Rehabilitation of Degraded Forest Lands through Agroforestry in Thailand

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Abstract

The field experiments and demonstration plots aiming at indicating the feasibility and desirability of agroforestry in Thailand have been first designed since 1978 in the representative marginal lowland areas characterized by infertile sandy loam soils at the Huey Thar Silvicultural Research Station, Sisaket Province, Northeast Thailand. These long-term comprehensive studies have mostly been concentrated on some systems that are widely adopted such as agrisilvicultural or partial overlap system, one-storey hedgerow intercropping, cyclical planted fallow or shifting cultivation system, multi-storey mixed intercropping, one-storey alley cropping, as well as the modified multi-storey strip planting. These studies also involved the selection of tree species based on biomass production, soil improvement ability, optimum tree-crop combination with respect to fuelwood production and its economic feasibility. These preliminary assessments are not intended to be an isolated effort, rather, they are envisaged as the beginning of a sustained program to develop and introduce apprppriate pilot models to solve the problems of wood and food crises, deforestation and rural poverty throughout the country. Similar studies are being continuously duplicated and expanded to other sites and locations, following these initial phases, to provide on-going support to the implementation effort.

Evidence accumulating from these studies and the advantages attributed to the implementation of agroforestry systems are sufficient grounds to assume that agroforestry might be a sustainable land-use system in our fragile tropical environments.

Introduction

The development of tree farms through agroforestry systems is a new popular concept which seems to offer a significant potential. Its main advantage is that, apart from providing a major wood source, it can simultaneously offer a continuous system of food, shelter and in some cases, enables to reclaim degraded areas, hence promoting the development of rural areas. In the conceptualization and principle formulation of agroforestry, a number of hypotheses have been put forward recently. The premises on which the concept of agroforestry is based are both biological and socio-economic. The biological premises include all the advantages of the forest for the soil and the environment, such as closed and efficient nutrient cycling, maintenance of organic matter, prevention of runoff and soil erosion, regulation of microclimate, and above all the adaptability of trees to soils that are incapable of sustaining annual agricultural crops. The socio-economic factors supporting the potential value of agroforestry are based on the fact that the poor farmers in developing countries, who live in an environment of mounting population pressure and lack of resources, are forced to utilize inherently unproductive areas for crop production and to adopt land management systems that have disastrous consequences, such as deforestation, degradation of soils, flood and drought. These farmers should be given the alternative of a system of land management

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that combines the practice of agriculture and forestry to provide food and wood without causing the deterioration of the ecosystems.

To substantiate the validity of the concept of any agroforestry land use system field performance is the major criterion, based on the results of which the concepts can be modified and the system suitably refined. However, the premises on which the concept is based and the evidence for its implementation can not be taken as strong indications of its validity unless field trials demonstrate its applicability. The field experiments and demonstration plots that indicate the feasibility and desirability of agroforestry systems have been formulated since 1978 in the representative marginal lowland areas characterized by infertile sandy loam soils at the Huey Thar Silvicultural Research Station, Sisaket Province, Northeast Thailand. These involved the major systems, i. e., the taungya system, the multistorey mixed intercropping system, the planted fallow or cyclical system, the hedgerow intercropping system, as well as the modified multistorey strip planting system. Evidence accumulating from these studies and the advantages attributed to the implementation of agroforestry systems are sufficient to assume that agroforestry might be a sustainable land use system in our fragile tropical environments.

Traditional agroforestry systens in Thailand

The concept of agroforestry in Thailand dates back to more than one decade. This system had also been put into practice prior to the concept was popularly adopted but with a different terminology, i. e., agrisilviculture or taungya system. It originated when the Forest Industry Organization (FIO) was entrusted by the government to assist the Royal Forest Department (RFD) in establishing the forest plantations in addition to its own duties of forest exploitation. The taungya system of reforestation has been adopted in order to cope with the problem of shifting cultivation and forest squatters by allowing the farmers to grow cash crops in the reforestation areas. Since, during that time, it was found that the system was not effective due to the lack of social concern, the FIO modified the taungya system into the forest village system in which this system has been improved since 1968 and expanded throughout the country.

