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...to my father Silvio (in memoriam) and my
mother Mirtes whose encourage me
since the beginning, I dedicate...

1. Introduction

... "this year I will slash-and-burn and plant crops on the last piece of land with remaining primary forest"... This farmer's statement reflects the reality of the recent past of the Bragantina region, State of Pará, Eastern Amazonia. In this region, with more than 100 years of colonization, the primary forest was transformed into fallow vegetation, caused primarily by agricultural activities.

In the recent past, slash-and-burn agriculture was considered environmentally in balance, since on average, only 1 to 2 ha were cultivated per family annually (YARED, 1991; SERRÃO, 1995). But nowadays it is necessary to adapt the system considering new factors such as market economy, land tenure and use of appropriate technologies (SERRÃO, 1995; KLEINMAN *et al.*, 1995).

As the slash-and-burn agriculture still uses rudimental technology there is little opportunity for the small landholder to accumulate capital and to improve his or her livelihood. Moreover, some factors such as a) demographic growth, b) the division of the family's land and consequently its intensified use, and c) the appearance of a new market for agricultural products (SILVA *et al.*, 1998) have contributed to the shortening of the fallow periods. The results is a decrease in soil fertility and loss of nutrients due to insufficient time for the accumulation of biomass. These factors are providing a land use instability, resulting in abandoned areas.

These problems have a significant impact on the landscape when the total number of farmers is taken into account. In the Amazonia of Brazil, around

800,000 rural properties exist with temporary crops and fallow cultivated land (IBGE, 1996). An annual decrease of 10% of the total area under shifting cultivation would be expected by extending the cultivation period by one year through the appropriate technology (SERRÃO and HOMMA, 1993).

For the small-landholder the fallow vegetation is an important source - among others - of firewood, charcoal, medicinal plants, and offers the opportunity for hunting. But, from the researcher's point of view, the fallow vegetation facilitates the recovery of the biogeochemical stability. In order to develop appropriate management strategies to avoid land degradation caused by agricultural activity, it is important to know the function of fallow vegetation.

The previous land use and management as well as the duration of land cultivation has a major influence on the type and vigor of the fallow vegetation (DANTAS, 1989; DENICH, 1989; UZÊDA, 1995; VIEIRA, 1996; BAAR, 1997). Soils of fallow vegetation at different ages compared to soils of the forest, have not shown clear differences in fertility (FALESI, 1976; VIEIRA, 1996).

Soil productivity is generally considered the main limiting factor for maintaining the sustainability of the slash-and-burn systems. Two important effects have to be considered in relation to the use of fire in shifting cultivation. First, during the burn of biomass there is a considerable loss of nutrients, mainly nitrogen (HÖLSCHER *et al.*, 1997). The second effect is represented by two aspects. Initially, there is a momentary improvement of soil fertility provided by the ash from the burn (FALESI, 1976; SEUBERT *et al.*, 1977; KATO, 1998a and 1998b). But this soil improvement will support only one or two cropping periods. Nutrient loss also occurs during the agricultural land-use cycle caused by leaching and crop exportation (HÖLSCHER, 1995; KATO, 1998a and 1998b).

This suggests that the main role of fallow systems is the biomass accumulation as a source of nutrients. When the small-landholder shortens the traditional fallow period, there will not be enough time for biomass accumulation and nutrient re-establishment to a level that provides adequate food production for the small holder In the long-run, this will bring the slash-and-burn system to collapse. Fallow management must, therefore, contribute to the efficient maintenance of the nutrients in the system. The planting of fast growing and nitrogen fixing trees as an enrichment of fallow vegetation, can improve the biomass production and its nutrients stock. This type of land management could be a promising means to alleviate the pressure on the primary forest and allow its conservation.

Thus, increasing the technological foundation of the slash-and-burn agriculture could increase its productivity, sustainability, and contribute to food security in the Bragantina region, State of Pará and the Amazon region.

In order to improve the fallow-vegetation biomass production and keep the - now common - shorter fallow the performance and the above- and belowground biomass of five fast growing leguminous tree planted in association with the crops maize and cassava in a crop-fallow cycle were evaluated.

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2. Review of Literature

2.1 Fallow vegetation

About 40% of the total agricultural population of the developing countries (300-500 million people) depend on shifting cultivation for their daily livelihood. This land use covers about 36 million km^2, or about 30% of the world's exploitable soils (STOCKING, 1984; LANLY 1985, cited by BEETS, 1990).

Most of the agriculture in the Brazilian Amazon region is based on shifting cultivation. A forest is usually slashed and burned and crops are planted (rice, corn, beans and cassava) during one to three years. The area is then abandoned for fallow, and the nutrients are stocked in the fallow-vegetation biomass. The fallow periods vary between three to four years but could reach up to 20 years, depending on different land use pressures. This system is typically oriented to subsistence farming, although the production surplus can be marketed in areas close to urban centers.

Under high demographic pressure and land-use intensification, changes in the agricultural landscape can be observed. Farmers who are unable to use appropriate technology to extend the land use are forced to move to other places or to shorten the fallow period. This land-use intensification has a negative impact on the regeneration of the fallow vegetation.

In the context of the present work, the spontaneous fallow vegetation is defined as the vegetation developed between two agricultural periods. Its growth begins after the last weeding in the agricultural period. In the Brazilian Amazon this vegetation is known as "capoeira". The capoeira has different succession stages with variable structure and density (DENICH, 1989; WATRIN, 1994; VIEIRA, 1996; BAAR, 1997).

Three floristic types of fallow vegetation were distinguished by BAAR (1997) in the landscape of the Bragantina region, which resulted from different land use. The first was called sand-capoeira and was found on Entisols at low disturbance intensities. The second was named Latosol-capoeira and appears on Oxisols at greater disturbance intensities. The last type was identified as pepper-capoeira, which follows after several years of cultivation of black pepper. Considering all identified fallow types this author recognized three phases of successional development. They were described as herb (up to 1 year), shrub (1 to 2 years) and tree phase (from 2 years on).

A remote sensing study conducted in Igarapé-açu, comparing fallow vegetation at different ages with the primary forest, permitted the following vegetation classification in 1991 initial secondary succession (1-3-year-old capoeiras; 24%), intermediary secondary succession (4-8-year-old capoeiras; 32%) and advanced secondary succession (13-18-year-old capoeiras; 18%). For superior ages of advanced secondary succession, the result of spectral image was similar to that found in a primary forest (WATRIN, 1994).

A floristic composition survey showed that the flowers of young capoeiras are mostly generalists. When the capoeira is becoming older and denser, the flowers are more specialized and they are visited by more specific pollinators (STEVENS *et al.*, 1993a).

The regeneration capacity of the fallow vegetation after a cropping period depends on certain factors and is fundamental for the growth and formation of the fallow vegetation. The fallow age and the different forms (land preparation) and intensities (system of cultivation) of land use act as decisive factors for floristic composition, species diversity and biomass accumulation of fallow vegetation (DANTAS, 1989; DENICH, 1989; SALOMÃO *et al.*, 1996; NUNEZ, 1995; BAAR, 1997).

The number of species found during the fallow period increased with the age of the fallow and varied between 62, 84, 108 and 112 for 5-, 10-, 20- and 40-year-old capoeiras, respectively (VIEIRA *et al.*, 1996). Among trees, bushes, vines and herbaceous plants in capoeiras with 4-5-years of age, DENICH (1989) found 183 species belonging to 54 families. In 20-year-old capoeira SALOMÃO *et al.* (1996) found 26% of primary forest species (316 species ha^{-1}). VIEIRA *et al.* (1996) observed that disturbances caused by shifting cultivation created ecological opportunities for some species which had been of restricted occurrence in the primary forest. These authors discovered that 35.4% of the forest tree species are favored by the agricultural activity.

According to the fallow classification proposed by BAAR (1997), the sand-capoeira had the largest number of primary forest tree species as a result of low disturbance intensity. Some species as *Eugenia biflora* (tree/shrub) and *Platonia insignis* were classified as indicator species for sand-capoeira. The Latosol-capoeira showed high dominance and frequency rates of typical fallow species (tree/shrub) like *Vismia guianensis, Myrciaria floribunda, Myrcia sylvatica, M. deflexa, M. bracteata, Lacistema pubescens* and *Phenakospermum guyannense*. The pepper-capoeira is influenced by prior land use practices. The majority of primary and fallow species observed in sand- and Latosol-capoeira were not present in the early stages of plant succession in pepper-capoeira. Some species found in this land use were *Chromolaena odorata, Lantana camara, Cordia multispicata, Miconia minutiflora, Cecropia palmata, Homolepis aturensis,* and *Marsipianthes chamaedrys*. Generally, this vegetation is dominated by low growing shrub species, herbs and grasses such as *Borreria verticillata*, *Eragrostis ciliaris* or *Paspalum maritimum*.

The two main mechanisms of fallow-vegetation regeneration are seeds and the resprouting of roots and stumps. Seed regeneration plays a minor role for fallow regeneration. STEVENS *et al.* (1993b) observed that the soil seed bank of the capoeira has a larger pool of herbaceous species, because seeds and seedlings of forest trees are practically nonexistent. VIEIRA (1996) found that of a total of 140 species (≥ 5 cm dbh) of the capoeira, only 14 were present in the seed bank. In young fallow vegetation some abiotic factors such as high temperature and water stress cause damage to unprotected seeds. The seeds apparently have no chance of surviving under the prevailing adverse conditions (STEVENS *et al.*, 1993b). A study of seed dispersion (seed rain) conducted in the Bragantina region showed more seeds per square meter in fallow vegetation than in the primary forest. The number of species increased with the succession age, varying from 70 species in 5-year-old capoeira to 134 species in the primary forest. Species with fleshy and arilate fruits dominated the seed rain of the fallow vegetation. Most wind and self dispersed seeds were vines and herbs, but some pioneers and mature species used the same mode of dispersal (VIEIRA, 1996). STEVENS *et al.* (1993b) also observed that hardly any seeds from fragments of the mature vegetation made their way into deforested areas.

Most of the fallow vegetation species regenerate by the resprouting from coppice or root (DENICH, 1989; VIEIRA, 1996; WIESENMÜLLER, 1999). VIEIRA (1996) observed an initial coppice growth of 80-85% of the individuals in a stand in which 70-80% of the species had this capability.

Land preparation with mechanization (FLOHRSCHÜTZ, 1986; DENICH, 1990), excessive use of fire (UHL *et al.*, 1981; JACOBI, 1997) or prolonged time of cultivation (NUNEZ, 1995; WIESENMÜLLER, 1999) reduces the regeneration capacity of fallow vegetation, mainly because the resprouting capacity (stumps and roots) is affected. Thus, the opportunities for the establishment of grass and herbs from seeds are accentuated leading to their initial predominance.

There are large nutrient losses in slash-and-burn agriculture. When a 7-year-old fallow vegetation was slashed and burned and crops were planted, the highest losses observed were caused by burning (51.3%), removal of crop harvest (35.5%) and leaching (13.2%). Even when chemical fertilization was used, the nutrient balance in slash-and-burn was negative, except for P (positive value of 4 kg ha^{-1} due to fertilization). Losses of 308 kg N ha^{-1}, 175 kg Ca ha^{-1}, 94 kg K ha^{-1}, and 41 kg Mg ha^{-1} were observed (HÖLSCHER, 1995).

Not all fires are properly controlled. Apart from the economic damages caused by the losses of cropland and natural resources, accidental fires can also take away the entire basis of existence. MATTOS, M.M (personal communication) reports about a Capim river community in Paragominas-PA, searching for an area for crop cultivation after an accidental fire almost burned the entire property of the community. After the fire, there was not enough fallow biomass in the following year to support adequate agricultural production sufficient for the needs of the community.

The deforestation to open up new cropland does not only affect the floristic composition. Birds and animals that depend on the forest are also harmed. VIEIRA *et al.* (1996) observed that 84% of the primary-forest flora produce fruits that feed birds and animals, compared to 74% in the fallow vegetation. Such observations are confirmed by the comment of farmers that game has become very scarce, although the reduction is not only a function of vegetation composition alteration, but also reflects the increase in hunters' pressure and the fragmentation of vegetation.

As the fallow vegetation becomes older there is an increase of above- and belowground biomass. NUNEZ (1995) found values of aboveground biomass of around 10, 28, 49 and 95 t ha^{-1} in 1-, 4-, 7- and 10-year-old natural fallow, respectively. The nutrients stock accumulated in fallow vegetation over time is presented in Table 1 After 20 years of fallow, the accumulation of nutrients in fallow biomass is equivalent to 35% found in primary forests (VIEIRA *et al.*, 1996).

Table 1: Nutrients stock on biomass of fallow vegetation aboveground at different ages

Fallow time (years)	Biomass $t\ ha^{-1}$	Nutrients ($kg\ ha^{-1}$)		
		N	P	K
1	10	97	3	55
4	28	137	6	79
7	49	217	6	103
10	95	466	12	173

Source: adapted from NUNEZ (1995)

The litter biomass, an important component for nutrients cycling through decomposition, also increases with age. DIEKMANN (1997) observed litter biomass of 3.7; 9.9; 10.1 and 13.0 $t\ ha^{-1}$ in capoeiras with 1, 4, 15 and 30 years of age, respectively.

The root system of the fallow vegetation stays active during the cropping period. Like the aboveground biomass, the root biomass increases with fallow age (NUNEZ, 1995). An evaluation of fine root (< 2 mm) biomass dynamics over a year to a depth of 50 cm, showed values varying from 3.8 to 5.5 $t\ ha^{-1}$ in 3-4 year-old capoeira and from 6.8 to 8.2 $t\ ha^{-1}$ in 8-9 year-old capoeira (WIESENMÜLLER, 1999). However, its maintenance depends on soil preparation. Plowing and harrowing act as limiting factors for the regeneration of fallow vegetation by resprouting.

Nutrients and microbial activity determine the soil quality. The biological activity assures that nutrient cycling between soil and vegetation is maintained. The soil biological activity is reduced after traditional land preparation for cropping and recovered during the fallow period. Enzymatic activity and pH were considered important parameters to determine soil degradation under fallow vegetation (DIEKMANN, 1997).

The soil nutrient stock in the first 30 cm of a 5-year-old capoeira was 7 kg ha^{-1} of extractable P, 47 kg ha^{-1} of exchangeable K, 405 kg ha^{-1} of exchangeable Ca and 62 kg ha^{-1} of exchangeable Mg (DENICH, 1989). Compared with soil of the primary forest, the soils of capoeiras did not show great differences at different ages, indicating that cropping periods followed by fallow maintain the soils in similar conditions (VIEIRA, 1996).

It was also observed, that the fallow vegetation is capable of extending its root system down to a depth of six meters (SOMMER, submitted). This observation shows that the root system of capoeira is maintained live even after the fallow vegetation is cut during the cropping period. The maintenance of the root system permits the fallow vegetation to persist over a long period of time and to support successive land-use cycles of slash-and-burn agriculture.

2.2 Degraded and Improved Fallow Vegetation

In global terms, from the annually deforested areas about 60% are used for the establishment of slash-and-burn agriculture. The most important reasons for this kind of crop cultivation are social problems, inappropriate land use and land tenure policies (ICRAF, 1993).

One of the largest impacts on the of forest ecosystem in the Brazilian Amazon region are agricultural activities. This land use is primarily criticized because forest areas are slashed, burned, cultivated and then abandoned. As a result of this, a mosaic of fallow vegetation is established. Under high demographic pressure associated with market opportunities for new agricultural products, fallow periods are shortened. This means, that there is not enough time to accumulate a sufficient amount of fallow biomass and enough nutrients for the re-establishment of the next cropping period, thus causing a decrease in agricultural productivity. This process is accentuated when the total population of Brazilian Amazonia - engaging in slash-and-burn agriculture - is considered, where about 800,000 farms are engaged in temporary agriculture and have fallow areas (IBGE, 1996). Considering that each farmer slashes and burns, on average two hectares a year, about 1,600,000 hectares of fallow of different ages are been altered annually. According to INPE (1998), the deforestation in Legal Amazonia was about 2.9, 1.8 and 1.3 million of hectares in 1995, 1996 and 1997, respectively.

Ecosystem degradation can be analyzed from an agricultural and environmental point of view. Agricultural degradation is related to economic-productivity loss. The environmental degradation refers to damages or losses of animal or plant species and can be considered as biodiversity degradation. This degradation, normally is a result of human actions, provokes losses of the structural and functional integrity of the ecosystem and modifies the ability to regulate the storage and the flows of water, energy, carbon and nutrients (NEPSTAD *et al.*, 1992; VIEIRA *et al.*, 1993).

Although the tropical forest is considered an ecosystem in dynamic equilibrium (BRUENIG, 1986), there are limits to its capacity to resist environmental changes and degradation happens when that limit is exceeded.

The recovery processes of a forest ecosystem can be characterized by three levels according to MAINI (1992):

a) Self-renewal: the forest is capable of rejuvenation after a low disturbance level, returning to the initial or close to the original stage without any human interference;

b) Rehabilitation: after a medium level of degradation, the forest needs a long period to recover naturally, which can be reduced with management; and

c) Restoration: after an irreversible forest degradation, with consequent losses of biodiversity and site productive capacity, human interference is necessary to create a new forest that can be constituted of one or more species.

The search for new alternatives in the natural resources management, with low impacts, should begin using the traditional knowledge of local populations (MÜLLER-SÄMANN and KOTSCHI, 1994; AB'SÁBER, 1995). In addition, production systems should favor the interaction: soil-vegetation-soil. Recovery strategies should be based on socioeconomically adapted alternatives of production that can be used by different users in similar conditions.

