Role and Effective Use of Nitrogen-fixing Trees in Agroforestry Systems

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Abstract

Tropical forests are often cleared to make room for agricultural land for the cultivation of food products to meet the needs of a rapidly increasing population, or for industrial land, buildings, etc. On the other hand, forests play an important role in water conservation, prevention of land erosion or landslides and air pollution as well as supply of forest products. Therefore, optimum land use could be achieved if crops were cultivated simultaneously or temporarily in forest land. This combination referred to as agroforestry consists of a variety of systems depending on the background of the local communities.

Nitrogen-fixing tree species play on important role in agroforestry systems, because atmospheric nitrogen is fixed by certain bacteria which colonize the root nodules of the trees, resulting in the improvement of soil fertility by this symbiotic activity.

Characteristics of some legume trees suited to agroforestry systems, such as trees for shade, fuelwood, etc. will be described, including comparison of seed dispersion and germination, distribution and growth of *Erythrina* species. In addition, experiments showing that the mixture of soil with charcoal powder resulted in the promotion of root nodulation by the bacteria will be reported.

Introduction

It is generally recognized that the area covered with forests, natural resources with essentially regenerative and sustainable characteristics, is rapidly decreasing, especially, the tropical forests.

Forests supply not only forest products such as lumber, pulp and paper materials, fuelwood, etc. but also play a role in the conservation of water resources, soil erosion control, air purification, etc. However, forest land is often cleared for other purposes due to the increase of the population in the tropical countries, for instance, farm land where many kinds of crops and vegetables can be cultivated, pasture land, industrial lands, residential areas, etc.

The optimum land use is to combine the cultivation of food crops with tree crops in forest lands, or tree crops in agriculture or pasture land temporarily or over a long period of time for the supply of food and fuelwood.

This combination system which is called agroforestry consists of various systems based on the social background of the local communities of each country.

Role of tree species in agroforestry systems

What is the role played by trees in the agroforestry systems? As mentioned above, the role played by trees is considerable and varied, however, in the case of the agroforestry systems, trees fulfil the following functions :

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1) provide shade for the crops,
2) provide fuelwood or charcoal materials,
3) provide fodder for livestock,
4) provide multipurpose trees,
5) provide fruits,
6) contribute to the establishment of forest land in the future, and
7) provide environmental areas.

Functions 1) to 5) are mostly related to the daily life of local habitants, while items 6) and 7) are concerned with political matters.

Leguminous tree species that can fix atmospheric nitrogen through the symbiosis with bacteria in root nodules could be selected because these tree species are very useful for multipurpose use and prevention of soil degradation in the tropics.

Choice of leguminous tree species in agroforestry systems

Leguminous tree species which can be used for fuelwood, charcoal, shade of crops or as fodder trees, multipurpose trees, living fences, and windbreaks must not necessarily exhibit a strait and elegant trunk form unlike industrial timber.

For the selection of tree species for use for fuelwood the following characteristics must be present : (1) fast-growing species, (2) vigorous coppicing, (3) catch fire quickly, (4) high calory content, and (5) keep fire for a long period of time.

For shade trees the following requirements must be met : (1) provide shade through canopy structure, (2) vigorous coppicing of leaves and branches, and (3) use as mulch.

Fodder tree species for cattle must exhibit the following characteristics : (1) high protein content, (2) mass production of leaves and branches compared with trunk. These tree species can be also used as fence poles. In addition, these tree species must be able to fix nitrogen through the symbiosis with bacteria in root nodules for the preservation of soil fertility.

Major leguminous tree species which can be used in agroforesry systems were selected from plantation sites and based on some references in the literature. They are listed in Table 1.

The characteristics of these tree species were summarized. Environmental conditions such as duration of dry season, amount of rainfall, soil type are the most important factors for the use of these trees in the tropics.