The main feature of the Modified Taungya system is the organization of rural development schemes incorporated into the plantation establishment acitivity, whereby the labor force can be stabilized for the reforestation task. As the forest land belongs to the state according to the forestry laws, the farmer will be allocated temporarily 0.16ha for one family to use as living quarters to build a house, make a homegarden, and so on, but this land can not be sold except for transfer to the next generation. The piece of land for one planting unit is allocated based on the annual planting area and the felling cycle. For instance as a teak plantation is harvested after 60 years of age and the planting area remains constant at 160 ha per year, the total piece of land must cover 9,600ha. Each family will be allowed to utilize 1.6 ha per year for intercropping practices in which trees and crops are planted simultaneously by the farmer. Tree seedlings are provided by the FIO and planted at a spacing of 2 × 8m or 4 × 4m to reach the normal density of 625 trees/ha. Some facilities are also provided such as service road, reservoir, electricity, school and health care center.

The advantage of this planting method is that the tending of the tree plantation will be more intensive than in ordinary tree planting since the farmers will take care of their crops and the trees can benefit from such practice. The FIO has, also, developed an incentive method to reward the farmers who are able to keep more than 80% of the trees. Since one family is allowed to utilize 1.6ha per year for 3 consecutive years, therefore, one family must take care of one new planting plot and tend the other two previous planting plots over a total area of 4.8ha. Such a family, will receive a special bonus besides the regular wages and subsidies.

According to the concepts of agroforestry that have been adopted throughout the world, agroforestry in Thailand can be classified into 7 types as follows : 1) Modified taungya system, 2) Shifting cultivation/

bush fallow crop rotation, 3) Crop-forest complex, 4) Farm forestry, 5) Multistorey planting, 6) Tree integration on farm lands and 7) Silvopastoral system. These forms of agroforestry are characterized by their own distribution, practices, role in production and protection, structure, species composition as well as some significant ecological and socio-economic functions.

Research evidence for the development of agroforestry systems in Northeast Thailand

The study site is located at the Huey Thar Silvicultural Research Station in Sisaket Province, Northeast Thailand. It is a flat plain area with an elevation of 130 m asl, which was previously covered by a mixed deciduous forest with pine and scrub woodland. The climate of the area is generally hot, with rainfall amounting to approximately 1,500mm, and 114 rainy days per year reaching a maximum of 300mm in June. There is a marked long dry period lasting for 6 months from November to April. The average temperature is 26.5°C, with a mean monthly range of 15.7°C to 35°C. The relative humidity ranges from a minimum of 62% in March, and a maximum of 84% in September.

The soil generally shows a low fertility with respect to nutrients and organic matter. Parent materials consist of sandstone and sedimentary rock, giving a sandy loam soil texture. As the low pH of 5.3 may be due to high leaching rates, the effective cation exchange capacity is low with an average of 3.0 meq/100g soil. These characteristics indicate a low plant nutrient availability. Some of the chemical properties of the surface soil at the initial stage of the experiment indicated an average of 1.5% OM, 7.4 ppm P, 35.8ppm K, 251ppm Ca and 56.9ppm Mg.

Onestorey hedgerow intercropping practice

The first project was started in 1978. Four fast-growing tree species *Acacia auriculiformis, Leucaena leucocephala, Eucalyptus camaldulensis* and *Peltophorum dasyracis* were planted at a specing of 4m × 4m. Three agricultural crops, upland rice, mungbean and peanuts were intercropped between the tree rows during the first two years, while in the third year these crops were replaced by sweet potato, cassava and castor bean plant. The control plots were the same for all the rotation period, with slash-weeding twice a year to simulate normal plantation practices. The tree stands were maintained without any crops during the following year prior to final cutting at a 4-year and 8-year rotation, respectively, after which intercropping was resumed in each respective cutting year to quantify the effects of the different tree species on the soil productivity through crop production. The accumulation of certain mineral nutrients in the living tree biomass and the return of nutrients to the soil through litterfall were also estimated within these stands at 4 years and 8 years, respectively. Therefore, only the intra-system flows of nutrients by litterfall and uptake by tree vegetation were dealt with in this study. The cost-benefit analysis of various tree-crop combinations throughout the 4-year rotation within the framework of the agrisilvicultural system was also carried out.