The fallow period is an attempt to build up a new biogeochemical nutrient cycle. Under low pressure of land use, the recovery time may vary from 10 to 100 years (FÖLSTER, 1994). However, shortening the fallow period affects the biological capacity to maintain the regeneration potential (FÖLSTER, 1994) and ecological system capacity to stay and to regenerate after a disturbance (ULRICH, 1987 cited by FÖLSTER, 1994).

In case of short fallow periods, planting trees as an enrichment of the fallow vegetation can aid the build up of biomass (rehabilitation process). Using leguminous trees would be advantageous due to the benefits of nitrogen fixation. The enrichment could reproduce in a short period the same vigorous vegetation as found in old fallow.

Enriched fallow practices normally start during the agricultural period. Wood trees, perennial or temporary fruit trees were observed in different indigenous and "caboclo" communities in the continental Amazon region (ANDERSON *et al.*, 1985; PADOCH *et al.*, 1985; DUBOIS, 1988). A systematic study by the scientific community began only in the last three decades. Among other management possibilities, the use of agroforestry systems has been one of the techniques discussed. At least about 100 native species have already been investigated. Some of them are potentially suitable for forestry systems as shown by BRIENZA

JÚNIOR and SÁ (1995), although not all of the species have been tested in agroforestry systems. DUBOIS (1988) also mentions other species capable to adapt to different situations.

Different fallow vegetation enrichment techniques, using wood trees, already seemed to be viable in some cases in the Brazilian Amazon. One tested method is called line planting and another is named recrû. In both cases, the pre-existing fallow vegetation is maintained. In the first method, clean lines are opened and in the second one the fallow vegetation is pruned before planting trees. The tree species adapted to shade conditions must be previously selected for planting and then, through adequate fallow management, trees grow up to harvest (YARED and CARPANEZZI, 1981; SIPS, 1993; YARED, 1996). These management techniques tie up the land during the growth of the trees planted and generally take between 20-30 years. Therefore, this procedure is not feasible for smallholders, but rather for forest management units.

Under pressure to shorten the fallow period two alternatives could be presented. In the first case, a leguminous tree or shrub or cover crop is used to improve soil conditions for the next cropping period. The planting density is generally high to suppress weed growth. This technique requires an in-depth knowledge of the species used. Species such as *Pueraria phaseoloides* or *Mucuna* sp. are, however, so aggressive that they may suppress the growth of the crop planted subsequently.

In some African countries various leguminous trees, shrubs and cover crops are being used as planted fallow, in order to shorten the fallow periods which still improving soil fertility to increase the productivity of the subsequent planted crop. Some of these species studied in different situations are shown in Table 2.

Table 2: Leguminous species studied in some African countries to shorten the fallow period by planting (compiled from the proceedings of the "International Symposium on the Science and Practice of Short-term Improved Fallow", 11-15 March 1997, Lilongwe, Malawi)

Tree	Shrub	Cover Crop
Acacia leptocarpa	*Acacia angustissima*	*Cajanus cajan*
Acacia polyacantha	*Aeschynomene histrix*	*Centrosema macrocarpum*
Albizia lebbeck	*Azadirachta indica*	*Crotalaria ochroleuca*
Brosimum alicastrum	*Calliandra calothyrsus*	*Crotalaria zanziberica*
Casuarina equisetifolia	*Chromolaena odorata*	*Desmodium distortum*
Columbrina grandulosa	*Gliricidia sepium*	*Dodonaea viscosa*
Eucalyptus tereticornis	*Leucaena leucocephala*	*Dolichos lablab*
Gmelina arborea	*Peltophorum dasyrrachis*	*Mucuna pruriens*
Inga edulis	*Senna siamea*	*Pueraria phaseoloides*
Mimosa scabrella	*Senna spectalis*	*Stylosanthes guianensis*
Sesbania sesban	*Tephrosia candida*	
Tephrosia vogellii	*Tithonia diversifolia*	

In the papers presented during the international symposium on "The Science and Practice of Short-term Improved Fallow", 11-15 March 1997, Lilongwe, Malawi, the scientists showed a strong tendency to use dense planting to improve soil fertility in short-term fallows.

In the municipality of Marabá-PA, farmers from different regions outside Amazonia use *Calopogonium* sp. as soil cover under cassava and beans. This procedure of eliminating the fallow vegetation can be easier introduced in places where farmers are immigrants and therefore are not familiar with the different possible uses of native fallow vegetation species.

The second option is to enrich and shorten the natural fallow period conserving the fallow vegetation as a base for biodiversity capable of maintaining the integrity of the system and the farmer's needs.

The term "fallow period" does not mean that the area is not being used. Besides contributing to the biomass accumulation, the fallow vegetation plays an important role, as a source of energy production, medicinal plants, and for hunting. In Thailand it was observed that 110 alimentary species and 42 species of medicinal plants could be found in the fallow vegetation (KUNSTADTER *et al.*, 1978). In a survey done in the Bragantina region by WITHELM (1993), 145 types of trees belonging to 38 families, which could be used for different purposes (energy, construction, tools, medicines, etc.) were discovered. The substitution of spontaneous and heterogeneous fallow vegetation with homogeneous fallow may therefore not be in the farmers' best interest.

2.3 Desirable tree attributes for fallow enrichment

The tree species chosen for fallow enrichment can be native or exotic. The species should, however, be adapted to the system and address the user's demand. After identifying a high potential native species, in some cases, it not be used due to the difficulty to obtain seeds or poor seed germination characteristics. A certain species may address a farmer's demand in one community but may not be adaptable for another (WOOD and BURLEY, 1991). According to RAINTREE (1991) a selected species may not be useful due to the following factors:

a) inadequate function: trees for firewood production where there is no shortage of this resource, or trees to improve soil fertility where this problem does not occur;

b) inappropriate market orientation: cash crop trees where subsistence needs prevail or in places without the appropriate transport infrastructure and market;

c) excessive land demand: trees demanding lots of space in places of land scarcity;

d) excessive labor demand: trees that require intensive labor in places where this can not be met; and

e) excessive demand for capital: trees that require an input of extra capital. Some leguminous species, for example, only develop when they are inoculated with a specific type of rhizobium that could be difficult to obtain locally; some wood is harvested with expensive or non available equipment.

The ideal tree is called "ideotype", which specifies the ideal plant attributes for a specific purpose (WOOD and BURLEY, 1991; RAINTREE, 1991). The ideotype concept is derived from the field of genetic improvement, where different desirable characteristics are grouped in the same plant. For fallow enrichment, the ideotype concept can be applied to indicate desirable characteristics of species in early growth without suppressing crops during the agricultural period, and later, fast growth in association with the fallow vegetation.

The species selection process for enrichment should take into account some parameters observed in the area of origin such as: a) the succession position (WHITMORE, 1990) or is the selected species a pioneer that colonizes great gaps or small gaps (PICHETT, 1983; BROKAW, 1987; POPMA *et al.*, 1988); and b) morphological characteristics such as leaf size or crown structures (BAZZAZ, 1979; HART, 1980; OLDEMAN, 1983; GIVINISH, 1984). Pioneer species have seeds that can germinate in natural forest gaps under intense light, at least during a part of the day. The climax species are those that germinate under shade of the canopy of the natural forest (WHITMORE, 1990; SWAINE and WHITMORE, 1988).

Species selected for agroforestry systems should ideally have the following characteristics: good adaptation to different soil conditions; fast to very fast growth; multiple uses; resprout easily; demand a low level of nutrients; low pest and disease susceptibility; economically profitable; and without allelopathic effects (YARED *et al.*, 1998). The ecosystem function and level of competition should also be considered as well as associative characteristics (TORQUEBIAU, 1992).

2.4 Carbon in slash-and-burn agriculture

Green house gas emissions from land cover changes are of increasing concern. Several studies about carbon dynamics in different land-use systems have been carried out and several approaches were discussed by HOUGHTON (1993); POST *et al.* (1997) and BRUNO and JOOS (1997). Among different land-use changes the conversion of tropical forests to pasture have been getting more attention.

Burning forest to convert to pastures in the Brazilian Amazon liberates 8.4 to 15.3 kg C m^{-2} (CERRI *et al.*, 1996a). After the first 10 years of pasture the most important adjustments in the soil carbon stores occur (TRUMBORE *et al.*, 1995). After a period of 35 years from the conversion of the forest to pasture, the soil increases the accumulated carbon by 0.76 kg C m^{-2} (CERRI *et al.*, 1996b). Using different carbon fractions (active-, slow- and passive- carbon pool, CO_2 flux form soil and litterfall) TRUMBORE *et al.* (1995) gave a good information about belowground dynamics of carbon in pasture and forest in the Brazilian Amazon region.

For a better understanding of carbon dynamics in a forest ecosystem, and consequently its modeling, it is necessary to quantify the biomass and transfer rates among different ecosystem components. Starting from that information it is possible to infer about the stability of the studied ecosystem.

In slash-and-burn agriculture, the most important contribution to carbon sequestration is represented by fallow vegetation. The carbon dynamics in this land-use system have been studied in terms of fallow-vegetation biomass compartments. Whether the fallow vegetation is a carbon source or sink over time is still not known.

The impact of slash-and-burn on carbon dynamics will depend on factors such as: i) the aboveground burned biomass; ii) the fire management used (intense or non-intensive burn); iii) the fate of the residues after burning; iv) the cropping system chosen; v) the period of land cultivation; and vi) the fallow duration for biomass accumulation.

WOOMER *et al.* (1997) quantified the carbon stock from different land use systems in tropical areas in Brazil, Peru, Indonesia and Cameroon. The authors observed a variable carbon stock as a function of land use. The monocrop systems maintained the lowest carbon stock whereas in systems where trees were included, the carbon stocks were larger (Table 3).

Table 3: Total aboveground carbon stock at different land uses converted by slash-and-burn (adapted from WOOMER *et al.*, 1997)

Land Use	Time (year)	Total Carbon Stock (t ha^{-1})
Original forest	-	305
Secondary forest	19.4	219
Tree fallow	9.4	136
Bush fallow	4.6	85
Burned and cropped	2.1	52
Pasture	10.0	48

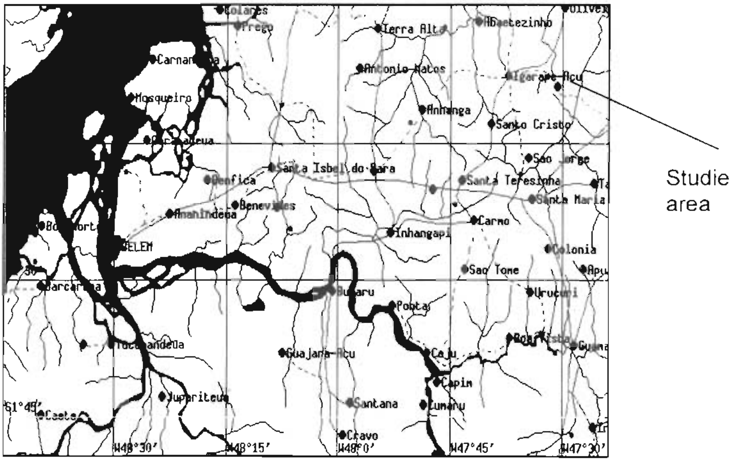
The soil carbon stock to a depth of 6 m in a fallow-vegetation chronosequence of 1, 5, 12 and 40 years of age, in the Igarapé-açu region, increased with age. The carbon stock of the fallow vegetation with 40 years of age, was close to that found in the primary forest (SOMMER *et al.*, submitted). Considering different possibilities of fallow management (fire-free land preparation - KATO, 1998a and 1998b - and enrichment using fast growing trees) DENICH *et al.*, (in press) present a carbon balance for slash-and-burn system over a period of 12 years. Fire-free land preparation followed by a mulch system stocked 30% more carbon than traditional cultivation. With fallow enrichment by *Acacia* *auriculiformis* it is possible to stock 2.5 times more the aboveground carbon than in the traditional fallow system.

3. Material and Methods

3.1 Description of Study Region

3.1.1 Bragantina Region

The Bragantina region is one of the most important agricultural zones in the Northeast of the State of Pará. Its population, distributed in 13 municipal districts, is around 302,000 inhabitants, which comprises 5.5% of the total population of the State of Pará (IBGE, 1996). The experiment was conducted in the municipality of Igarapé-açu, located 120 km from Belém, the capital of the State of Pará (Figure 1).



Studied area

Figure 1: The Site Location of the Experiment

The municipality of Igarapé-açu (1°07'41" latitude South and 47°47'15" longitude West) was founded in 1906 and covers approximately 786 km^2 (SILVA *et al.*, 1998). Its population in 1996 was 36,000 and 50% of the inhabitants lived in rural areas. The demographic density was 39 inhabitants per square kilometer (FIBGE, 1998).

Under the SHIFT program, the project named "Secondary forests and fallow vegetation in the agricultural landscape of Eastern Amazonia - Function and Management" – which includes the present study - has been carried out in this municipality since 1991.

3.1.2 Climate

The Bragantina region is classified as climatic zone "Am" (KÖPPEN classification; DINIZ, 1986). The annual temperature average is 25-27°C and the annual precipitation ranges from 2000 to 3000 mm. The relative humidity varies between 80 and 90%. There are two climatic periods in this region, the dry season and the rainy season. In general, the driest period is September-November and the wettest months are February-April (Figure 2).

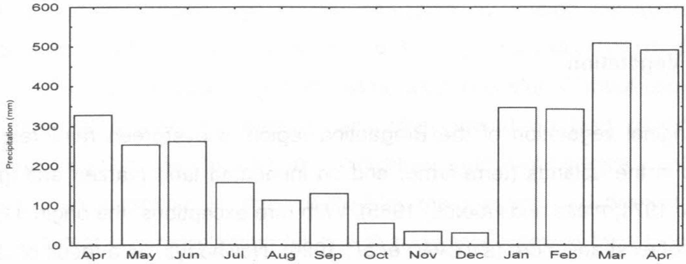


Figure 2: Rain distribution from April-96 to April-97 (Climatological Station Embrapa-Amazônia Oriental, Igarapé-açu, Pará)

3.1.3 Soil

The landscape of the Bragantina region is flat. Its soils were formed on Tertiary sediments of the Barreiras formation and the most important groups are Latosol (Oxisol) and Podzol (Ultisol) (VIEIRA *et al.*, 1967; NUNES *et al.*, 1973; SILVA and CARVALHO, 1986). The soils of the Bragantina region are therefore poor and will never be very fertile (FALESI 1992), without the use of fertilizers. Results of the soil chemical analysis and physical characteristics are shown in Table 4.

Table 4: Average of some soil characteristics from 5 places of the Bragantina region. Adapted from DENICH (1989)

Soil Characteristics	Depth (cm)	
	0-10	10-30
Sand (%)	86	82
Clay (%)	14	18
pH (water, 2:1)	5.1	5.0
P (mg kg^{-1})	2.0	2.0
K ($cmol^{+}$ kg^{-1})	0.03	0.03
Ca ($cmol^{+}$ kg^{-1})	0.82	0.33
Mg ($cmol^{+}$ kg^{-1})	0.18	0.09
CEC pH 7 ($cmol^{+}$ kg^{-1})	3.59	3.31
Saturation Al (%)	37.6	60.2

3.1.4 Vegetation

The original vegetation of the Bragantina region is evergreen rainforest that occurs in the uplands (terra-firme) and on inundated land (várzea and igapó) (VIEIRA, 1971; PIRES and PRANCE, 1985). With rare exceptions, the original forest does not exist any more (SALOMÃO *et al.*, 1996). Nowadays, as a result of slash-and-burn agriculture practiced during the last 100 years, the Bragantina landscape is a mosaic of fallow vegetation of different ages and agricultural fields.

From 1984 to 1991 the dense forest area decreased from 10% to 5% of the municipal district area. In the same period, an increase from 20% to 32% in area of "initial fallow vegetation" was observed while the "intermediary fallow vegetation" area increased from to 24% to 31% (WATRIN, 1994).

The fallow vegetation or "capoeira" is a natural regeneration that develops after the land is cleared for crop cultivation and then abandoned. In the municipality of Igarapé-açu the fallow vegetation is generally not over 4-7 years old. Floristic composition and species diversity of fallow vegetation are functions of fallow age and land-use intensity (DANTAS, 1989; DENICH, 1989; BAAR, 1997).

3.1.5 Agricultural Production System

The agricultural history of the Amazon region is based on the heritage of the indigenous people (FLOHRSCHÜTZ and KITAMURA, 1986), which involve slash-and-burn for the cultivation of cassava, mainly consumed in the form of meal (ALBUQUERQUE and CARDOSO, 1980). The first agricultural colonization in the Brazilian Amazon region developed in the Bragantina region in the beginning of the twentieth century. Initially, the government provided incentives for rubber exploitation and handed out land. Later it constructed the railway Belém - Bragança. Thus, a big and accessible agricultural market to supply Belém was created and this region was quickly populated by foreign immigrants and Brazilian migrants. But, due to many reasons (NISHIZAWA and UITTO, 1995; SILVA *et al.*, 1998) the colonization projects were not successful. Without capital and with the use of only rudimentary technology based on land rotation, the migrants kept to slash-and-burn agriculture and subsistence production systems. Land rotation is characterized by the slashing and burning of the primary forest for crop planting for one to two years followed by a long fallow period. This practice was the best way to release nutrients and control weeds (SALOMÃO *et al.*, 1996; SILVA *et al.*, 1998).

Today the area remains essentially agricultural and the original practices with extensive and itinerant characteristics are generally still maintained. The economy is based on food and cash crops (Table 5). Cassava still plays an important role for the farmers' economy, mainly because this crop has various advantages. Cassava grows on poor and acid soils without the requirement of fertilization, and the harvest time can be extended throughout the year, i.e. the crop can be stored in the field until it is needed, or until the time it will be sold (KITAMURA *et al.*, 1983). To the small landholders this crop functions as a "savings account".