Effective use of *Erythrina* spp. in Central America

More than one hundred *Erythrina* spp. are distributed mainly from the subtropical to tropical regions of the world even though *Erythrina laurifolia* and *E. indica* are cultivated as ornamental plants in the western and southern parts of Japan.

E. poeppigiana, E. fusca, E. berteroana and *E. costaricensis* are native to Central America and southward to Bolivia. They are tall trees, reaching ten to fifteen meter in height with stout spines, broad trifoliate leaves except for *E. fusca* which shows egg-shaped leaves, and deep orange or crimson colour flowers coming into blossom at the end of the dry season. These species are used as shade trees for *Coffea arabica* or *Theobroma cacao*, and also offer a great potential for agroforestry systems, for example, alley cropping, silvo-pastoral system with living fence, fodder, etc. because these trees are pollarded two to three times a year.

1) Characteristics of *Erythrina* spp.

The four *Erythrina* spp. previously listed are widely distributed in Costa Rica, Central America. Since each species exhibits different characteristics, various experiments were carried out.

Seeds for tests were obtained from the Seed Bank of Latin Amereca at CATIE (Tropical Agriculture Research and Training Center), Costa Rica. For every 110 seeds which were collected from different areas for provenance tests, the length, width and weight of the seeds were measured. A part of the seed was scarified with sandpaper and soaked into boiling water for nearly one hour for pre-treatment. Thereafter

Table 1 Major leguminous tree species suitable for agroforestry systems

	A*	B	C	Dry season (month)	Rainfall (mm)
Acacia albida	3*	1	3	7－9	250－1,100
A. auriculiformis	1	2	3	4－6	1,300－1,800
A. catechu	1	2	3	6－8	500－1,500
A. mangium	1	1	1	3－4	900－2,000
A. melanoxilon	2	2	3	2－3	1,000－2,000
A. nilotica	1	1	2	6－9	200－1,400
A. saligna	1	2	1	6－8	600－1,200
A. senegal	1	2	1	6－8	200－5,000
A. tortilis	1	2	3	6－8	100－ 300
Albizia falcata	3	1	1	0－2	2,000－4,000
A. lebbek	3	1	1	2－4	500－1,500
Calliandra calothyrus	3	3	1	2－4	1,000－3,000
Cassia siamea	1	2	2	4－6	650－1,500
C. spectabilis	1	2	3	5－8	600－1,000
Dalbergia sisso	2	2	3	5－6	500－4,000
Erythrina berteroana	3	1	1	3－4	800－1,200
E. poeppigiana	3	1	1	3－4	1,000－3,000
Gliricidia sepium	1	2	2	4－6	800－2,300
Leucaena leucocephala	1	2	1	2－4	600－1,700
Parkinsonia aculeata	1	2	3	6－8	250－ 800
Prosopis chilensis	3	2	1	8－10	200－ 600
Samanea samon	2	1	3	2－4	800－3,000
Sesbania sesban	3	3	2	4－6	400－1,000
S. grandiflora	3	2	1	0－3	1,000－2,000
Tamarindus indica	3	2	1	9－10	200－1,400

Note: A: Fuelwood or charcoal, B: Shade, C: Fodder
Number in column: 1: Superior, 2: Ordinary, 3: Inferior

the seeds were inserted between tissues, and kept in a germination room. The number of seeds weighting 100g and the germination rate are shown in Table 2.

Table 2 Number of seeds and germination rate

Tree species	Number of seeds weighing 100g	Germination rate (%)
Erythrina fusca	219± 26	78.23± 2.83
E. poeppigiana	484± 81	70.15±16.76
E. berteroana	422±217	56.02±25.15

Number of *E. poeppigiana* seeds weighing 100g was larger than that of the other species. However in the case of *E. fusca* almost 50% of the seeds weighed 100g compared with the other spesies, indicating that the seed size of *E. fusca* was especially large. Germination started three days after sowing and ended within one week. The germination rate of *E. fusca* was high while in the case of *E. berteroana*, the germination rate was about 50%. Seedlings were transplanted from the germination beds to vinyl pots on the 8-th day and placed in a screen house to obtain optimum seedlings. When the seedlings reached a height of 50cm, all of them were transplanted to the nursery beds and immediately cut at a height of 30cm on the ground. Height increment and basal diameter were measured after 30 days, 60 days and 120 days. The results are shown in Fig. 1 and 2.