The results from these studies showed that all the tree species had benefited considerably from intercropping, wood production increasing on the average among the 4 species by 325% compared to the monoculture.

The effect of the tree species on the yield of each crop during the first two years of intercropping practices was not significant. However, in the third year, crop yield significantly decreased and the tree species also affected differently the yield of the respective crops.

A. auriculiformis showed the highest value for the average firewood dry weight with 43.94ton/ha and 109.34ton/ha over the 4-year and 8-year rotations, compared to *E. camaldulensis* which produced a little less, i.e. 37.09ton/ha and 100.05ton/ha over these two rotation periods, respectively, followed by *P. dasyrachis* while *L. leucocephala* produced only 8.54ton/ha and 35.39ton/ha at 4 years and 8 years, respectively.

A. auriculiformis and *E. camaldulensis* showed the maximum benefit/cost ratio of 1.52 after 4 years when they were intercropped with peanuts in the first two years and with sweet potato in the third year during the implementation of the agrisilvicultural system.

The ecological impact of the planting of these trees species on agricultural land was also analyzed during the period 1978 to 1986. Comparison between *E. camaldulensis* and *A. auriculiformis* during the 4- and 8-year rotations revealed that *E. camaldulensis* did not exert adverse effects on soil and the crop yield compared to *A. auriculiformis* during the 4-year rotation. Crop yield gains from the *Eucalyptus* plot during this period were surprisingly higher than those from the *Acacia* plot, presumably due to the considerably large amount of annual nutrient uptake by *Acacia* (twofold) compared to *Eucalyptus*. On the other hand, in the 8 year rotation, the planting of *Eucalyptus* led to a negligible decrease of corn yield by only 4% compared with the yield gain in the 4-year planted fallow and with the yield gain from *Acacia*. However in the *Acacia* plot, the increase of corn yield was significantly higher in the 8-year rotation compared to the 4-year rotation, mainly due to the higher rate of nutrient return to the soil by *Acacia* amounting to 48.4% compared to 32.7% provided by *Eucalyptus* during the 8-year period. However, the yield of peanut was higher in the *Eucalyptus* plot throughout the experimental period than in the *Acacia* plot, indicating that *Eucalyptus* did not exert significant harmful effects on soil productivity.

The results obtained from these studies are summarized in the following Tables.

Table 1 Average fuelwood dry weight of tree species in each stand at 4 years of age (ton/ha)

Tree species	Intercropping	Control
Acacia auriculiformis	43.94	7.23
Leucaena leucocephala	8.54	1.73
Eucalyptus camaldulensis	37.00	11.01
Peltophorum dasyrachis	37.46	7.79

Table 2 Yield of cassava and relative light intensity in each stand at 3 years of age

Stand	Yield of cassava kg/rai	Relative light intensity %
Leucaena leucocephala	977.40	67.30
Eucalyptus camaldulensis	530.00	48.80
Acacia auriculiformis	316.70	22.80
Peltophorum dasyrachis	125.30	15.80

Table 3 Annual nutrient uptake and return of each stand at 4 years of age (kg/rai/yr)

Elements	Stands	Uptake	Return	% Return
N	*A. auriculiformis*	33.18	6.15	18.53
	E. camaldulensis	13.21	1.86	14.06
P	*A. auriculiformis*	1.54	0.18	11.73
	E. camaldulensis	0.98	0.08	8.46
K	*A. auriculiformis*	16.94	1.95	11.49
	E. camaldulensis	11.34	1.48	13.01
Ca	*A. auriculiformis*	46.61	6.93	14.86
	E. camaldulensis	24.89	4.89	18.48
Mg	*A. auriculiformis*	4.58	1.11	24.12
	E. camaldulensis	2.93	0.66	22.57
Total	*A. auriculiformis*	102.85	16.32	15.87
	E. camaldulensis	53.35	8.97	16.81