Table 5: General Characteristics of Igarapé-açu Agriculture

Period	Main Crops	Average Production (kg ha^{-1})	Historical Characteristics
1895 to 1940	Cotton	750	Cotton, rice and cassava represented the main cash crops for most of the farmers, although beans and maize were also planted. The production system was slash-and-burn based on the natural soil fertility
	Maize	1320	
	Rice	2600	
	Beans	1560	
	Cassava meal	6000	
1940 to 1964	Cotton	600	Cotton and cassava still represented the main cash crop for most of the farmers. Rice was produced for self consumption due to the loss of natural soil fertility. The same argument could probably be applied to maize and beans. The slash-and-burn production system is still based on the natural soil fertility
	Cassava meal	4750	
After 1964	Cotton	600	The agricultural production system continues to be based on maize, rice, beans and cassava. Using slash-and-burn technique and stressed by land pressure the productivity is low. New cash crops are introduced but as they require high input they are restricted to income of capital.
	Maize	600	
	Rice	720	
	Beans	600	
	Cassava meal	3000	

Adapted from SILVA *et al.*, (1998)

A recent field survey carried out in the municipality of Igarapé-açu by SILVA *et al.*, (1998) showed its current agrarian reality. The farmers were divided in 4 categories: micro farmers (38%); small farmers (56%); medium farmers (4%)

and big farmers (2%). The micro farmers with less than 25 ha practice agriculture for subsistence and extractivism. The labor is provided by family members, the production is basically for self-consumption and an eventual surplus is sold. When the income is insufficient for the subsistence of the family, income generation from off-farm activities can quite commonly be *observed. The small farmers*, whose properties are between 25 and 100 ha, have more diversified land use (agriculture, agroforestry, and pasture) and the labor used in the property is provided by family members. The medium and big farmers, whose properties range from 100 to 300 ha and more than 300 ha, respectively, practice an agriculture based on high input and technology. For micro and small farmers the home garden, or "quintal caseiro", is - due to the diversity of species - an important food supply for the family the year round, and also serves a source of alternative income when the surplus is sold.

Since questions of global warming, increased pressure on natural forestry, excessive use of fire for land preparation, and the growth of regional demand for food are gaining in importance, studies on more efficient agricultural production systems are necessary.

3.2 Description of Experimental Site

For the present study a representative micro farm property of traditional slash-and-burn agriculture was chosen. The area had been cultivated at least for the last 20 years. To avoid soil and fallow vegetation heterogeneity caused by different land use as much as possible, a piece of land which was homogeneously cropped has been selected. For the experimental area, 1.5 hectare of a 4-year-old fallow vegetation was chosen. The crop sequence previously need by farmers was cowpea plus cassava. For the initial characterization, the experimental area was divided into 5 parts in one direction. In each part, 3 transects of 10 m x 1 m were located. The main parameters evaluated in the 15 plots are discussed below.

3.2.1 Biodiversity of Fallow Vegetation

An inventory of all plants in the 15 transects registered 20 different species and a total of 594 individuals. The most frequent species were *Lacistema pubescens* Mart. (19.9%), *Derris spruceanus* Benth. (15.3%), *Myrcia sylvatica* (G. F W. Meyer) D. C. (12.6%), and *Myrcia bracteata* (L.C. Rich.) D. C. (11.3%) (Table 6).

Table 6: Species of natural fallow vegetation (4-5-years-old) found in the experimental site

Species	Family
Abarema cochleata (Willd.) Barneby et Grimes	Mimosaceae
Alibertia myrciifolia K. Schum.	Rubiaceae
Annona montana Macfad.	Annonaceae
Banara guianensis Aubl.	Flacourtiaceae
Bauhinia macrostachya var.tenuifolia Ducke	Caesalpiniaceae
Bernardinia fluminensis var. Villosa (Gardner) Planch.	Connaraceae
Casearia arborea (L.C.Rich.)Urb.	Flacourtiaceae
Casearia grandiflora Camb.	Flacourtiaceae
Casearia javitensis H.B.K.	Flacourtiaceae
Cassia hoffmannseggii Marth. Ex Benth.	Caesalpiniaceae
Cecropia palmata Willd.	Cecropiaceae
Coccoloba sp.	Polygonaceae
Combretum rotundifolium L.C.Rich.	Combretaceae
Connarus perrottetii var. angustifolius (D.C.)Planch.	Connaraceae
Cordia multispicata Cham.	Boraginaceae
Cordia nodosa Lam.	Boraginaceae
Cupania c.f. scrobiculata L.C.Rich	Sapindaceae
Cupania diphylla Vahl	Sapindaceae
Dalbergia monetarea	Fabaceae
Dalbergia subcymosa Ducke	Fabaceae
Davilla kunthii St.Hil.	Dilleniaceae
Davilla rugosa Poir.	Dilleniaceae
Derris spruceanus Benth.	Fabaceae
Dichapetalum rugosum (Vahl) Prance	Dichapetalaceae
Doliocarpus brevipedicellatus Garcke	Dilleniaceae
Eschweilera ovata (Cambess.) Miers.	Lecythidaceae
Eupatorium odoratum L.	Asteraceae
Himatanthus sucuuba (Spruce ex Muell.Arg.) Woodson	Apocynaceae
Hymenaea parviflora Huber	Caesalpiniaceae
Inga c.f. gracilifolia Ducke	Mimosaceae
Inga heterophylla Willd.	Mimosaceae
Lacistema imatantus	Lacistemataceae
Lacistema pubescens Mart.	Lacistemataceae
Lantana camara L.	Verbenaceae

Lecythis lurida (Miers.)Mori	Lecythidaceae
Machaerium c.f. froesii Rudd.	Leguminosae
Machaerium inundatum	Leguminosae
Machaerium madeirense Pittier	Leguminosae
Machaerium quinata (Aubl.) Sandw.	Leguminosae
Maquira guianensis Aubl.	Moraceae
Matayba c.f. guianensis Aubl.	Sapindaceae
Neea cf. oppositifolia Ruiz & Pav.	Nyctaginaceae
Memora allamandiflora Bur.& K.Schum.	Bignoniaceae
Memora flavida (D.C.) Bur.& K.Schum.	Bignoniaceae
Memora magnifica (Mart. Ex D.C.) Bur.	Bignoniaceae
Miconia eriodonta var. oblongifolia D.C. var. D.C.	Melastomataceae
Miconia minutiflora (Bonpl.) D.C.	Melastomataceae
Myrcia bracteata (L.C. Rich.) D.C.	Myrtaceae
Myrcia cuprea (Berg.) Kiaerk.	Myrtaceae
Myrcia sylvatica (G.F.W. Meyer) D.C.	Myrtaceae
Myrciaria tenella (D.C.) Berg	Myrtaceae
Myrciaria floribunda (West.ex Willd.) Berg	Myrtaceae
Ocotea guianensis Aubl.	Lauraceae
Pavonia malacophylla Britton.	Malvaceae
Pogonophora schomburgkiana Miers. ex Benth.	Euphorbiaceae
Rollinia exsucca (D.C. ex Dunal) A.D.C.	Annonaceae
Rourea c.f. ligulata Baker	Connaraceae
Serjania paucidentata D.C.	Sapindaceae
Simaba cedron (Planch.) Baill.	Simaroubaceae
Solanum caavurana Vell.	Solanaceae
Strychnos pirifolium	Strychnaceae
Swartzia arborescens (Aubl.) Pittier	Fabaceae
Tabernaemontana angulata Mart.	Apocynaceae
Talisia retusa Cowan	Sapindaceae
Tapirira guianensis Aubl.	Anacardiaceae
Terminalia amazonia (J.F. Gmel.) Exell	Combretaceae
Virola calophylla Spr. ex Warb.	Myristicaceae
Vismia guianensis (Aubl.) Choisy	Guttiferae
Vitex triflora Vahl	Verbenaceae
Wulffia baccata (L.F.) O.Kuntze	Asteraceae

3.2.2 Aboveground and Litter Biomass of Fallow Vegetation

In the above mentioned 15 plots (10 m^2) the aboveground biomass was cut and measured. The plants were separated into leaves and stems. The fresh weight of each tissue was taken and sub-samples for dry weight measurement were made. The accumulated litter on the forest floor of all 15 plots was estimated through one sample per plot with the size of 40 cm x 40 cm. All samples for biomass and litter were dried at 60^0C temperature until constant weight were achieved. Then the dry weights were converted into tons per hectare. The results are shown in Table 7

Table 7: Biomass average and standard errors (SE) of original 4-year-old fallow vegetation (n = 15)

Biomass (t ha^{-1})			Total
Leaves	Stem	Litter	
4.5 ± 0.3	16.4 ± 1.8	10.8 ± 0.7	31.7 ± 2.0

3.2.3 Soil Characteristics of Fallow Vegetation

The soil of the experimental area was classified as Entisol, well drained, deep and with plastic clay. The soil horizons characterization are presented in Table 8.

Table 8: Soil description of the experimental area (FALESI, I.C. personal communication)

Horizon	Description
Oo (2-0 cm)	Dried leaves, fragments of branches, decomposed and non-decomposed roots
Ap (Ap) (0-7 cm)	Dark brown, gray (10 YR 3/3 kneaded whitish); sand, detached, not plastic and not clammy, plan and diffuse transition, lots of small pores, charcoal fragments
AB (A_3) (7-15 cm)	Dark brown (10 YR 5/2 kneaded whitish), sand, detached, not plastic and not clammy, plan and diffuse transition, lots of small pores and channels
BA (B_1) (15-29 cm)	Brown gray (10 YR 5/2), sand, weak, very small and small sub-angular blocks, soft, detached, not clammy, not plastic, plan and diffuse transition, common pores and few channels
B_{w1} (B_{21}) (29-61 cm)	Brown yellow (10 YR 5/8), sand franc, small/median and weak, median sub-angular blocks, free, very fragile, not plastic and not clammy, plan and diffuse transition, lot of small pores and few channels
B_{w2} (B_{22}) (61-96 cm)	Brownish yellow (10 YR 6/8), sand franc, weak, very small and small blocks sub-angular, soft, very fragile, not plastic, not clammy, plan and diffuse transition, lot of small pores and channels
B_{w3} (B_{23}) (96-150 cm)	Brownish yellow (10 YR 6/6), sand franc, heavy, very small and small blocks sub-angular, soft, very fragile, not plastic, not clammy, small pores and few channels

Ten single soil samples were taken to compose one sample for soil fertility analysis in each of the 15 transects and each of then follows 0-5 cm; 5-10 cm; 10-20 cm; 20-30 cm and 30-50 cm. The results are shown in Table 9.

Table 9: Soil chemical characteristics before the start of the experiment (n=15)

Soil Characteristics	Depth (cm)				
	0-5	5-10	10-20	20-30	30-50
Density (g cm^{-3})	1.3	1.3	1.4	1.4	1.5
pH (water 1:2.5)	5.6	5.4	5.2	5.2	5.2
P (mg kg^{-1}) ①	7.0	3.8	2.3	1.0	1.0
K ($cmol^{+}$ kg^{-1}) ①	36.8	25.0	20.5	15.5	13.5
Na ($cmol^{+}$ kg^{-1}) ①	18.5	16.5	13.5	9.8	8.3
Ca ($cmol^{+}$ kg^{-1}) ②	2.9	1.5	0.8	0.5	0.3
Al ($cmol^{+}$ kg^{-1}) ②	0.1	0.3	0.5	0.8	0.9

① Mehlich-1 (HCl + H_2SO_4) and ② 1 mol l^{-1} KCl extraction (GUIMARÃES *et al.*, 1970)

3.3 The Experimental Lay-out

To test the hypothesis that with enrichment plantings the fallow period may be shortened and the biomass accumulation of the fallow vegetation be improved, an experiment was laid out in a randomized complete block design with 4 replications. The treatments were composed of 5 leguminous tree species for enrichment, 3 spacings of planting, 1 control treatment without enrichment planting and 1 leguminous tree planted at only one density. The total number of experimental plots were 68 and the size of each plot was 10 m x 8 m (80 m^2) (Figure 3).

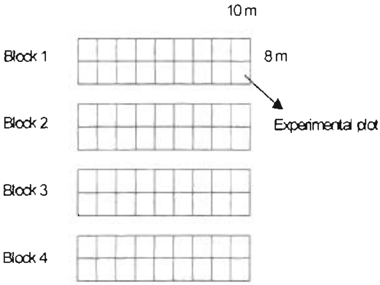


Figure 3: Experimental lay-out design

The characterization of the experimental area started in October of 1994. In November of 1994 the area was slashed. In December of 1994, after a short period for the drying of the vegetation, the whole area was burned. Following the burning, all unburned big trunks were removed from the area. This is a regular farming procedure for land preparation. The crop sequence was maize (*Zea mays*) followed by cassava (*Manihot esculenta*).

In January of 1995, the maize cultivar BR 106 was planted at 0.5 m x 0.5 m. At planting the chemical fertilizer applied was at 200 kg ha^{-1} of 10-28-20 (SOUZA and ARAÚJO, 1998). After 35 days, an additional 70 kg ha^{-1} of urea and 30 kg ha^{-1} of KCl were applied. Maize was harvested in May of 1995.

In February of 1995, the cassava cultivar "olho verde" was planted at a spacing of 1.0 m x 1.0 m and in February of 1996 it was harvested. Among 5 or 6 different varieties of cassava used by the farmer, the cultivar "olho verde" was chosen because this variety has a low number of bifurcation branches. The resulting erect growth form was preferred to minimize as much as possible the early shade provided by the cassava to the leguminous trees, which were planted between the cassava following maize harvest.

The following leguminous tree species were chosen: *Acacia angustissima* Kuntze (ligeirinha), *Clitoria racemosa* G. Don (palheteira), *Inga edulis* Mart. (ingá), *Acacia mangium* Willd. (acacia), *Sclerolobium paniculatum* (taxi-branco) and *Erythrina poeppigiana* (eritrina). The process of species selection took the following parameters into consideration: a) adaptation to adverse environments, b) availability of seeds, c) production and quality of litter, d) N fixation and e) fast growth.

The nursery to produce the tree seedlings was installed at the "Fazenda Escola of Igarapé-açu" of the "Faculdade de Ciências Agrárias do Pará – FCAP" All seedlings were produced in plastic bags. First, the dormancy of *A. angustissima and A. mangium* was broken through scarification of seeds. Then the seeds were placed directly in plastic bags. The total time to produce seedlings was generally 3 to 4 months. The seedlings were selected based on their vigor before planting. At that time the selected seedlings had a height of 20-30 cm.

The leguminous trees were planted at densities of 10000, 5000 and 2500 plants per hectare or spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, respectively, with the exception of *S. paniculatum* which was planted only in 2 m x 1 m. Tree spacing was arranged to maintain the usual number of cassava plants per hectare. After harvesting of maize (June of 1995) the trees were planted. Trees and cassava grew together for 8 months until the cassava harvest in February of 1996. The last cassava weeding was done between October and November 1995. After this time, the fallow vegetation started to grow as an enriched fallow. The experiment was extended until November of 1997 when the whole area was cut.

3.4 Characteristics of the Leguminous Trees

The leguminous trees used in this study are not so well known, with the exception of *Acacia mangium* and *S. paniculatum* for which more information is available. These leguminous trees have been studied by forestry researcher groups at Embrapa-Amazônia Oriental and others.

3.4.1 *Acacia angustissima* Kuntze (Ligeirinha)

This leguminous species is a Mimosaceae. Geographically it occurs from the South of the United States to Panama and the northern part of South America. It is found in altitudes up to 2700 m above sea level and tolerates acid soils (MCQUEEN, 1993 cited by DZOWELA, 1994).

A. angustissima reacts well to many prunings, and produces plenty of material that can be used for animal feeding or for mulch. It flowers strongly and the seeds produced can eventually be used to make a type of brown coffee (DZOWELA, 1994). Indigenous people from Mexico eat its cooked green pods. *A. angustissima* is an excellent melliferous species because its abundant flowers are appreciated by bees (ANONYMOUS, p. 557).

An agroforestry research project in Harare, Zimbabwe showed that *A. angustissima* leaves have a larger amount of N than *Sesbania sesban, S. macrantha, Cajanus cajans, Gliricidia sepium, Calliandra calothyrsus* and *Flemingia macrophylla*. However, its leaves contain a great amount of condensed tannin, which indicates a slow N liberation during leaf decomposition. Thus, *A. angustissima* can not be used as a good immediate source of N, but it represents a potential N liberation rate that can benefit subsequent cultivation (DZOWELA, 1994).

3.4.2 *Clitoria racemosa* G. Don (Palheteira)

Data about silviculture of this Mimosaceae do not exist. During the expansion of cacao plantations in the Amazon region, this species was used to shade the agricultural crop. Its use as a shading tree began to be discouraged when the appearance of a caterpillar that defoliated the whole plant, became frequent. The seeds of this species do not have dormancy and they can be handled easily. BURGER and BRASIL (1986) suggested the use of *C. racemosa* in alley cropping systems for biomass production.

The seed of *C. racemosa* contain an oil that is similar to olive oil with vitamin A and D and with a good flavor. All *Clitoria* species it might be used as medicine but is not well studied (FIDALGO, 1956).

3.4.3 *Inga edulis* Mart. (Ingá)

This species is a Mimosaceae and is native in the Amazon region of Brazil. It is widely used in home gardens because its fruits can be used for feeding the family and may be sold in case of surplus.

