry seasons. All trees were affected to different degrees. Mangoes were almost completely destroyed while leucaena made the best recovery. Despite having the second highest growth rate, sesbania seedlings were difficult to establish as they did not withstand harsh conditions as well as other tree seedlings and several replantings were done. Neem does not adapt well on paddy bunds and display stunted growth. It has been concluded from the study that leucaena and pradu are the two most promising trees that can adapt well on paddy bund conditions. However, while *pradu* is a familiar native tree, leucaena is an introduced species and its multipurpose use is rather obscure to farmers. More information, therefore, should be provided to the farmers regarding its use.

Efforts of promoting integration of more trees into fields must also take into account who in the farm household is the decision maker. Further studies on decisions concerning trees in cultivated fields have shown that decisions about planting trees, or retaining or cutting existing trees, are usually made by men, who commonly do most of the field work. In some cases, men and women make joint decisions. Only in exceptional cases, for example when households are managed by widows, do women act as sole decision makers regarding the status of trees in farming systems [Vityakon *et al.* 1996].

VI Conclusions

Trees in fields have a high potential to be used as a measure to deter land degradation in agricultural land in Northeast Thailand especially when they are already part of the agroecosystem and the farmers already understand their potential benefits. The existence of the trees in the agroecosystem can be understood through knowledge of agricultural land-use development of the region which shows that farmers make concious decisions to maintain these trees both for their use in normal livelihood and for their ecological services. Studies of trees-in-fields both directly in the Northeast farming systems and elsewhere have demonstrated positively that they can bring about restoration and improvement of soil fertility and, hence, reduce soil degradation. The key question is, therefore, how best to integrate more of them into farms. Considerable information on farmers' criteria for tree integration into farming systems has been gathered and greater understanding of this subject has been achieved. However, there are still more studies required to provide more knowledge that will lead more effectively to integrating appropriate trees into farming systems. These include:

— Appropriate tree species, planting densities, distance to associated crops, and tree management (such as pruning) in different agroecosystems, i.e. paddy and upland fields.

— Fertility distribution from areas close to trees to other parts of the field that may raise the total fertility of the whole system.

— Comparative advantage of trees' benefit on rice yields in dry years and wet years.

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