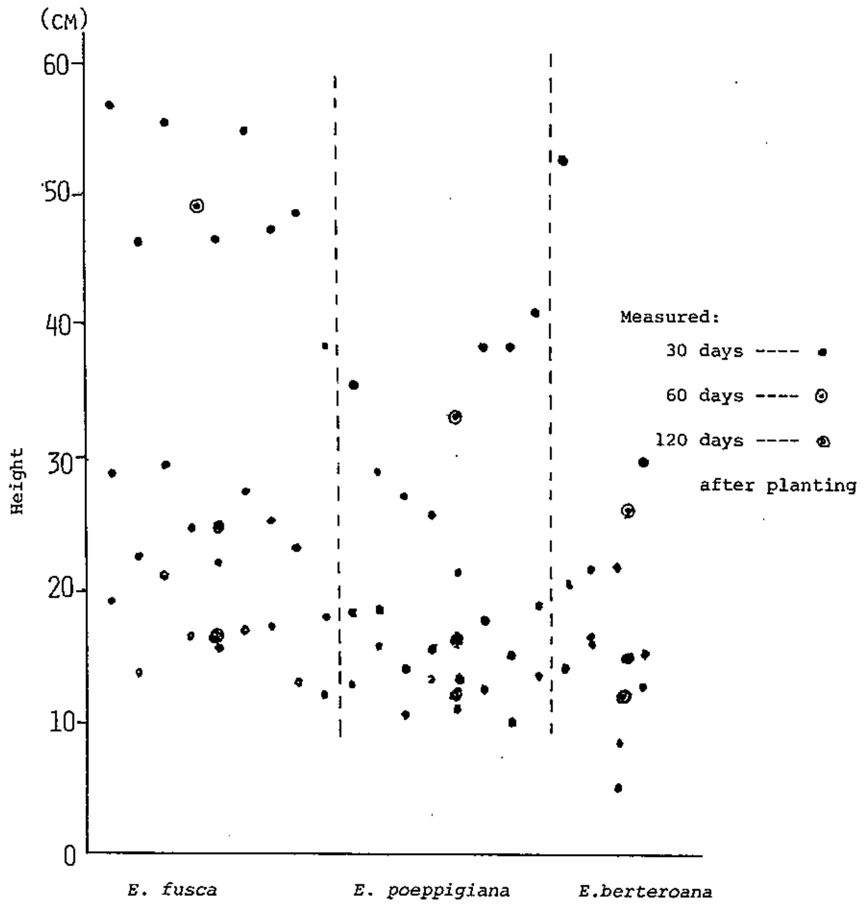

Fig. 1 Height increment of *Erythrina* spp. depending on the provenance.