Besides the supply of N through symbiotic N fixation, *I. edulis* produces a lot of leaves and branches that can be used for covering the soil. BURGER and BRASIL (1986) and SMYTH (1993) reported the use of this species in alley cropping systems for biomass production in Igarapé-açu and Capitão Poço, respectively.

In an agroforestry system studied by MARQUES *et al.* (1993) the second tree pruning (leaves and branches) of 5-year-old plants produced 40 kg of dry matter per plant (BRIENZA JÚNIOR and MARQUES, unpublished data). Considering the nutrient concentration of 1.77% (N), 0.09% (P) and 0.53% (K), given by SMYTH (1993), this amount of biomass represents an potential output per plant of 710 g of N, 36 g of P and 210 g of K.

3.4.4 *Sclerolobium paniculatum* Vogel (Taxi-branco)

Sclerolobium paniculatum is an arboreal species of Caesalpiniaceae, and has four varieties: paniculatum, subvelutinum, rubinosum and peruvianum. The

States of Pará and Amazonas in Brazil are the main regions where the paniculatum variety can be found (PEREIRA, 1990).

Phenology observations in Trombetas National Forest indicate that flowering occurs between May and July and fruit production from August until November (MINERAÇÃO RIO DO NORTE, manuscript). In the Santarém region, near Tapajós National Forest, mature fruits and seeds dissemination occur from October to December (LEÃO, N.V.M. personal communication). The reproductive biology of taxi-branco was well studied by VENTURIERI *et al.* (submitted).

The seeds of taxi-branco are small and hard. About 15,000 seeds per kilo could be observed (MINERAÇÃO RIO DO NORTE, manuscript). The mechanical dormancy of seeds can be overcome by the application of adequate technologies (CARPANEZZI *et al.*, 1983; CARVALHO and FIGUEIREDO, 1991) so that the germination occurs in approximately 30 days.

The time required to produce seedlings varies from 120 to 180 days, depending on the climatic conditions, soil characteristics and the presence or absence of N fixing bacteria. In the greenhouse, taxi-branco did not respond to the application of Ca and S. The critical soil levels for the following nutrients were 26 mg P kg^{-1}, 27 mg K kg^{-1}, 5 mg S kg^{-1} and 74 mg Ca kg^{-1}. The critical leaf levels for N, P and K were 2.2, 0.12 and 0.7%, respectively (DIAS *et al.*, 1991, DIAS *et al.*, 1992a and 1992b).

The taxi-branco trees in homogenous plantations present an architecture similar to eucalyptus plantations. The adult trees found near Santarém, have heights varying from 20 to 30 m and diameter at breast height of 70 to 100 cm. In secondary succession it occupies open spaces and is characterized as a light demanding species with a great capacity for adaptation to unfavorable soil conditions (CARPANEZZI *et al.*, 1983; ERFURTH and RUSCHE, 1976; LEMEÉ, 1956; DUCKE, 1949; CORREA, 1931).

In field experimentation, taxi-branco has shown good silvicultural performance compared to other species considered to be pioneers in secondary succession (YARED *et al.*, 1988; MATOS, 1993). Taxi-branco has shown its potential for the reclamation of degraded land in an experiment in an abandoned pasture in Paragominas (PEREIRA and UHL, in press). This behavior can be explained by its capacity to fix N (CARPANEZZI *et al.*, 1983) and its association with endomycorrhizal fungi (OLIVEIRA JÚNIOR *et al.*, 1994).

The wood of taxi produces charcoal with characteristics comparable to the species traditionally used for fuel needs in Brazil (TOMASELLI *et al.*, 1983; VALE *et al.*, 1996).

3.4.5 *Acacia mangium* Willd. (Acácia)

Acacia mangium is a leguminous tree from the family Mimosaceae. It naturally occurs in the Southwest of New Guinea, in the Molucas Island (Eastern Indonesia) and the Northeast of Australia. Adult trees show heights ranging from 25 m to 30 m and diameter at breast height of 90 cm. *Acacia mangium* generally has an erect stem and the ramifications start above half of the total height. The canopy has globular form under plantation competition or conical in smaller spacing (UNITED STATES NATIONAL RESEARCH COUNCIL, 1983; LATIF *et al.*, 1985).

In the places of origin of *A. mangium*, the annual precipitation can vary between 1500 to 4500 mm. The maximum temperature ranges between 32^0C to 34^0C the minimum temperatures from 12^0C to 16^0C. This species is normally adapted to soils of low fertility and to acid soils (SALAZAR, 1989).

The seeds of A. mangium have dormancy that can be overcome by immersing the seeds in boiling water for 30 seconds and leaving them immersed in the cool water during 18 hours (BOWEN and EUSEBIO, 1981 cited by ADJERS and SRIVASTAVA, 1993).

Seedlings reacted positively to P addition and no to K, Ca and Mg applied to soil. The lack of a Ca and Mg response was due to the 60 mg S kg^{-1} added as gypsum (0.37 mg Ca 100 cm^{-3}) which was enough for plant needs. In greenhouse experiments, the critical soil level was 5 mg K kg^{-1} and 110 mg P kg^{-1} In seedlings, the leaves critical levels were 0.45% P, 0.40% K, 0.69% Ca and 0.34% Mg (DIAS *et al.*, 1991). This suggest that *A. mangium* supports low soil fertility.

Acacia mangium fixes N through *Rhizobium* bacteria and in the root system the following mycorrhiza fungi have been found: *Gigaspora margarita, Glomus etunicatum, Scutellispora calospora* and *Thelephora ramarioides* (UNITED STATES NATIONAL RESEARCH COUNCIL, 1983; CRUZ and YANTASATH, 1993).

Experimental plots of *A. mangium* showed a great silvicultural potential (YARED *et al.*, 1988; YARED *et al.*, 1990; FERREIRA *et al.*, 1990). In Belterra, State of Pará, good growth was observed but some plant mortality was associated with fungus of the genus *Botryodiplodia*. For *A. mangium* a larger spacing is recommended to avoid precocious competition among plants and consequently, higher plant mortality rates (FERREIRA *et al.*, 1990).

The wood of *A. mangium* shows a good potential for charcoal production. Its characteristics are comparable to *Eucalyptus grandis*, a species traditionally used in siderurgy and metallurgy industries in Brazil (LELLES *et al.*, 1996).

The use of adequate inoculation of *Rhizobium* and mycorrhizal fungi can increase the initial growth of seedlings in marginal areas and could economically substitute fertilizer applications (CRUZ and YANTASATH, 1993).

3.5 The Measurements Carried Out

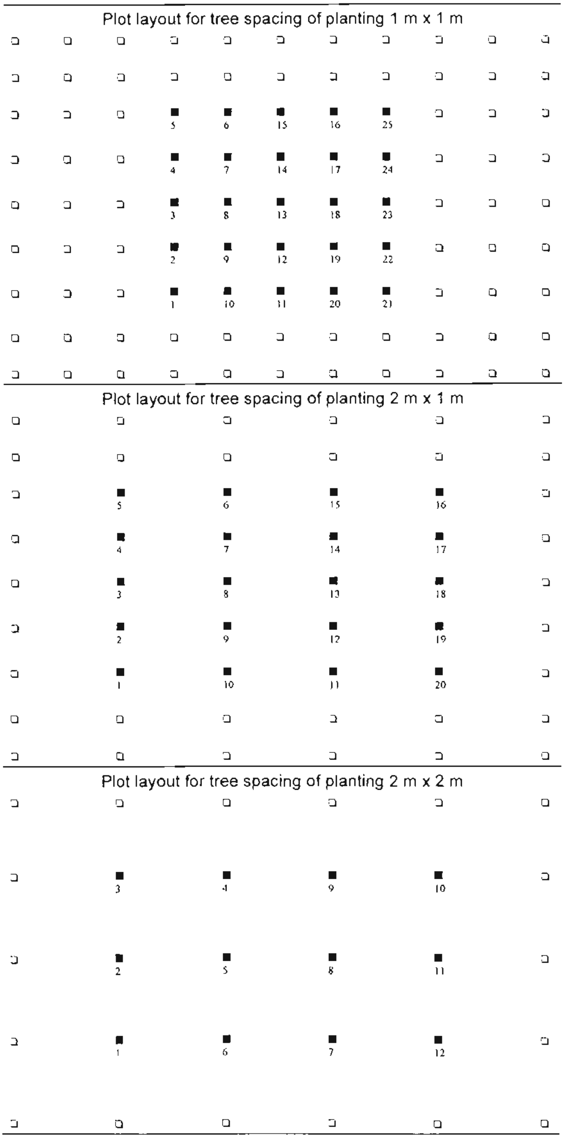
3.5.1 Crops

The maize was harvested from plots of 10 m^2, randomized distributed in each experimental plot. Fresh samples of grain, cob, husk were taken for dry matter estimations after drying to constant weight at 60^0C. Dry weight data were transformed to hectare equivalent.

The cassava yields were measured in completely randomized, 12 m^2 sub-plots in all 52 studied plots. The total fresh weight of leaves, stems and tuber were taken and then, using sub-samples the dry weight was determined.

3.5.2 Tree Height, Diameter at Breast Height (Dbh) and Volume Index

The number of measured trees was a function of plant density. In each experimental plot of 80 m^2, 25, 20 and 12 trees in spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, respectively, were selected, numbered and marked to follow the trees growth. To avoid border effects only the central trees were measured (Figure 4). Using a measuring stick, the tree height was measured every 2 months up to 12 months of age and again after 18 and 24 months. The diameter at breast height at 1.3 m (Dbh) was taken only when the trees had a diameter of at least 1 cm.



Plot layout for tree spacing of planting 1 m x 1 m

Plot layout for tree spacing of planting 2 m x 1 m

Plot layout for tree spacing of planting 2 m x 2 m

Figure 4: Plot design as a function of trees planting density. Numbers are identifying trees which were evaluated during the experiment

At the end of the experiment the wood volume per plot was determined as follows: after determination of the fresh weight of accumulated biomass, the trunks and branches were placed inside a known water volume. The displaced water volume was measured and transformed to per hectare basis (volume index m^3 ha^{-1}) for each species and treatment.

3.5.3 Aboveground Biomass

The total aboveground biomass of all experimental plots was evaluated using an area of 4 m x 3 m (12 m^2) at the end of the experiment. The biomass was subdivided into spontaneous fallow vegetation material and planted leguminous trees.

The fallow vegetation biomass was divided into leaves and stems. The total fresh weight was determined for each class and sub-samples were taken for the determination of the dry weight. The biomass of the leguminous trees was divided into leaves, branches and trunks. The 12 m^2 plots had a different number of trees with 12, 6 and 3 trees in a spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, respectively. Total fresh weight was obtained for each plant component and sub-samples for dry weight determination were taken separately from each tree species and the compartments of the fallow vegetation. All fresh sub-samples were dried at 60^0C temperature until constant weight. Then the dry weights were converted into tons per hectare.

3.5.4 Root Biomass and Growth

The accumulated root biomass in the enriched fallow vegetation was appraised during a 12-months period. The study included the depths of 0-15 cm and 15-30 cm. To evaluate the root growth, bags of plastic net with 1 mm mesh size were used as in-growth bags. The in-growth bags were filled with the soil taken from the two previously chosen depths. The soil was air dried and coarsely sieved. After being filled with 1.4 kg of soil, the in-growth bags had approximately 15 cm (height) x 12 cm (diameter) or a volume of ≈1700 cm^3 In each plot, a total of 8 holes were dug for the placement of two in-growth bags at the two depths. The in-growth bags were placed in April of 1996, in the middle of the rainy season. The first in-growth bags collection was after 4 months and the last collection after 12 months. The first collection coincided with the end of the rainy period and the last collection was in April of 1997, in the middle of the next rainy season. Each time, 4 samples were collected from both depth yielding a total of 8 in-growth bags.

When the in-growth bags were put into the ground (April of 1996) and at the first and the second in-growth bags collections, soil cores were taken simultaneously using an auger to estimate the root biomass. The auger had cylindrical rings of 100 cm^3 The soil cores were taken from 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm depth, at four randomly chosen points in each plot. The samples of the same depth in a plot were pooled and homogenized.

Both, soil samples for root extraction and in-growth bags, were stored at 4^0C until analysis. The roots were extracted and sorted by washing with tap water above a sieve column with from 10 mm to 0.5 mm mesh size and hand sorting under 10 x magnification when necessary. Root biomass was obtained after the samples been dried and weighed.

3.5.5 Carbon Analysis

The soil and tissue carbon analysis were done through dry digestion at the Centro de Energia Nuclear na Agricultura - CENA. The equipment used was a LECO CR 412 Carbon Analyzer

3.5.6 Litterfall

The litterfall was studied from April 1996 to April 1997 Two litter traps of 50 cm x 50 cm x 10 cm were distributed in each experimental plot at random. After every 30 days the litterfall was collected and separated into natural fallow vegetation and planted leguminous tree. Then, each sample was separated into leaves and other material. Biomass was determined after the samples had been dried and weighed.

At the beginning and at the end of the litterfall studies, two litter samples from the soil surface were taken in each plot. Samples were separated as litterfall according to the procedure described above and than dried and weighed.

3.6 Statistical Analysis

The data of the different parameters studied were subjected to analysis of variance (ANOVA) using STATISTICA (1998) and SYSTAT (1994) statistical packages. To obtain normal distribution, the data of tree survival were transformed to Arc Sin and then analyzed. The evaluation of treatments was done using a two-away ANOVA considering a complete factorial model (trees species, spacing of planting and the interactions). Then, the treatment control was compared against species, independent of density and density regardless species. LSD test was used to compare means in appropriate cases.

4. Results and Discussion

4.1 Crop production

The natural question when enriching fallow vegetation, modifying the traditional agricultural system, that arises is: is it possible to modify the traditional cropping systems by introducing leguminous trees and with a positive or neutral impact on crop productivity ?

The answer to this question depends on cultural, socioeconomic, and technological variables. "New alternatives" can not be too "distant" to be manageable and used. First, the present study identified the cropping system to be used in consultation with farming partner and the maize - cassava system was chosen. The introduction of leguminous trees as a new component was planned so as to cause no decrease of area planted with crops, minimizing as much as possible the impact on crop production practices. A locally adapted maize cultivar was opted for and the selection of cassava was done with the farmer's participation. Among the many types of cassava used, one was chosen with erect architecture that minimizes light impact on leguminous trees planted for fallow enrichment. Regular spacing in lines was used for crop planting.

4.1.1 Maize

The maize BR 106 remained in the cropping system during the first four months. Thus, its cultivation can be considered monocropping. Production of grain, cob, husk and total are presented in Table 10.

Table 10: Average, standard errors (SE) and coefficient of variation (CV) of maize dry matter of grains, cob, husk and total

	Yield (kg ha^{-1})			
	Grain	Cob	Husk	Total
Average (n=68)	1890	360	440	2690
SE	32	5	8	43
CV (%)	17	15	18	16

Yield average of maize grains in the Bragantina region is 620 kg ha^{-1} and for the State of Pará 1380 kg ha^{-1} (IBGE, 1996; production averages from 1990 to 1995). The following comments may be made regarding the observed higher experimental values compared to the Bragantina region:

a) the experiment was installed according to traditional methods using slash-and-burn. Under this situation a great amount of existing stubs make movement and planting of crops difficult. Nevertheless, line planting in the experimental plots was adopted. Farmers usually randomize space occupation and consequently, the total number of plants per hectare can be different (smaller), when compared to plantation ordered in lines;

b) in the region studied, the farmers cultivate the local maize cultivar "pontinha" and often, seeds are stored to be planted the next year This custom has negative consequences, because it causes seed deterioration, with a reduction in productivity. Also, one could comment the great yield potential of BR 106 compared to local cultivar;

c) the experiment had appropriate maize seed and fertilizer addition followed by a sufficient amount of weeding. Those factors contributed to good harvest, but use of such inputs are not always possible in smallholder's conditions; and

d) the results show that the experimental area was homogeneous.

Different studies have been done in tropical and subtropical countries promoting the improvement of fallow vegetation. The difference between these studies compared to the present study, is that fallow vegetation is homogeneous, and composed only of species planted for enrichment. The biomass produced by fallow vegetation is used for incorporation in the soil, animal feed or as energy source (SLAATS, 1997; MAFONGOYA and DZOWELA, 1997; MAGHEMBE *et al.*, 1997; COBBINA, 1997; OTSYNA *et al.*, 1997).

Based on the results of the present study, one may conclude that maize productivity can be improved, if genetically improved cultivars and appropriate agricultural practices are applied.

4.1.2 Cassava

... "on my farmed area ("roça") I always have cassava ready to harvest, so I can make meal at any time"... This testimony shows the cultural importance of cassava to the smallholder's life, either to feed his family with the meal, or as a source of income when surpluses are sold. In Capim river community, near Paragominas-PA, a municipality 200 km from the studied area, MATTOS, M.M. (personal communication) reported that each family sells 87% of the produced meal and the remainder is used for family consumption. During meal production, the by-products generated are used to feed animals. Thus, with the introduction of leguminous trees there was a concern of cassava production loss. Different spacings were tested to assess the possible interference of the trees with cassava development.

The cassava crop was planted in February 1995 without fertilized, after maize had already been planted one month earlier In June 1995 the leguminous trees were planted to enrich the fallow vegetation. Thus, cassava and the trees grew in association during 8 months, until cassava harvest after 12 months.

The parameters measured of cassava were fresh and dry weight of tuber The ANOVA for those two parameters, using a complete factorial model (blocks, leguminous trees, and planting densities) showed no significant differences among species nor a significant interaction species x spacing. A significant effect was observed only for planting density ($F_{1303097\ 80}=9.13$; $p<0.0001$ for dry yield and $F_{9912668.35}=9.13$; $p<0.01$ for fresh yield).