Table 4 Annual nutrient uptake and return of each stand at 8 years of age (kg/rai/yr)

Elements	Stands	Uptake	Return	% Return
N	*A. auriculiformis*	31.88	15.95	50.03
	E. camaldulensis	12.29	3.74	30.43
P	*A. auriculiformis*	1.07	0.28	26.16
	E. camaldulensis	1.46	0.16	10.96
K	*A. auriculiformis*	7.12	1.39	19.52
	E. camaldulensis	5.43	0.25	4.60
Ca	*A. auriculiformis*	22.86	12.39	54.20
	E. camaldulensis	16.25	7.47	45.97
Mg	*A. auriculiformis*	3.11	1.94	62.38
	E. camaldulensis	2.19	0.67	30.59
Total	*A. auriculiformis*	66.04	31.95	48.38
	E. camaldulensis	37.62	12.29	32.67

Table 5 Comparison of some soil chemical properties in each stage between the two stands

Stand	Age (yr.)	pH	O. M. (%)	P	K	Ca	Mg	CEC
				(ppm)				meq/100
A. auriculiformis	0	5.4	1.4	6.8	35.1	244.2	56.6	2.9
	4	4.8	1.4	3.7	26.6	225.2	51.6	—
	8	5.4	1.2	5.5	35.0	460.0	81.5	3.9
E. camaldulensis	0	5.4	1.4	6.8	35.1	244.2	56.6	2.9
	4	5.0	1.6	4.1	26.9	225.5	53.3	—
	8	5.7	0.9	5.5	35.0	400.0	65.0	5.9

Table 6 Average grain yield of agricultural crops as affected by tree species after planted fallow in 4 and 8 year rotations (kg/rai)

Species	Rotation (yr)		
	0	4	8
Peanut			
A. auriculiformis	246	187	310
E. camaldulensis	260	222	332
Corn			
A. auriculiformis	454	354	635
E. camaldulensis	418	480	367

Multistorey mixed planting within the framework of an agrisilvicultural system

Biological complexities and interaction of the mixing of multiple tree species in an agroforestry system present an interesting challenge for the improvement of system productivity. Although efficient use of resources becomes operative when two or more tree species coexist in the same field with annual crops during the same years, the interactions become most complex when trees/crops are grown simultaneously. Multipurpose trees are most suitable, but it is necessary to identify species that are adapted to particular sites. A mixture of tree species that serve different purposes in the same site simultaneously would be suitable.

To determine whether this concept is applicable, a study on multistorey mixed planting using tree species with different purposes within the framework of an agrisilvicultural system has been conducted at this station since 1985. The layout of trial is shown in Fig. 1.

There were five treatment combinations of threetier mixing systems comprising 5 different *Acacia* species, the non-legume fast-growing tree, *Eucalyptus camaldulensis* and the indigenous slowgrowing *Dipterocarpus alatus*. Each *Acacia* species was planted between *Eucalyptus* and *Dipterocarpus* in each row at a spacing of 2m within a row and 8m between rows. There were 4 plots, each plot with a size of 40m × 40 m and 5 rows of such three-tier mixed species.

Both trees and crops were first planted simultaneously in June, 1985. Crops were planted between the tree rows at 50cm apart from both sides of the tree rows each year. In the third year, root pruning of trees in all the plots was carried out by trenching 30cm in width and 45cm in depth with an interval of 1.50m from both sides of the tree rows.

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x	x	x	x	x	x
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Species: o *Acacia*, x *Eucalyptus*, * *Dipterocarpus*

Fig. 1 Multistorey intercropping

After three years, the *Acacia* trees displayed a satisfactory growth and provided the benefit of nitrogen fixation by the rhizobi present in their root nodules, resulting in the acceleration of the growth of either *Eucalyptus* or *Dipterocarpus*, mixed between the same rows of *Acacias* trees. To analyse these effects, the stem diameter at 30cm above ground level of all the tree species was measured in 1988 when the trees were three years old.