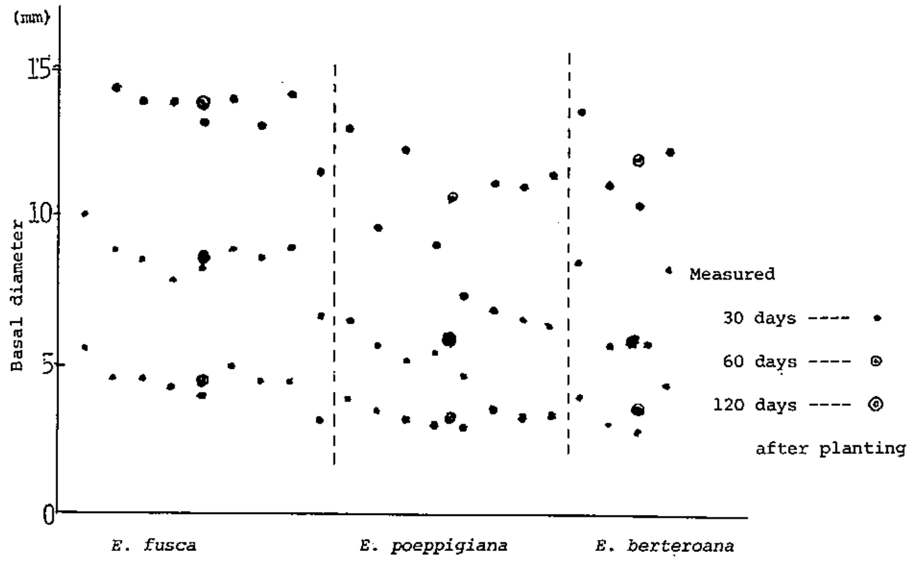

Fig. 2 Basal diameter of *Erythrina* spp. depending on the provenance.

Both the height increment and basal diameter of *E. fusca* were larger than those of the other species. Namely, *E. fusca* 120 days after planting showed the largest tree height of 49.23cm on the average followed by *E. poeppigiana* and *E. Berteroana* with 32.82cm and 26.94cm. Basal diameter also followed the same order as that of height increment.

Investigations over a period of two years for *E. poeppigiana, E. berteroana* and *E. costaricensis* are still continuing. The results are shown in Table 3.

Table 3 Growth of 2 years old *Erythrina* spp.

Tree species	D. B. H. (cm)	Height (m)	Crown	
			Diameter (cm)	Height (m)
E. poeppigiana	11.0	4.6	3.6	2.8
E. berteroana	6.0	3.6	2.3	1.8
E. costaricensis	7.3	3.1	1.8	1.6

Growth of *E. poeppigiana* was more active than that of *E. berteroana* and *E. costaricensis*, with the formation of a large and wide crown suitable for shade trees in agroforestry systems. Biomass production of five-and six-year-old *Erythrina* spp. subjected to pollarding two times a year is shown in Table 4.

Table 4 Biomass production of 5-and 6-year-old *Erythrina* spp.
(ton/ha/yr)

Tree species	Years	Leaves	Branches		Total
			Tender	Woody	
E. poeppigiana	5	7.76	3.04	4.47	15.27
	6	8.97	4.05	4.47	17.49
E. berteroana	5	2.64	0.39	2.95	5.98
	6	3.23	0.57	5.26	9.06
E. costaricensis	5	5.77	1.10	3.58	10.45
	6	5.34	0.48	4.06	9.88

Note: Spacing: 2.5m×2.5m, fresh weight.

The branches were divided into two categories as indicated in Table 4.

The term "tender" refers to the top to middle part of a branch with a high water content and a green and soft bark. The term "woody" refers to the middle to the basal part of a branch with a standard water content and gray and hard bark. In five and six-year-old *E. poeppigiana* which produced a larger amount of biomass than the other species, "tender" branches accounted for nearly 40 to 50% of the branches against the total weight of branches. This characteristic is suitable for use of the trees as fodder material and litter that decomposes easily to make compost. Russo (1983) showed that 4.2 ton/ha/yr of litter fall (dry weight basis) could be produced from *E. poeppigiana* in a coffee plantation.

2) Natural distribution of *Erythrina* spp. in Costa Rica

Although the major *Erythrina* spp. mentioned above are widely distributed, *E. fusca* occurs generally at an elevation of more than 1,000m asl with two to three months of dry season while *E. poeppigiana* grows well at elevations in the range of 800 to 1,200m asl in humid areas, and *E. berteroana* grows at elevations intermediate between those of two former species. *E. costaricensis* sometimes grows at higher elevations. Nevertherless, *Erythrina* spp. are not usually observed in the tropical lowlands with annual average temperature exceeding 25°C.