The different trees planted for enrichment, regardless of the spacing, did not have a negative impact on dry tuber yield. The highest tuber dry weight (7120 kg ha^{-1}) was obtained in a system enriched with *S. paniculatum*, and the lowest (6100 kg ha^{-1}) with *C. racemosa* (Table 11). Although statistical differences have not been observed among planted trees and between planted trees and the control (6060 kg ha^{-1}), all observed dry yields for enriched systems were larger than the control. Thus, planted leguminous tree used for fallow vegetation enrichment did not interfere negatively on production of dry weight of cassava tuber and consequently, on the farmer's meal production.

Table 11· Averages, standard errors and coefficient of variation (CV) of tuber dry weight of cassava obtained in a mixed cropping with planted leguminous trees for fallow vegetation enrichment at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m and the control

Enriched System	n	Tuber Dry Weight (kg ha^{-1})	Standard Error	CV (%)
S. paniculatum	5	7120	730	23
A. angustissima	15	6750	350	20
I. edulis	15	6560	290	17
A. mangium	15	6320	350	22
C. racemosa	15	6100	290	19
Control	5	6060	780	29
LSD ($p<0.1$)		1408		

In the agricultural production system chosen (maize-cassava), trees were planted for enrichment of fallow vegetation four months after cassava planting. This time difference desynchronizes the planting of cassava and trees and permitted cassava to establish itself well, thus apparently avoiding possible disadvantages relating to tree competition.

The analysis of tuber dry weight as a function of spacing, independent of leguminous tree species, is presented in Table 12. There was an increase in the dry weight of cassava tuber with decreasing number of planted trees per hectare. The lowest value of dry weight, observed at the spacing of 1 m x 1 m (5610 kg ha^{-1}), was statistically lower than that when trees were planted at the spacing of 2 m x 2 m (Table 12). The yields at the spacing of 2 m x 1 m and 2 m x 2 m were larger than the control, but were not statistically different (Table 12). With the spacing of 1 m x 1 m, the experimental plots have the equivalent of 10000 leguminous trees and 10000 cassava plants per hectare. This great concentration of plants resulted in greater competition for site resources and a decrease in tuber dry weight.

Table 12: Averages, standard errors and coefficient of variation (CV) of tuber dry weight of cassava obtained in a mixed cropping with *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum* planted to enriched the fallow vegetation at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, and control

Plant Spacing	n	Dry Tuber Weight (kg ha^{-1})	Standard Error	CV (%)
1 m x 1 m	20	5610	300	24
2 m x 1 m	25	6660	220	16
2 m x 2 m	20	7140	200	13
Control	5	6060	780	29
LSD (p<0.1)		1260		

The fresh tuber yield of cassava is important because it allows the farmer to estimate the amount of meal that can be produced. Fresh yields showed the same tendency as that of dry weight. The yields obtained as function of spacing of planting, regardless of trees planted and as a function of trees planted regardless of planting density are shown, respectively, in Tables 13 and 14.

Table 13: Averages, standard errors and coefficient of variation (CV) of fresh tuber yields of cassava in a mixed cropping with leguminous trees planted to enrich the fallow vegetation at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Enriched System	n	Tuber Fresh Weight (kg ha^{-1})	Standard Error	CV (%)
S. paniculatum	5	23920	1690	16
A. angustissima	15	22800	950	16
A. mangium	15	22290	880	15
I. edulis	15	21930	920	16
Control	5	21200	1510	16
C. racemosa	15	20890	740	14
LSD (p<0.1)		3560		

Table 14: Average, standard errors and coefficient of variation (CV) of fresh tuber yields of cassava in a mixed cropping with *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum* planted to enrich the fallow vegetation at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Plant Spacing	n	Tuber Fresh Weight (kg ha^{-1})	Standard Error	CV (%)
1 m x 1 m	20	20060	800	18
2 m x 1 m	25	22490	580	13
2 m x 2 m	20	23750	640	12
Control	5	21200	1510	16
LSD ($p<0.1$)		3250		

In the present study, fresh tuber yields of cassava were higher when compared to the averages of Bragantina region (9.5 t ha^{-1}) and the State of Pará (13 t ha^{-1}) (IBGE, 1996; averages of yields from 1990 to 1995). The possible reasons for that could be:

a) in the present study, adequate weeding was done at appropriate times, which is not always possible under smallholder's conditions;

b) the experiment was installed in a burned area with a large number of stumps. Even in this situation, the experiment was installed using in-line planting as much as possible. The randomized land planting done by farmers decreases the number of plants per hectare and consequently, reduces the yields per hectare; and

c) the cassava stems used for planting had been carefully selected and the residual fertilizer applied to the previous maize crop could be used by the cassava plants.

The results observed may also be compared with other studies done by different authors in the same area.

Another fallow enrichment experiment with *Acacia auriculiformis* gave similar results as observed in the present study. At equivalent planting densities of 10000 trees ha^{-1} and 2500 trees ha^{-1} and the control (without planted trees), the cassava yields were 22, 24 and 25 t ha^{-1}, respectively (DIEKMANN, U. unpublished data).

The dry matter of leaves, stems, and tubers, harvest index (total plant weight / tuber weight) and tuber fresh weight obtained in the present study are also comparable to those reported by KATO (1998b) in a cassava screening carried out in the same area. Different cassava species for slash-and-mulch agriculture and with and without fertilizer gave different values for tuber yields and harvest indices (Table 15).

Table 15: Dry matter of leaves, stems, tubers, harvest indices and fresh yields of different cassava species and without fertilizer

Cultivar of Cassava	Production of Dry Matter (t ha^{-1})				Harvest Index	Fresh Yield (t ha^{-1})
	Leaves	Stem	Tuber	Total		
Mameluca	1600	4700	8000	14200	0.56	25700 *
Milagrosa	1000	2700	6700	10400	0.65	21500 *
Pretinha	900	4000	6900	11800	0.58	23300 *
Aipim Rosa	800	3300	6400	10500	0.62	23200 *
Tapioqueira	1900	7200	4900	14100	0.35	16700 *
Olho Verde	700	2900	7900	11200	0.71	21200 **

* Source: KATO (1998a e 1998b)

** Source: present study

The results of dry and fresh weights of cassava tubers show that it is possible to maintain productivity of cassava in systems where fallow vegetation is enriched by planting leguminous trees, as long as tight spacing is avoided. Comparing the studied situation and the Bragantina region, cassava productivity can be doubled, if appropriate agricultural practices are used.

4.2 Silvicultural Aspects of Planted Trees

...."I do not believe that those different plants in the middle of my "roça" will grow"... These were the thoughts of Mr Raimundo during the installation of the experiment which he revealed in a conversation during the last days of the experiment.

4.2.1 Direct seeding

The option of direct seeding of trees during maize planting was discussed during the planning phase of this study. Direct seeding has certain advantages such as: a) easier planting compared to seedlings; b) there is no nursery cost; and c) seedlings are robust due to gradual rooting adaptation. Despite these advantages, this possibility was rejected because no knowledge was available on natural seed and seedling predators. It was necessary to guarantee a minimum field stand of plants in the present study, enough to enable the biomass effects to be studied.

Nevertheless, a direct-seeding pilot experiment was undertaken to gather further information on the behavior of the trees chosen in the field. The direct seeding was done in February of 1997 (rainy season). The species studied were: *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum*. All seeds presented germination capacity of more than 80%.

The evaluation at 150 days after direct seeding showed the following survival results: *A. angustissima* and *A. mangium* < 10%; *C. racemosa* and *S. paniculatum* 70% and *I. edulis* 90%.

During the development of the experiment, no seedlings were attacked by predators such as leaf-cutter ants. It is possible that the low survival rates of *A. angustissima* and *A. mangium* are due to seed size in association with planting during the more intense rainy period. The seeds of these species are small and the seeding was done at the depth of 2.5 cm. The soil was exposed during the experimental period, simulating the area to be planted with crops. Thus, it is possible that the small seeds were removed or exposed by the impact of rain water on the soil. The large seeds of *I. edulis* and *C. racemosa*, besides easy handling, are fast rooting which aids in efficiently fixing the seeds in place. *Sclerolobium paniculatum* with larger seeds than the two Acacias, but smaller than *I. edulis* and *C. racemosa*, has slower initial development, but develops a vigorous tap-root, also aiding in good soil fixation.

Acacia angustissima flowered profusely within the experimental plots one year after of planting (June of 1996). During the subsequent rainy period (January-June of 1997) natural regeneration of that species inside the experimental plots, and in the alleys separating plots was observed. This fact shows that species has a natural capacity to regenerate. However, as its seeds are small, it is necessary that they be protected against the impact of rain water.

In an enriched fallow vegetation experiment set up at the community of Rio Capim, Paragominas-PA, the leguminous trees *I. edulis* and *A. mangium* were planted by direct seeding. According to PEREIRA, C.A. (personal communication) the trees were satisfactory, and although direct seeding was done during the rainy season, the rainy period was not intense.

4.2.2 Survival of planted trees

The survival percentage of a species reflects its capacity to adapt to the environmental conditions where it is planted. Tree survival evaluation after two months of planting showed an accentuated mortality for *Erythrina poeppigiana*. Re-planting was done with the expectation of a possible recovery of this species. However, in the second evaluation at 4 months of age, practically 90% of the stand had not survived. For this species, part of the seedlings was obtained by direct seeding in plastic bags, and the rest was collected from natural regeneration, and transplanted into plastic bags. During field planting both types of seedlings were approximately 20 cm in height. The high mortality rate observed cannot be attributed only to the seedling type. In case that one seedling type was more appropriate than the other, at least some of the plants should have survived. In the same region, BURGER and BRASIL (1986) also observed similar behavior for seedlings of *E. poeppigiana* produced in plastic bags and with free roots.

Following the timetable of the present study, trees were planted in June/1995. A planting time was at the end of the rainy period and associated with the fact that 1995 was a particularly dry year, it can be argued that the negative behavior of *E. poeppigiana* might have been caused by low water availability.

The ANOVA of average survival rate evaluated at 24 months of age, considering the complete factorial model (blocks, leguminous trees and planting density; without *S. paniculatum* which was planted at one density only) showed differences among the leguminous trees ($F_{13\,46}=10.81$, $p<0.0001$), but a significant effect was not observed for plant density.

The survival percentage of the trees used for enrichment did not show dependence on spacing of the planting, even when a larger number of trees per hectare, with a spacing of 1 m x 1 m, was considered (Table 16).

Table 16: The average of survival (%) at 24 months of age presented by plant spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, regardless of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted to enrich the fallow vegetation

Plant Spacing	n	Survival (%)
1 m x 1 m	16	96 a
2 m x 1 m	16	96 a
2 m x 2 m	16	97 a

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

Excluding *E. poeppigiana* for reasons discussed previously, the survival percentage of planted trees species varied from 99% (*C. racemosa*) to 91% (*A. mangium*) (Table 17). All species studied had survival rates within standards set by commercial plantations. For example, in *Eucalyptus* sp. plantations at least 90% of survival is required (FAO, 1981). About 90% survival was also observed for *S. paniculatum*, which is still a commercially acceptable rate.

Table 17: The average rate of survival (%) at 24 months of age, of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted to enrich the fallow vegetation, regardless of spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Trees Species	n	Survival (%)
C. racemosa	12	99 a
A. angustissima	12	98 a
I. edulis	12	97 a
A. mangium	12	91 b

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

Three important phases in relation to the survival rate of planted species were identified during the experiment. The first phase is seedling production. Producing seedlings of good quality allows better chances of field adaptation to adverse conditions at the moment of planting. The second phase is the period when trees develop together with the cassava crop. During this phase, weeding activities must be carried out carefully so as not to cause any mechanical damage to the planted trees, particularly a problem when the trees used are unknown to the farmer The last phase corresponds to the period of fallow. In the timing of planting of trees and crops in the experiment, trees were already well established (8 months of age) when spontaneous fallow vegetation began developing, and could withstand competition without any suppression of the tree's survival rate.

Other studies on tree fallow vegetation enrichment, accomplished in the Brazilian Amazon region, presented comparable survival rates to those observed in the present study.

In the recrû method (CATINOT, 1965) used for enrichment of fallow vegetation with the main goal of wood production in 25-30 year rotations. The trees planted to enrich the fallow vegetation, according to this method, gave survival rates varying from 87% to 100% (YARED and CARPANEZZI, 1981).

In the Tapajós region, State of Pará, the enrichment of fallow vegetation was also tested based on the Taungya method (KING, 1968), where trees are planted during the cropping period and at the end of the agricultural period, trees continue growing until harvest (between 25-30 years, depending on the species). The survival rates under those conditions of different species tested varied from 70% to 100% (BRIENZA JÚNIOR, 1982; BRIENZA JÚNIOR *et al.*, 1993). In another study in the Tapajós region, involving intercropping of different wood trees and annual and perennial crops, tree survival rates ranged from 20% to 100% (MARQUES *et al.*, 1993).

The silvicultural behavior of some native trees for fallow vegetation planted in open areas was evaluated by YARED *et al.* (1988). The authors observed survival rates of 97%, 95% and 95%, respectively, for *Laetia procera* (66 months of age), *S. paniculatum* (66 months of age) and *Jacaranda copaia* (78 months of age). GONZALEZ and FISHER (1994), studying the growth of several trees planted in abandoned pastures in Costa Rica, observed 86% and 92% of survival rate, respectively for *A. mangium* and *I. edulis*.

4.2.3 Height and diameter growths

Height measurements of planted trees were taken every two months up to one year of age, and from then on at 18 and 24 months of age. Growth analyses comparing height and diameter of different planted trees was done based on the last measurement at 24 months. The following increments were calculated with chronosequence data of height measurements: a) monthly height increase – MHI obtained by the difference between height at a certain age (H_n) minus the previous height (H_{n-1}) divided by the period of time between evaluations; and b) monthly general height increase - MGHI, calculated as follows: [H(24 months) - H(2 months)]/22, where H(24) is the height value measured at 24 months of age; H(2) is the height at 2 months of age; and 22 is the lapsed time (months) between the first and last height measurement. For *S. paniculatum* the calculation was done based on H(24) - H(4)/20, because height evaluations for this species started only from the fourth month on. As *S. paniculatum* was planted only at the density of 2 m x 1 m, the results are presented and discussed with and without this species.

The ANOVA of the averages values of height and the diameter at the breast height (Dbh), using the complete factorial model (blocks, trees leguminous and plant density; without *S. paniculatum* which was planted at one density only), presented the following results: i) the effect of leguminous tree species showed statistical differences ($F_{1930.59}=146.17$, $p<0.0001$); and ii) the planting density effect was significant only for the Dbh parameter ($F_{0.21}=21.18$, $p<0.0001$).

At 24 months of age, the *A. mangium* trees were the tallest, followed by *I. edulis*, *A. angustissima* and *C. racemosa* (Table 18). The *A. mangium* trees were twice as high as *C. racemosa*. That same tendency of superiority of *A. mangium* trees height was observed for the Dbh parameter In this case, the values varied from 5.6 cm (*A. mangium*) to 3.0 cm (*C. racemosa*) (Table 18).

Table 18: Averages and standard errors of diameter at breast height (Dbh) and height of trees at 24 months of age for *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted for fallow enrichment at spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Trees Species	n	Height (m)	Dbh (cm)
A. mangium	12	7.1 ± 0.2 a	5.6 ± 0.5 a
I. edulis	12	4.7 ± 0.3 b	3.5 ± 0.3 b
A. angustissima	12	4.5 ± 0.2 b	3.2 ± 0.3 bc
C. racemosa	12	3.4 ± 0.3 c	3.0 ± 0.3 c

Data followed by the same letter and located in the same column are not statistically different; LSD test ($p<0.05$)

Comparing plant spacing, regardless of leguminous tree species, shows that as the number of planted trees per hectare increased (1 m x 1 m) there was a restriction in diameter growth. This suggests that by the age of 24 months, trees were already competing for "site resources", and the widest plant spacing (2 m x 2 m) allowed better tree development (Table 19).

Table 19: Averages and standard errors of diameter at breast height (Dbh) at 24 months of age for plant spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m obtained for *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*

Plant Spacing	n	Dbh (cm)
1 m x 1 m	16	4.3 ± 0.1 a
2 m x 1 m	16	3.9 ± 0.2 b
2 m x 2 m	16	3.2 ± 0.2 c

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

The analysis of the height parameter as a function of spacing, regardless of planted trees, showed no statistical differences between treatments, suggesting that during the period of time studied, the growth in height was not restricted by the different numbers of trees planted per hectare (Figure 5).