The results obtained from this preliminary assessment showed that *Acacia auriculiformis* displayed optimum growth and that the nitrogen-fixing nodules promoted the growth of the other two adjacent non-legumes *Eucalyptus* and *Dipterocarpus*, followed by *A. leptocarpa, A. aulacocarpa* and *A. cincinnata*, respectively.

This study, indicated that Acacia species could be used in agroforestry systems if the Acacia trees are planted in a three-tier mixing pattern with trees displaying silvicultural characteristics and enduses. There are both biological and economic buffering mechanisms in the systems in which more than one tree species is produced in an area. There is a wide range of suitable mixtures of tree species as well as crops in an agroforestry system that emulates to some extent the natural tropical ecosystem and its diversity, and evolved through conscious intervention of farmers to meet their goals of covering all purposes with a sustainable system. From the point of view of a prolonged intercropping period, these multistorey mixing systems could be timely for continuous intercropping until the canopy of the slowest growing species becomes closed. This process may require 10 years compared to less than 3 years for a single fast-growing species planted under the same spacing and practices.

In this study, all the Acacia trees will be cut when they are 3-4 years old, the leaves will be used for green manure while, stem and branches will be utilized for firewood. In this case, since the open crown regenerates, the intercropping practice should be continued. The remaining two-tier mixing between *E. camaldulensis* and *D. alatus* with a spacing of 4m × 8m, will be maintained for intercropping. *Eucalyptus* will be the next to be harvested at the age of 5 years. This tree is mainly used for posts, poles or small construction wood. After 5 years, only the slow-growing *D. alatus* at a spacing of 8m x 8m will be left in the site, and other crops could be interplanted between such tree rows until the sprouting of *Acacia* and *Eucalyptus* leads to the closure of the canopy again. Although this practice may appear to be complicated, it is found from both the biological and management point of views to achieve a sustainable agroforestry system in the tropics.

Into this three-tier mixing system, the farmers could introduce fruit trees by replacing the indigenous slow-growing species. In this case, the spacing between trees within a row will be set at 4m to avoid the competition between fruit trees and forest trees. This system could provide edible fruits in addition to wood and food in the same piece of land simultaneously to meet the subsistence requirements of the smallholder farmer whose main concern is the production of food, fuel and some construction and utility materials as well as other minor products.

Alley width and optimum tree/crop production

Food production is the major objective of subsistence farmers. The introduction of a hedgerow intercropping system on arable land could reduce the land area available for cropping. The land lost for annual crop production depends on the alley width, i.e., the distance between the hedgerows. The information available on the comparative effects of alley width was derived from the experiment carried out in this station since 1987. Two species, *Eucalyptus camaldulensis* and *Acacia leptocarpa* were selected for comparative studies among 5 different types of alley width or cropping spacing. The results throughout the four year period showed that in the case of 4m, 6m, 8m, 12m, and 20m alley width, crop yields were not significantly affected by the trees during the first two years. In the third year, crop yield was satisfactory only for 8m, 12m, and 20 alley width. In the fourth year, the crop yield was satisfactory only for a 20m alley width.

These results suggest that, among the fast-growing tree species, tree rows or strips should be arranged to provide alleys of at least 20m width so that sustainable crop production could be continuously and simultaneously maintained throughout the 4-5 year rotation period. Thereafter intercropping practice could be resumed within such limited arable areas.

However, in each planting unit area of 40m by 40m with a density of 200 trees, the number of tree rows must be regulated to fit to the alley width based on 5 types as follows: 1) ten single rows of 2m × 4 m spacing, 2) five strips of two rows at a spacing of 2m × 2m, 3) five single rows at a 1m by 8m spacing, 4) two strips of five rows at a spacing of 2m × 2m, and 5) one strip of ten rows at a spacing of 2m by 2m.