3) Application of powder charcoal to *E. fusca*

It is well known that charcoal application results in the increase of the yield of agricultural crops and mushrooms in Japan. Accordingly, experiments were carried out to determine whether biomass production and/or the activity of root nodule bacteria would be stimulated by charcoal application.

Forty one trees were planted in one plot at a 50cm spacing. At the same time, all the trees were pollarded at 30cm above the ground surface. One block consisted of three plots to which powder charcoal was applied at the rates of 200g, 100g, and 0g per tree at the base of each tree and also once a month for two consecutive monthes.

Table 5 Biomass production of *E. fusca* after charcoal application

Amount of charcoal (g/pot)	Leaves (kg)	Branches (kg)	Trunk (kg)	Total (kg)	Roots (kg)	Number of root nodule bacteria
200	1.31±0.11	1.42±0.07	0.37±0.06	3.09	0.58±0.04	92.13±33.74
100	1.27±0.15	1.19±0.16	0.36±0.03	2.82	0.64±0.18	62.52± 9.06
0	1.19±0.15	1.09±0.16	0.30±0.04	2.58	0.42±0.02	46.80± 4.71

Note: Fresh weight/tree.

The investigations were carried out over a period of only six months. It was found that in the plot to which a large quantity of charcoal had been applied, the amount of biomass and number of root nodule bacteria were large.

Although the root biomass did not increase during the observation, the application of a large quantity of charcoal resulted in the production of a large number of new white roots with bacterial nodules. These results were obtained by the improvement of the soil structure such as soil physical properties, aeration water permeability, etc.

4) Relationship between spacing of *E. poeppigiana* and production of *Manihot esculenta*

This experiment in an example of agrisilvicultural practice. The results are shown in Table 6.

Table 6 Biomass production of *E. poeppigiana* depending on spacing and yield of *Manihot esculenta* (tuber)

Spacing	*Erythrina poeppigiana*			*Manihot esculent*
	Density	Branches	Biomass	Yield
2.5m×2.5m	1681	7.76	5.11	9.52
3.5m×3.5m	840	6.89	2.44	7.74
4.5m×4.5m	530	4.56	0.99	5.08

Note: Biomass production and yield; ton/ha, dry weight basis.

Manihot esculenta was planted in a field with one-year-old *E. poeppigiana* cuttings subjected to pollarding at 1.5m height. Spacing was as follows: 2.5m×2.5m, 3.5m×3.5m, and 4.5m×4.5m. Closed spacing with high density plot resulted in the production of a larger amount of biomass of *E. poeppigiana.*

It is obvious that in a high density plot a large quantity of biomass is produced due to the abundance of materials. The large production of tuber by *Manihot esculenta* may be ascribed to the litterfall of *E. poeppigiana* and fertilization by nitrogen fixation of leguminous trees. Since *Erythrina* spp. is subjected to pollarding two to three times a year, shading is not a limiting factor.

Conclusion

In order to analyze the activities of leguminous tree species, some *Erythrina* species were selected in this study. The reasons for the importance of *E. poeppigiana* in Costa Rica are as follows: (1) rapid coppicing, (2) large biomass production, (3) large crown, (4) large quantity of fodder, (5) growth in the same area as coffee plantations, etc. Plants of economic importance most commonly grown under the shade in the tropics are coffee, cacao, tea, pepper, vanilla, Zingeberaceae, etc. The use of leguminous trees for the cultivation of annual and perennial crops is an important component in agroforestry systems, as these trees act as living fences, fodder, etc.

Leguminous trees with root nodule bacteria which are widely distributed in the tropics are able to improve the soil fertility, but for the selection of leguminous tree species for the plantations, various factors must be considered such as soil conditions, amount and duration of rainfall, duration of dry, spells, availability of seeds or stock as materials in the area or through introduction, growth rate, etc. Further studies on Leguminous tree species in the tropics are necessary for the future progress of agroforestry systems.

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