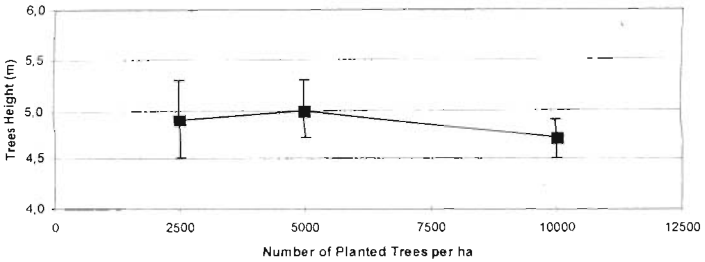


Figure 5: Averages and standard errors of tree height values (*A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*) at a density of 2500, 5000 and 10000 trees per ha, at 24 months of age (n = 16)

The comparison of height and Dbh of species planted only at the spacing of 2 m x 1 m, including *S. paniculatum* is presented in Table 20. The best performance was again by *A. mangium* and the worst by *C. racemosa.*

Table 20: Averages and standard errors of height and diameter at breast height (Dbh) growth for the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum* planted to enrich the fallow vegetation at the spacing 2 m x 1 m

Trees species	n	Height (m)	Dbh (cm)
A. mangium	4	7.0 ± 0.2 a	5.6 ± 0.2 a
I. edulis	4	4.9 ± 0.5 b	3.7 ± 0.4 b
A. angustissima	4	4.9 ± 0.1 b	3.4 ± 0.2 b
S. paniculatum	4	4.9 ± 0.3 b	3.9 ± 0.1 b
C. racemosa	4	3.4 ± 0.2 c	2.9 ± 0.2 c

Data followed by the same letter and located in the same column are not statistically different LSD test ($p<0.05$)

Acacia mangium planted in experimental plots at different sites throughout Brazil showed good silvicultural growth potential (YARED *et al.*, 1988; YARED *et* *al.*, 1990; FERREIRA *et al.*, 1990). In Belterra, State of Pará, some plant mortality was associated with fungus of the genera *Botryodiplodia* (FERREIRA *et al.*, 1990). In Costa Rica, in 3-year-old plantations, termite attacks were also observed and many trees had been broken or toppled by wind (GONZÁLEZ and FISHER, 1994). Larger plant spacing is recommended for *A. mangium* in order to avoid early competition between plants and consequently, higher plant mortality rates (FERREIRA *et al.*, 1990).

The results of height and Dbh growth obtained in the present study are proportionally comparable to those observed in earlier studies planted in the Brazilian Amazon region and in Costa Rica (Table 21).

Table 21· Tree height (H), diameter at breast height (Dbh) and age of some fallow-planted species in the Brazilian Amazon region and in Costa Rica

Species	Location	Age (months)	H (m)	Dbh (cm)	Author
A. mangium	Costa Rica	36	14.5	14.1	GONZÁLEZ and FISHER (1994)
I. edulis	Costa Rica	36	7.0	9.4	GONZÁLEZ and FISHER (1994)
Cordia goeldiana	Belterra-PA	36	3.6	2.7	BRIENZA JUNIOR *et al.* (1995)
Bagassa guianensis	Belterra-PA	36	4.8	6.3	BRIENZA JÚNIOR *et al.* (1995)
Jacaranda copaia	Belterra-PA	36	3.3	5.4	BRIENZA JUNIOR *et al.* (1995)
Jacaranda copaia	Belterra-PA	78	12.4	14.3	YARED *et al.* (1988)
Laetia procera	Belterra-PA	66	7.0	8.8	YARED *et al.* (1988)
S. paniculatum	Belterra-PA	66	12.1	9.4	YARED *et al.* (1988)

Tree development depends on availability of site resources and genetic factors. In a tight spacing, trees are induced to grow higher, as plants tend to seek out light quickly, and resulting in "forest form" as it is called in silviculture. In plantations with larger spacing, trees tend to develop more crowdedly, as there is less available light, and in this case a "natural form" is developed.

In general, wide spacing is recommended for poor sites, while narrower spacing can be used on fertile sites (FAO, 1981). In commercial plantations for wood energy production, e.g. *Eucalyptus* for a charcoal, a short spacing is recommended because the major interest is to produce biomass.

The observed growth in height during the study period (from 2nd to 24th month), generally followed the behavior of the perennial crops. Slower growth was seen in the beginning, followed by a phase of faster growth and, later on, a phase of either stopping growth or very slow growth. This behavior was quite evident for *A. angustissima* and *C. racemosa*, while *A. mangium*, *I. edulis* and *S. paniculatum* showed a more linear growth tendency (Figures 6 and 7). *Acacia mangium* possesses a growth pattern with strong apical dominance, and can reach great heights. *Acacia angustissima*, *I. edulis* and *C. racemosa* present a height growth pattern without apical dominance, reaching lower heights. *Sclerolobium paniculatum* is in an intermediary position between *A. mangium* and the other species.

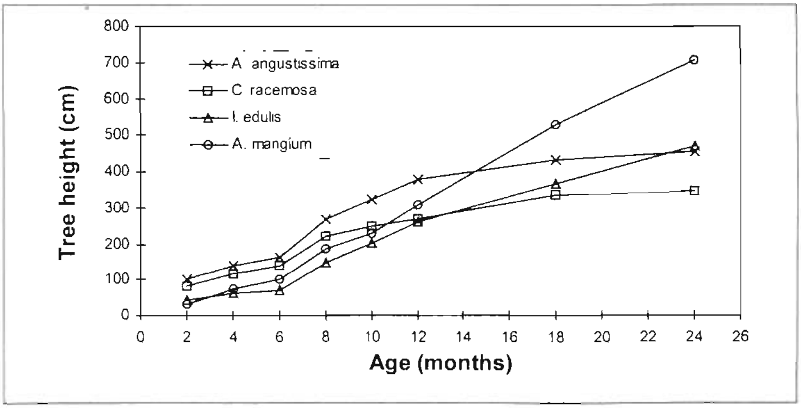


Figure 6: Average of height for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted to enrich fallow vegetation, regardless of plant spacing (1 m x 1 m, 2 m x 1 m and 2 m x 2 m)

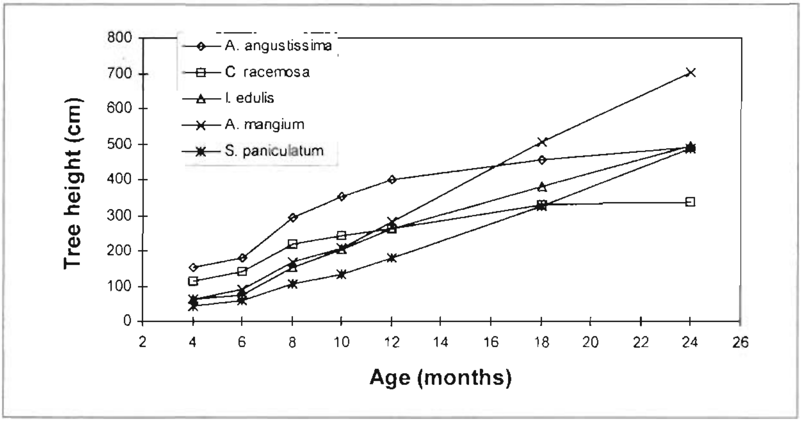
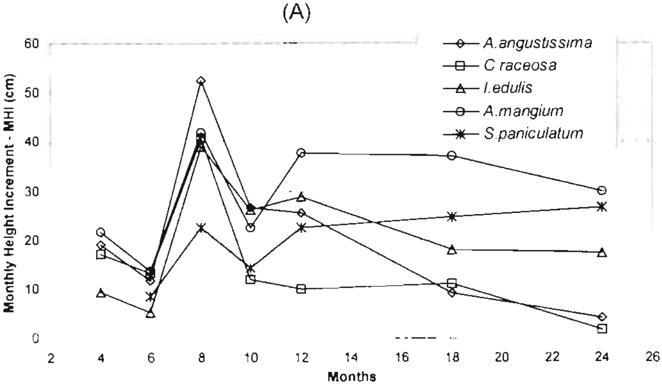


Figure 7: Average of height for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum* planted at 2 m x 1 m to enrich fallow vegetation

The tree height development is not indicative of stand development, but assesses site growth-potential (GADOW and HUI, 1998). However, in the case of enrichment of fallow vegetation, beginning during the crop period, planted tree growth in height can be used to estimate potential development of the enrichment system. Final estimate of tree height alone does not allow conclusions about tree growth dynamics and system management. For this, the analysis of tree growth dynamics was made based on MHI data.

The MHI value over time for planted trees regardless of plant spacing and for plant spacing regardless of trees planted are presented in Figure 8 (*Sclerolobium paniculatum* planted at the spacing of 2 m x 1 m, was included).



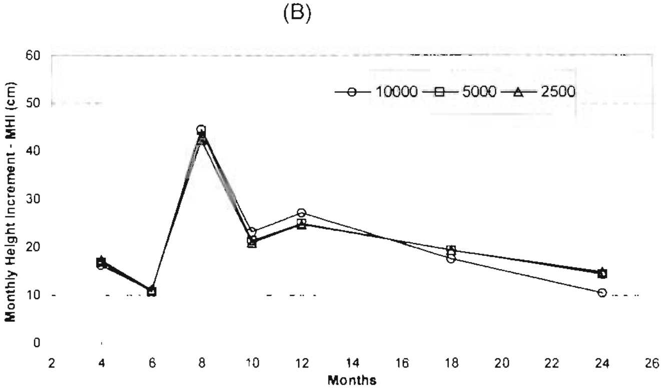


Figure 8: Monthly medium increment in height - MHI for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis, A. mangium* and *S. paniculatum* (A) and for spacing of plantations at 1 m x 1 m, 2 m x 1 m and 2 m x 2 m (B)

Based on the two charts (Figure 8) it is possible to recognize a similar tendency for all species as well as the four distinct periods in fallow vegetation enrichment, as follows:

i) Adaptation: until the 6th month (December 1995) all planted leguminous trees grow, but this growth rate is smaller when compared to that presented at the 4th month. This decrease in MHI may be associated with the fact that planted trees were investing in root development, in the adaptation to the new environment. It was, however, the period of lowest precipitation (Figure2);

ii) Growth explosion: from the 6th month to 8th month, when the rainy season begins, rapid growth in height is observed for all leguminous trees planted. *Acacia angustissima* showed the fastest growth during this phase;

iii) Competition: still during the rainy period, a decrease of MHI values from the 8th month to the 10th month was observed. The cassava was harvested at the 8th month, and therefore, it can be surmised that after harvest, the fallow vegetation could also develop quickly and as a result, there was a tendency to constrain growth the planted leguminous trees, showing the existing competition for site resources. Alternatively, some root disturbance during cassava harvest may have set back the planted trees; and

iv) Stability: from 10th month onwards MHI values of trees showed different behaviors, and two groups of species could be characterized. The first is composed of *A. mangium*, *I. edulis* and *S. paniculatum* that showed tendencies of recover their growth rates, although with different magnitudes attributed to each species and less than observed between the 6th and 8th months. In the second group *A. angustissima* and *C. racemosa* decreased their rate of height growth. From 12 months of age, MHI values for all species, except *S. paniculatum*, showed a decrease until 24 months of age. Although the species planted in the fallow vegetation continued growing, this growth occurred with less intensity. It was visually observed that, at 12 months of age, *A. angustissima* buffered from drying of shoot sprouts during the dry period, which resprouted at the beginning of the rains. The same effect, although with lesser intensity, was also observed for *C. racemosa.* This fact can explain the low MHI values for those two species, particularly for *C. racemosa* during the last observation the age of 24 months.

The analysis of MHI values over the experimental period facilitated visualization of the growth dynamics of the trees planted for fallow enrichment. Comparisons of the average of monthly general height increments (MGHI) permitted the establishment of growth ranking of the trees studied.

The ANOVA of MGHI values using the complete factorial model (blocks, leguminous trees and plant density; without *S. paniculatum* which was planted at one density only) showed statistical differences only among leguminous trees ($F_{2973\ 74}=267.31$, $p<0.0001$). The highest observed value of MGHI for *A. mangium* was about three times the lowest found in *C. racemosa* and it was followed by *I. edulis* and *A. angustissima* (Table 22).

Table 22: Average of monthly general increment of height - MGHI for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted for fallow vegetation enrichment at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Trees Species	n	MGHI (cm)
A. mangium	12	32 a
I. edulis	12	21 b
A. angustissima	12	16 c
C. racemosa	12	11 d

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

Considering *S. paniculatum* the ANOVA results showed the same tendency as when this species was not considered ($F_{1028.71}=41.53$; $p<0.0001$). The growth ranking has *A. mangium* in first place followed by *A. angustissima*, *I. edulis*, *S. paniculatum* and *C. racemosa* (Table 23).

Table 23: Average of monthly general increment of height - MGHI for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted for fallow vegetation enrichment at the spacing of 2 m x 1 m

Trees Species	n	IMA (cm)
A. mangium	4	32 a
S. paniculatum	4	22 b
I. edulis	4	22 b
A. angustissima	4	17 c
C. racemosa	4	11 d

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

To be successful in fallow vegetation enrichment, planted trees must have fast initial growth and withstand initial fallow competition. It is possible to make the following ranking of species: i) *A. mangium* - fast growth; ii) *I. edulis*, *A. angustissima* and *S. paniculatum* - intermediary growth; and iii) *C. racemosa* slow growth.

4.2.4 Volume index

To calculate the wood volume produced by a certain tree, a factor should be considered that corrects for the conical stem form. In commercial plantations of *Eucalyptus* sp., volume calculations take into account a specific form factor for each species. In the present study, the form factor of the species studied was unknown. Therefore, at the end of the experiment the wood volume index for each treatment was determined.

The ANOVA of the volume index data considering a complete factorial design (blocks, leguminous trees, and planting density; without *S. paniculatum* which was planted at one density only) showed significant differences for leguminous tree species ($F_{259.44}=18.35$, $p<0.0001$) and planting density ($F_{259.44}=6.25$, $p<0.01$) factors. The interaction of leguminous trees x planting density was significant, at a statistically level of $p<0.1$ ($F_{259.44}=2.04$) only. Thus, the planted species produced different wood volumes and this depended on plant spacing. For example, the largest volume found for *A. mangium* planted at the density of 10000 trees ha^{-1}, was 10.8 times that obtained with *C. racemosa* at the density of 2500 trees ha^{-1} (Figure 9).

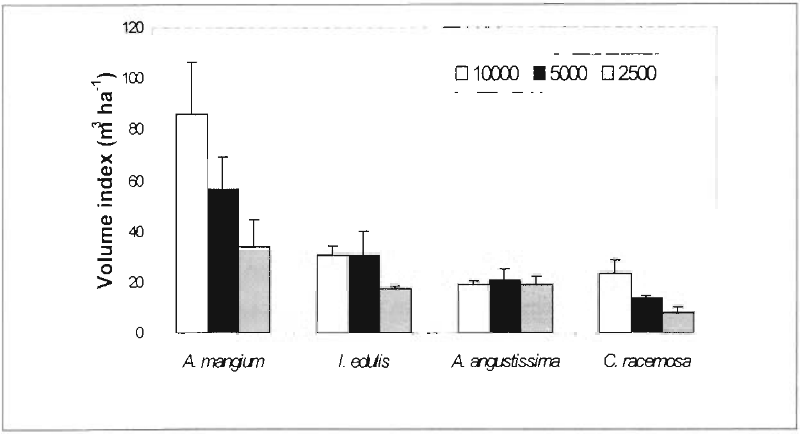


Figure 9: Averages and standard errors of volume index (m^3 ha^{-1}) for *A. mangium*, *I. edulis*, *A. angustissima* and *C. racemosa* planted to enrich fallow vegetation at 10000, 5000 and 2500 trees per hectare (24 months of age)

Acacia mangium and *C. racemosa* behaved similarly with lower wood volume production with decreasing number of trees planted per hectare. *Inga edulis* showed decrease at the widest plant spacing only while *A. angustissima* practically maintained the same wood volume at the three plant densities (Figure 9).

The wood volume index comparisons, regardless of plant spacing showed that *A. mangium* produced about 4 times more wood than *C. racemosa* (Table 24).

Table 24. Averages and standard errors of volume index of the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, planted to enrich fallow vegetation, regardless of planting density (10000, 5000 and 2500 plants ha^{-1}) (24 months of age)

Trees species	n	Volume Index (m^3 ha^{-1})
A. mangium	12	59 ± 10 a
I. edulis	12	26 ± 4 b
A. angustissima	12	20 ± 2 b
C. racemosa	12	15 ± 3 b

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

The comparisons of wood volumes produced for all the species planted at the density of 5000 trees per hectare, including *S. paniculatum*, are presented in Table 25. The superiority of *A. mangium* is marked. It is followed by *I. edulis*, *A. angustissima*, *S. paniculatum* and *C. racemosa*. Wood volume produced by *A. mangium* was about 4.2 times more than that found for *C. racemosa*.

Table 25. Averages and standard errors of volume index of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and *S. paniculatum* planted at the density 5000 trees ha^{-1} (24 months of age)

Trees Species	n	Volume Index (m^3 ha^{-1})
A. mangium	4	57 ± 13 a
I. edulis	4	30 ± 10 b
A. angustissima	4	21 ± 4 b
S. paniculatum	4	18 ± 3 b
C. racemosa	4	14 ± 2 b

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

The analysis of wood volume as a function of plant spacing averaged for all tree species, showed that the larger number of trees planted increased the volume produced (Table 26). However, the volume of wood produced also depended on the performance of the different species studied (Table 24).

Table 26: Averages and standard errors of the volume index obtained for planting densities of 10000, 5000 and 2500 trees per hectare, averaged for leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, planted to enrich fallow vegetation (24 months of age)

Plant Density (trees ha^{-1})	n	Volume Index (m^3 ha^{-1})
10000	16	40 ± 8 a
5000	16	30 ± 6 a
2500	16	20 ± 4 b

Data followed by the same letter are not statistically different; LSD test ($p<0.1$)

In Costa Rica, GONZÁLEZ and FISHER (1994) studied the growth of 11 species planted at the spacing of 3 m x 3 m for recovery of abandoned pastures. At 36 months of age, *A. mangium* produced the largest volume (108 m^3 ha^{-1}), while *I. edulis* produced 28 m^3 ha^{-1} The volumes found for other fallow vegetation species evaluated in plantations in the Brazilian Amazon region are shown in Table 27

Table 27· Wood volume of three tree species planted in fallow vegetation at a spacing of 3 m x 2 m, in the Brazilian Amazon region (YARED *et al.*, 1988)

Trees Species	Local	Age (months)	Volume (m^3 ha^{-1})
Jacaranda copaia	Belterra-PA	78	176
S. paniculatum	Belterra-PA	66	106
Laetia procera	Belterra-PA	66	37

Fallow vegetation enrichment is done primarily for biomass production to develop source of organic matter and nutrients for subsequent cycles of slash-and-burn agriculture. The wood volume produced by trees planted for fallow enrichment can also represent an opportunity for capital gain when wood is harvested, especially if the species used have charcoal potential or can be used in construction. According to LELLES *et al.* (1996) *A. mangium* wood has the advantage of producing good charcoal. However, the best decision for using the wood produced will depend on market prices for other products that the farmer could obtain.