In such arrangements of both trees and crops it was shown that the maximum production of wood was achieved by the single hedgerow intercropping at a spacing of 2m by 4m, while the maximum crop yield was obtained by the 20m alley width of the single ten row strip. The optimum hedgerow intercropping pratices should consist of a strip of 5 tree rows at a spacing of 2m × 4m with a distance of at least 20m between successive strips for crop cultivation.

Multistorey strip planting in the framework of an agrisilvicultural system

In the principle and functions of agroforestry, emphasis has mainly been placed on the productivity, sustainability and suitability of the system to meet the increasing socio-economic demands of the people. On the basis of the systematic pilot studies carried out from 1978 to 1991, effective management of poor soils and rehabilitation of denuded lands were promoted to improve the living conditions in these areas as well as land productivity to fulfill the potential of agroforestry.

As a result, the adoption of strip planting consisting of mixtures of different 3 multistorey species has been suggested in these marginal low land areas since 1989. Each strip of 5 tree rows composed of indigenous species which require some shade during their early growth phase was planted under the other two fast-growing species, one being a nurse crop consisting of nitrogen-fixing or legume trees (*Acacia* species) the other being a tree with a light canopy and a straight clear bold stem (*Eucalyptus camaldulensis*).

The nurse crop will provide green manure, while, stem and branches will be utilized for firewood. *Eucalyptus* will be mainly used for posts, poles or small construction wood. The slow-growing but valuable tree remains in the site to become the main tree at maturity.

In the multistorey strip planting, 100 trees per unit area (40m by 40m) were arranged as shown in Fig. 2. In each unit area, 40% of the total area was used for the tree strip 16m in width while 60% or the 24m alley width was used for crop cultivation. Each strip consisted of 5 rows at a spacing of 2m within a row and 4m between rows. The outer 2 rows were planted with a mixture of *Acacia* and *Eucalyptus*, while in the middle row indigenous slow-growing trees were mixed with the nursing *Acacia* trees. Legume crops were intercropped within a strip to promote tree growth. The other perennial or non-legume crops were cultivated within the alley to avoid the strong competition of such crops with trees.

This model was beneficial for crop cultivation and two varieties of crops were obtained. Legume crops can be cultivated between tree rows within each strip for 2 years. The other non-legume crops could be cultivated continuously for a long period of time within the alley 24 m in width until the canopy of the indigenous slow-growing trees planted in the middle row of each strip closes at 15-20 years. In the outer 2 rows planted with 2 fast-growing species the trees will be cut consecutively in the fifth and the sixth year, respectively, and will be able to reproduce by coppicing or replanting. By these practices, the alley can be maintained for continuous cropping and meet the requirements of the people for food or cash crops simultaneously and for a long period of time by this system.

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Fig. 2 Multistorey strip planting

x : Nitrogen-fixing fast-growing spp. (*Acacia mangium*)
o : Non-leguminous fast-growing spp. (*E. camaldulensis*)
* : Indigenous slow-growing spp. (*Dipterocarpus alatus*)

Conclusions

Agroforestry appears to be a promising technique to improve degraded forest lands to achieve sustainability in land use and fulfillment of needs of the local people. This system attempts to overcome serious social and environmental problems. The major technical challenge in agroforestry development today is the lack of ready, validated designs which can be disseminated with confidence to land users, and the lack of reliable technical information on components and component management with which to develop more general agroforestry design principles. There is a potential for the use of three-tier mixing among tree species with different silvicultural characteristics and enduses, especially, if a such mixing is arranged in the form of alley strip planting with the maintenance of a reasonable width of 24m for extending crop cultivation.

There is a wide range of combinations of suitable tree species as well as crops in this model which emulated to some extent the natural tropical ecosystems and their diversity, and evolved through conscious intervention of farmers to meet their goal of covering all purposes within a sustainable system. These practices appear to be complicated, but they are reasonable from both biological and management point of views for the implementation of a sustainable agroforestry system in the tropics.