4.3 Impacts on biomass production

"...this fallow vegetation with trees planted inside is strong and fat, but that other normal one is on a diet..." This sentence was uttered by an anonymous but observant farmer during a visit to the experimental area. The idea of enrichment conjured by the farmer translates into one of the main objectives of the present study, which was to increase fallow vegetation biomass. This biomass accumulation, however, should fulfill the following requirements: i) take place within the fallow period practiced in the region (no more than 2-3 years); ii) not have a negative impact on the biomass and biodiversity of natural fallow vegetation; and iii) no negative effects on crops.

4.3.1 Planted leguminous trees

The aboveground biomass evaluation of planted leguminous trees for enrichment of fallow vegetation was carried out at the end of the experiment, when trees were 2.5 years old (at this time the fallow vegetation was 2 years old). This biomass was separated into leaves, branches and stems. Samples in 12m^2 plots were taken in order to evaluate the biomass of planted trees. With 100% tree survival, each plot respectively contained 12, 6 and 3 trees, with the following plant spacing: 1 m x 1 m, 2 m x 1 m and 2 m x 2 m.

A total biomass ANOVA, using the complete factorial model (blocks, leguminous trees, and planting density; without *S. paniculatum* which was planted at one density only) showed a significant difference only among planted species ($F_{0\ 94E+08}=22.79$, $p<0.0001$). Biomass and respective standard errors as a function of plant spacing, independent of type of leguminous tree, were: 21350 ± 3770 kg ha^{-1} (1 m x 1 m), 17770 ± 3420 kg ha^{-1} (2 m x 1 m) and 16150 ± 4240 kg ha^{-1} (2 m x 2 m). Although there was no statistical difference, there is a tendency for biomass to decrease as plant spacing increases.

When leguminous trees are analyzed, regardless of plant spacing, the largest biomass accumulation per hectare was attained by *A. mangium* (37880 kg ha^{-1}), which was five times higher than the lowest biomass accumulation by *C. racemosa* (7550 kg ha^{-1}; Table 28).

Table 28: Average values and standard errors of total biomass of leguminous trees *A. mangium, A. angustissima, I. edulis* and *C. racemosa* planted to enrich fallow vegetation, averaged over spacing

Trees Species	n	Biomass (kg ha^{-1})
A. mangium	12	37870 ± 1940 a
A. angustissima	12	15740 ± 1230 b
I. edulis	12	12540 ± 750 bc
C. racemosa	12	7550 ± 630 c

Data followed by the same letter are not statistically different; LSD test ($p<0.1$)

Although the interaction leguminous tree x planting density was not significant, the species planted to enrich fallow vegetation exhibited a different behavior as a function of spacing. The species *C. racemosa, I. edulis* and *A. mangium* showed a tendency of decreasing biomass per hectare as plant spacing increased. On the other hand, *A. angustissima* produced the largest biomass per area at the spacing 2 m x 1 m (Figure 10). The highest biomass found for *A. mangium* planted at 1 m x 1 m (45020 kg ha^{-1}) was about 10 times higher than the lowest by *C. racemosa* at 2 m x 2 m (4120 kg ha^{-1}).

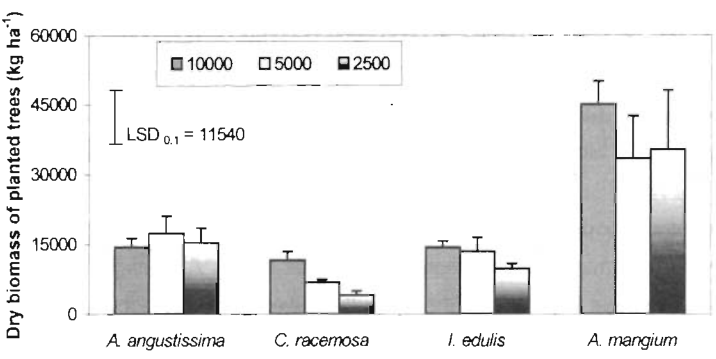


Figure 10: Dry biomass and standard errors of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, and *A. mangium* planted for enrichment of fallow vegetation, at densities of 10000, 5000 and 2500 trees per hectare (n=4)

When *S. paniculatum* was included, the ANOVA comparing biomass of planted leguminous trees at the spacing 2 m x 1 m, showed *A. mangium* producing 4.8 times more biomass than *C. racemosa* ($F_{0.49E+08}$=11.42, $p<0.0001$) (Table 29).

Table 29: Average values and standard errors of total biomass of the following leguminous trees *A. mangium*, *A. angustissima*, *I. edulis*, *C. racemosa* and *S. paniculatum* planted to enrich fallow vegetation, at the spacing 2 m x 1 m

Tree Species	n	Produced Biomass (kg ha^{-1})
A. mangium	4	33320 ± 9240 a
A. angustissima	4	17400 ± 3660 b
I. edulis	4	13480 ± 3010 b
S. paniculatum	4	12730 ± 1940 b
C. racemosa	4	6890 ± 640 b

Data followed by the same letter are not statistically different; LSD test ($p<0.05$)

The accumulated biomass was highest in the wood fraction (Figure 11). *Acacia mangium* (34060 kg ha^{-1}) demonstrated its potential to provide wood for different uses (energy, charcoal, among others). The lowest production of wood biomass (7450 kg ha^{-1}) was by *C. racemosa*.

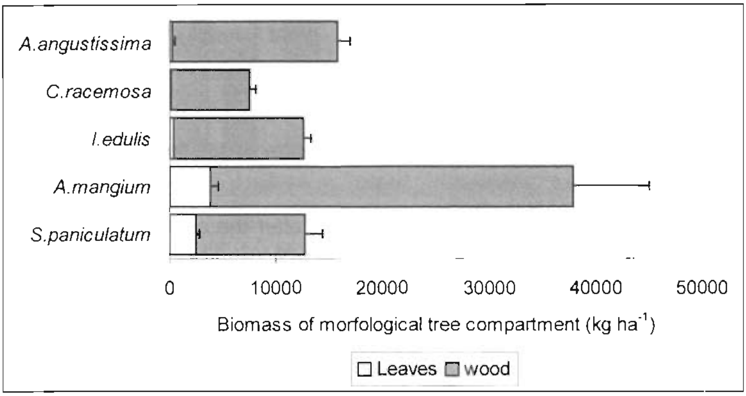


Figure 11: Dry biomass and standard errors of wood and leaves for the leguminous trees *A. mangium*, *A. angustissima*, *S. paniculatum*, *I. edulis* and *C. racemosa*, regardless of plant spacing (1 m x 1 m, 2 m x 1 m and 2 m x 2 m) grown in the fallow vegetation (n=4)

The following percentage of total produced biomass were found as leaves: 1% for *C. racemosa*; 2% for *A. angustissima*; 3% for *I. edulis*; 10% for *A. mangium* and 20% for *S. paniculatum*. However, leaf biomass was determined during the time of low precipitation (October - November, 1997; Figure 2). Trees had less leaves during this period. Therefore, these results may be different if leaf biomass had been determined during the rainy season.

4.3.2 Fallow vegetation

The evaluation of the biomass of the spontaneous fallow vegetation in control and enriched plots were done when the fallow vegetation was approximately 2 years old. The same 12 m^2 plots used for planted trees biomass assessment were used.

The ANOVA of average biomass values using a complete factorial model (blocks, leguminous trees, and plantation density; without *S. paniculatum* which was planted at one density only) showed statistical significance for leguminous trees ($F_{3503874.58}=19.62$, $p<0.0001$) and plant density ($F_{3503874.58}=34.09$, $p<0.0001$) and the interaction leguminous trees x planting density ($F_{3503874.58}=2.35$, $p<0.05$). This means that the planted leguminous trees at different spacings significantly influenced the fallow vegetation biomass.

The highest biomass of the fallow vegetation, after the control, were observed in the systems with *C. racemosa* planted at the spacing of 2 m x 1 m (14680 kg ha^{-1}) and 2 m x 2 m (14640 kg ha^{-1}), whereas the lowest ones were 5380 kg ha^{-1} and 5510 kg ha^{-1}, respectively, in the systems with *I. edulis* and *A. mangium* (1 m x 1 m) (Figure 12). In general, there was a tendency to increase biomass of the spontaneous vegetation by decreasing the number of planted trees per hectare. WETZEL *et al.* (1998) when evaluating the number of species and estimating the coverage of the spontaneous vegetation in the same plot also observed a reduction in fallow vegetation regeneration. Between enriched systems studied, those formed by planting *C. racemosa* showed the lowest interference with the regeneration capacity of the fallow vegetation. The same was observed by SÁ *et al.* (1998) when evaluating light quality during the development of the present study.

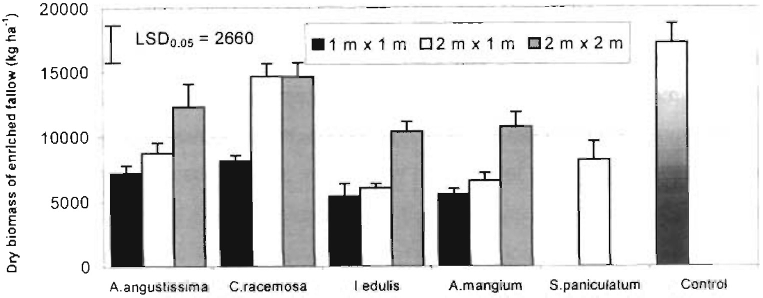


Figure 12: Aboveground dry biomass and standard errors of the spontaneous fallow vegetation in a stand enriched by planting leguminous trees *A. mangium, A. angustissima, S. paniculatum, I. edulis* and *C. racemosa* (n=4)

Like in the leguminous trees, wood was the largest compartment (71%) in the spontaneous fallow, followed by leaves (28%) and debris (1%) (Figure 13).

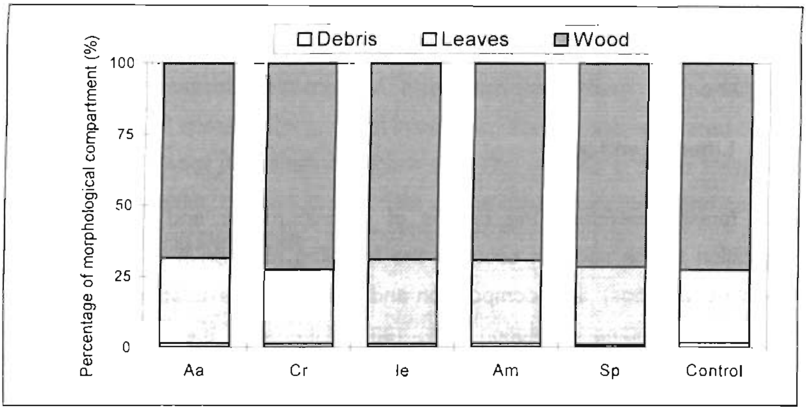


Figure 13: Percentage of fallow morphological (leaves, wood and debris) biomass distribution as a function of planted trees *A. angustissima, C. racemosa, I. edulis, A. mangium, S. paniculatum* and control

4.3.3 Carbon concentration

For a better insight into the enriched systems, the carbon concentration of the different morphologic compartments was determined for the species grown. The compartments analyzed were: i) planted trees: leaves, branches, wood; and ii) fallow vegetation: leaves and wood. The results observed are presented in Table 30.

Table 30: Average values and standard errors of carbon concentration (%) analyzed for leaves, branches, wood and litter for *A. angustissima, C. racemosa, I. edulis, A. mangium* and fallow vegetation

Enriched System	Carbon (%)			
	Leaves	Branches	Wood	Litter
A. angustissima	45.9 ± 0.9	43.0 ± 0.4	43.1 ± 0.4	-
C. racemosa	43.1 ± 0.8	42.3 ± 0.9	42.2 ± 0.3	-
I. edulis	43.4 ± 0.3	43.1 ± 0.3	42.8 ± 0.4	-
A. mangium	46.5 ± 0.6	41.9 ± 0.4	43.6 ± 0.5	-
Fallow Vegetation	43.2 ± 0.3	-	43.3 ± 1.0	39.1 ± 2.9

4.3.4 Litterfall and litter

In a forest ecosystem, the returns of organic matter and nutrients from vegetation to the soil can occur in the following manner: i) litterfall (leaves, branches and logs); ii) decomposition and root nutrient exudation; and iii) rain wash from standing vegetation (NYE, 1961). Litterfall is the main process of transferring organic matter and nutrients accumulated in primary production, from standing aboveground tree biomass to the soil (VITOUSEK, 1984; SZOTT *et al.*, 1991). Therefore, its quantification can aid in understanding the nutrient and biomass dynamics of an ecosystem.

The techniques used for litterfall collection can affect the results obtained. Preferably, collections should be frequent, repeated often and done above the soil surface (PROCTOR, 1983). KUNKEL-WESTPHAL and KUNKEL *et al.* (1979) cited by VITOUSEK (1984) pointed to the importance of frequent collections in tropical areas, because decomposition can lead to an underestimation of the litterfall.

Monthly samples of litterfall biomass in the present study were taken from natural and enriched fallow system plots. The samples were obtained over 13 months, starting from the fourth to the seventeenth month of the study period.

The existing litter biomass at the beginning and end of the period of litterfall collection was also obtained. Biomass of leaves, branches, flowers and fruits collected inside the boxes (50 cm x 50 cm) placed 10 cm of above the soil surface, was considered litterfall.

4.3.4.1 Seasonal distribution of litterfall

Litterfall in all treatments showed a similar seasonal pattern during the period studied, regardless of enrichment. A clear seasonal pattern of litterfall was observed. For all species, the greatest intensity of litterfall was registered during the period of lowest precipitation (Figure 14). The species *I. edulis* treatment exhibited two peaks, one in October (just as the other treatments and control) and another one in December.

When the litterfall was analyzed per plant spacing regardless of planted tree density, the same distribution pattern was observed during the period studied, but with the greatest fall intensity for the spacing of 1 m x 1 m, followed by 2 m x 1 m, 2 m x 2 m and the control. The heaviest litterfall occurred during the dry period, and the lowest values coincided with the rainy period (Figure 14).

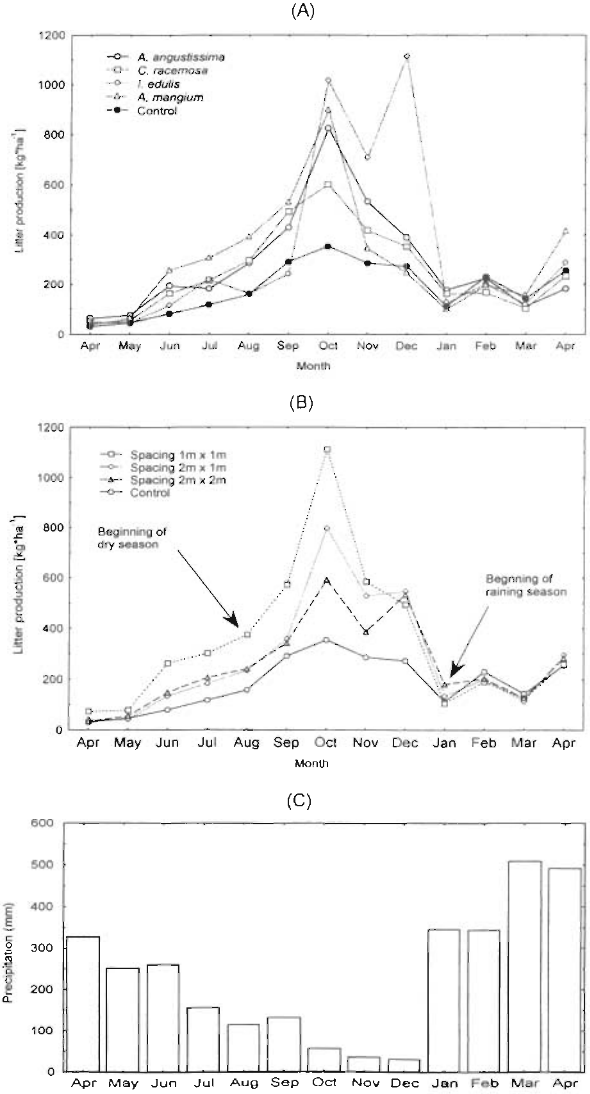


Figure 14: Monthly litterfall as a function of planted trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and control (A); plant spacing of trees (B) and rain distribution (C) during the period April-96 to April-97

Under the conditions of the present study, the following phenological characteristics of trees planted for fallow vegetation enrichment were observed during the period of low precipitation:

a) *Acacia angustissima*: among the species studied, it is the one that possesses the smallest leaflet size. From the beginning to the end of the period of low rainfall, this species exhibited a gradually of decreasing litterfall until the complete absence of leaves. Its branches were visible at the end of the dry season. At the first rain, its leaves quickly started to re-growth. This species was in its flowering process at 12 months of age (July-96) and fructification ended in December-96;

b) *Clitoria racemosa*: under isolated conditions it shows a large canopy. However, in the present study this species did not develop a dense canopy, even with the spacing of 2 m x 2 m, where theoretically it would better be able to express its natural form. This species also gradually lost all its leaves during the driest period. Fast new leave development was observed after the first rainfall;

c) *Inga edulis*: this species has large leaves. Its canopy is generally ramified and broad under natural conditions. In the experiment, planting in open spaces and in lines with in the fallow vegetation stimulated its apical development. This species also lost its leaves gradually until its complete absence during the driest period. Fast leave growths occurred after the first rainfall; and

d) *Acacia mangium*: this species has a typical forest form and strong apical dominance. Unlike the other species studied, it did not completely lose its leaves during the dry period. Its canopy always remained green.

Thus, besides precipitation, litterfall also reflected different physiological characteristics of the species studied (deciduous or semi-deciduous species).

Different authors studying litter production observed seasonal behavior and related it to rainfall and temperature, both in natural ecosystems and plantations (VIRO, 1955; NYE 1961, MÁLKÖNEN, 1974; VITOUSEK, 1984; HEUVELDOP *et al.*, 1988; MONTAGNINI *et al.*, 1993; FINÉR, 1996).

4.3.4.2 Litter production

In forest plantings the annual litterfall increases until the trees canopies close. Later, this remains constant during a long period of time until it decreases with the increase of age. due to decreased productivity or reduction of tree density caused by natural and/or man-made pruning (BRAY and GORHAM, 1964; ALBERKSTON, 1988).

Using average values of monthly litterfall, the accumulated totals were calculated per month (Figure 15) and over the period of one year (Figure 16). These values represent the primary biomass that can be recycled in enriched fallow vegetation systems. The ANOVA of the annual data, using a complete factorial model (blocks, species and plant spacing), showed statistical differences between species ($F_{502586.67}=5.15$; $p<0.005$) and planting density ($F_{502586.67}=12.56$; $p<0.0001$) as well as a species x density interaction ($F_{502586.67}=3.10$; $p<0.01$). Therefore, species accumulated litter in different ways and this accumulation depended on plant spacing. For example, the largest accumulation provided by *I. edulis* planted at the spacing of 1 m x 1 m was 2.3 times larger than the control, whereas *C. racemosa* planted at 2 m x 1 m accumulated only 1.15 times more than the control (Figure 16).

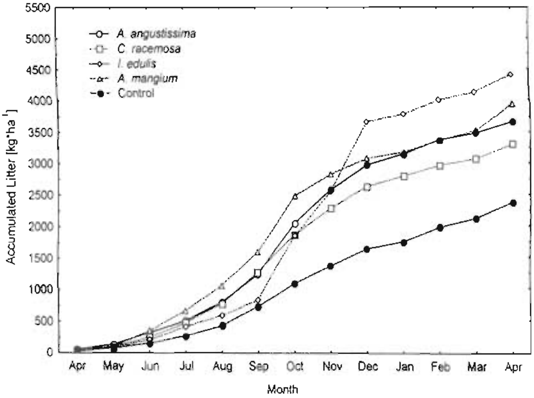


Figure 15: Average litterfall accumulation from April-96 to April-97 for enriched systems with *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted at the spacing of 1m x 1m, 2m x 1m and 2m x 2m, compared to the control

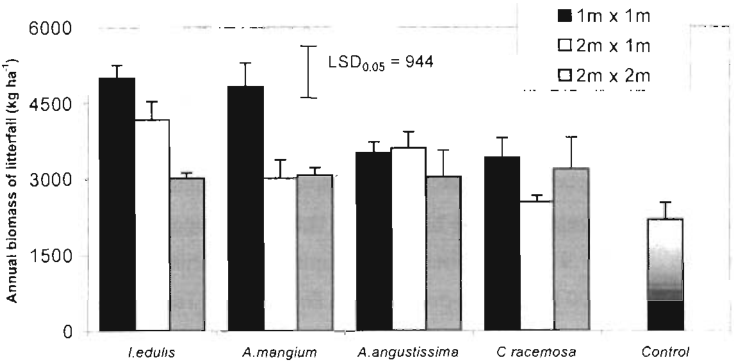


Figure 16: Annual accumulated litterfall biomass and standard errors of control and with leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, planted at the spacing of 1 m x 1 m, 2m x 1 m and 2 m x 2 m

The ANOVA analysis, comparing enriched systems, regardless of plant spacing showed greater litter accumulation than the control for all studied systems, except *C. racemosa*,. The enriched system with *I. edulis* resulted in the highest litter accumulation, 1.8 times more than control, whereas for *C. racemosa* this factor was only 1.4 (Table 31). Therefore, compared with the control, trees planted for fallow vegetation enrichment did not cause a negative impact on total accumulated litterfall.

Table 31: Annual averages and standard errors of accumulated biomass of litterfall for control and enriched fallow systems with *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, regardless of plant spacing (1 m x 1 m, 2 m x 1 m and 2 m x 2 m) (n=4)

Enriched Systems	Accumulated Litterfall (kg ha^{-1} y^{-1})
I. edulis	4060 ± 280 a
A. mangium	3640 ± 310 a
A. angustissima	3390 ± 210 a
C. racemosa	3050 ± 250 ab
Control	2190 ± 330 b

Values followed by the same letter are not statistically different; LSD test ($p<0.05$)

Litterfall accumulation, regardless of tree species, tended to increase as the number of trees planted per hectare for fallow vegetation enrichment increased (Table 31). Compared with the control, the tightest spacing (1 m x 1 m or 10000 trees ha^{-1}) had 1.9 times higher litter accumulation, while the widest spacing (2 m x 2 m or 2500 trees ha^{-1}) only had 1.4 times more (Table 32).

Table 32: Annual averages and standard errors of accumulated biomass of litterfall for control and enriched fallow systems, as a function of plant spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, regardless of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* (n=4)

Planting Spacing	Average of Accumulated Litterfall (kg ha^{-1})
1 m x 1 m	4190 ± 250 a
2 m x 1 m	3330 ± 210 ab
2 m x 2 m	3080 ± 190 b
Control	2190 ± 350 b

Values followed by the same letter are not statistically different; LSD test ($p<0.05$)

Planting a larger number of trees per hectare implied a larger accumulated biomass of litter However, what is the litter biomass composition, since the enrichment system also contains the fallow vegetation component ? This analysis can be made in two different ways.

The first option considers the average of trees species, regardless of plant spacing. The result of this analysis showed different rates ($p<0.0001$) of litter biomass (Table 33). Litter biomass of the planted trees predominated except for *C. racemosa* (45%). The species *I. edulis* and *A. mangium* were the greatest litter biomass contributors (74%). The litter biomass ratio between planted leguminous trees and the associated fallow vegetation varied from 3:1 for systems with *A. angustissima*, *I. edulis* and *A. mangium*, and 1:1 for *C. racemosa*.

Table 33: Percentage of total accumulated litterfall biomass (kg ha^{-1}) fractionated in natural fallow vegetation, planted trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, plant spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, and others (flowers, fruits, seeds and branches) (SE = standard error; CV = coefficient of variation)

Enriched System	Plant Density (trees ha^{-1})			Trees Species			
Compound	10000	5000	2500	*Acacia angustissima*	*Clitoria racemosa*	*Inga edulis*	*Acacia mangium*
Natural Fallow	17.2 c	29.1 b	47.3 a	22.4 b	50.6 a	25.9 b	25.9 b
SE	(± 2.4)	(± 3.4)	(± 4.9)	(± 3.1)	(± 5.8)	(± 4.7)	(± 4.5)
CV (%)	56.8	47.3	42.2	47.5	40.2	63.1	61.4
Legume	79.7 a	66.7 b	47.1 c	63.9 b	44.5 c	73.9 a	73.7 a
SE	(± 3.5)	(± 3.8)	(± 4.9)	(± 2.9)	(± 6.2)	(± 5.3)	(± 5.1)
CV (%)	18.0	22.8	41.7	16.0	48.9	24.9	23.5
Others	3.1	4.2	5.6	13.7	4.9	0.2	0.4

Data followed by the same letter and located in the same group (natural fallow and legume) are not statistically different ($p<0.0001$)

The second analysis considered the average values of each spacing studied, regardless of leguminous trees. The result showed that as the number of trees planted per hectare decreased, the litter biomass of planted trees and fallow vegetation became similar. The biomass rates of planted trees and fallow vegetation was 4.6-to-1, 2.3-to-1 and 1-to-1 respectively at the densities of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m (Table 33).

The observation that at a planting density of 2 m x 2 m (2500 trees ha^{-1}), practically 50% of produced biomass came from planted trees (Table 33), is important information in the search for enrichment systems that minimize possible negative impacts on fallow vegetation biodiversity. Furthermore, the reflection of this composition will be discussed further later on, regarding the capacity of litter decomposition.

In general, a lower coefficient of variation was observed for the planted tree component in the fractionating analysis of accumulated litter biomass. This may be explained by the fact that planted trees had been planted with regular spacing and, therefore, were systematically distributed throughout the area.

Litterfall biomass composition was also studied by SHARMA *et al.* (1997). These authors found different values of litter biomass in two systems, one with and the other without nitrogen fixing species. In the first, involving a mixed system of Alnus – cardamom, the litter was composed of 39% from N fixing trees and of 61% from the agricultural species. In the second, with Albizia – mandarin, the proportion was 43% for tree litter and 57% for crop residue.

To evaluate behavior of each leguminous species with the three planting densities, a linear regression model was used for litter production as a variable dependent on the number of trees planted per hectare. The control was inserted in the model as representing the condition of no trees planted.

The regressions were significant ($p<0.0001$) in the systems enriched with *I. edulis* and *A. mangium* and respectively account for 77% and 64% of the variation in litter production. Although the fitted model for enrichment with *A. angustissima* was significant ($p<0.05$), this only accounts for 24% of the variation. In the case of *C. racemosa,* no clear pattern was observed in accumulated litterfall biomass with increasing the number trees planted per hectare (Table 34).

Table 34: Regression equations for litter production (y) of different enrichment systems of fallow vegetation (*I. edulis*, *A. mangium*, *A. angustissima* and *C. racemosa*) as a function of planting trees per hectare (x) (10000; 5000; 2500 and 0 trees ha^{-1})

Enriched Systems	Equations	r^2	P
I. edulis	$y = 2360 + 0.28\ x$	0.77	0.0001
A. mangium	$y = 2190 + 0.25\ x$	0.64	0.0001
A. angustissima	$y = 2550 + 0.12\ x$	0.24	0.0300
C. racemosa	$y = 2420 + 0.01\ x$	0.11	0.1200

From 4 to 17 months of age the enriched system showed around 25% to 50% of the litterfall biomass founded in natural and planted forest (Table 35).

Table 35: Annual biomass of litterfall in different tropical ecosystems

Location	Forest Type	Trees ha^{-1}	Litterfall (t ha^{-1} yr^{-1})	Author
		Natural Forest		
Nigeria	Moist evergreen forest	-	7.2	HOPKINS, (1966)
Brazil	Terra firme	-	7.3	KLINGE and RODRIGUES (1968)
Costa Rica	Lowland rain forest	-	8.1	GESSEL *et al.* (1980)
Colombia	Lowland rain forest	-	8.5	JENNY *et al.* (1949)
		Fallow vegetation		
Nigeria	5-7-yr-old bush	-	8.6	SWIFT *et al.* (1981)
Colombia	16-yr-old	-	9.5	FOLSTER and de las SALAS (1976)
Ivory Coast	40-yr-old	-	10.5	NYE (1961)
		Plantation		
Costa Rica	3.5-4.5-yr-old			MONTAGNINI *et al.* (1993)
	H. alchorneoides	2500	8.2	
	V. ferruginea	2500	9.5	
	S. microstachyum	2500	11.7	
	V. guatemalensis	2500	12.6	
Ivory Coast	5-yr-old			SCHROTH *et al.* (manuscript)
	G. sepium	2500	3.5^{+}	$^{+}$ values obtained durinh
	A. guachapele	2500	5.3^{+}	6.5 months
	L. leucocephala	2500	5.9^{+}	
		Consortium		
Costa Rica	8-yr-old			ALPIZAR *et al.* (1986) and
	C. alliodora/cacao	278/1111	7.1	HEUVELDOP *et al.* (1988)
	E. poeppigiana/cacao	278/1111	8.9	

4.3.4.3 Litter decomposition

There are different approaches to study litter decomposition. The most common method is to use litter samples placed in bags that allow microorganisms to decompose the litter and the subsequent loss of weight is monitored over a period of time (HEUVELDOP *et al.*, 1988; MONTAGNINI *et al.*, 1993).

The evaluation of accumulated litter decomposition on the soil surface facilitates the understanding of the carbon flow between vegetation, soil and atmosphere. To characterize the litter decomposition in a natural forest, JENNY *et al.*, (1949) proposed the expression $k = A / (F+A)$, where k is the annual decomposition constant, A is the input (litterfall) and F is the mean standing crop of litter under a stand at a steady state.

The enriched systems were at the initial phase of development and did not reflect a steady state situation. It was not possible to install litter bags for decomposition studies at the beginning of the experiment, due to an insufficient litter layer Thus, it was decided that litter stocks would be measured at the beginning (T1) and at the end (T2) of a period during which also litterfall was measured. The difference between the latter and the former (T2 - T1) samplings represents the amount of litter which remained of the litterfall after decomposition. The relative amount of litter decomposed, which can be called rate of decomposition (Rd), was calculated by the equation [1-(T2-T1)/litterfall]*100.

The ANOVA of Rd data, using the factorial model (blocks, species, and planting density), showed statistical differences due species ($F_{157.18}=3.42$; $p<0.05$) and density ($F_{157\,18}=3.95$; $p<0.05$) and the interaction species x density ($F_{157\,18}=3.92$; $p<0.01$). Therefore, enriched systems presented different litter decomposition, depending on plant spacing (Figure 17).

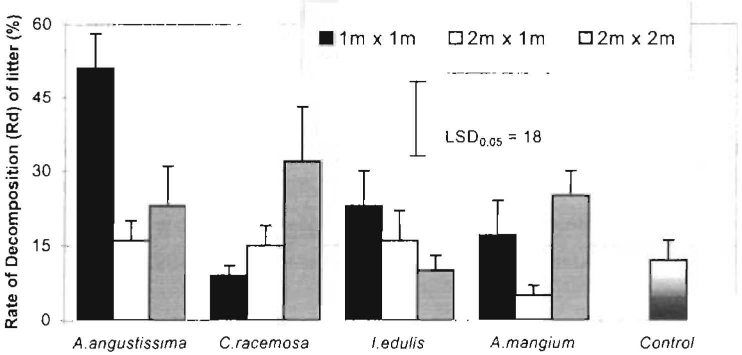


Figure 17: Rate of litter decomposition and standard errors of control and leguminous trees *A. angustissima, C. racemosa, I. edulis* and *A. mangium*, planted to enrich the fallow vegetation at the spacing of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m

Two distinct patterns of litter decomposition could be identified (Figure 17). *Acacia angustissima* and *I. edulis* showed a decrease of Rd values with decrease of the number of planted trees per hectare, whereas *Clitoria racemosa* and *A. mangium* presented an increase of Rd values with the increase of the number of planted trees per hectare.

Comparisons of only planted trees, regardless of spacing and including the control, showed the estimate of Rd values were different and statistically higher for enriched systems (Table 36). The enriched system with *Acacia angustissima* presented highest rate of decomposition. This could be explained, in part, with the narrow C:N ratio of its leaves (Table 37).

Table 36: Rate of decomposition (Rd) and standard errors as a function of trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* planted to enrich fallow vegetation, regardless of spacing (1 m x 1 m, 2 m x 1 m and 2 m x 2 m), compared to the control

Enriched Systems	n	Quotient of Decomposition (Rd)
A. angustissima	4	30 ± 4 a
C. racemosa	4	18 ± 4 b
I. edulis	4	16 ± 3 b
A. mangium	4	16 ± 3 b
Control	4	12 ± 4 b

Data followed by the same letter are not statistically different (LSD test; p<0.05)

Table 37: Concentration of carbon and nitrogen, and C:N ratio of leaves of *A. angustissima, C. racemosa, I. edulis* and *A. mangium* planted to enrich fallow vegetation, and of the natural fallow vegetation

Species	C (%)	N (%)	C:N
A. angustissima	45.9 ± 0.9	3.0 ± 0.16	15
C. racemosa	43.1 ± 0.8	2.7 ± 0.07	16
I. edulis	43.4 ± 0.3	2.5 ± 0.09	17
A. mangium	46.5 ± 0.6	2.4 ± 0.21	19
Natural Fallow	43.2 ± 0.3	1.5 ± 0.09	29

After fallow vegetation enrichment, one possibility is not to use fire for land preparation before cropping. In this case, all accumulated biomass during the enriched fallow could be used as mulch (KATO, 1998a and 1998b). Is fast or slow mineralization desirable during fallow ? The question is one of time synchronism of nutrients release. Litter mineralization is desirable in order to aid nutrient supply during the following cropping period. Studies are necessary to assess nutrient release from litter produced by different enrichment fallow systems.

4.3.5 Root - growth and standing stock of biomass

The slash-and-burn agriculture in the Bragantina region has been done over 100 years, and the system worked through time because the fallow vegetation was maintained. The main mechanism of fallow vegetation´s regeneration after slash-and-burn is the resprouting of roots and stumps. Intensive land use systems with mechanization and short fallow periods can produce a negative impact on root systems, endangering the agricultural sustainability (WIESENMÜLLER, 1999). Therefore, the fallow vegetation enrichment by planting fast growing trees will be acceptable only if the vitality of the root system is preserved.

Compared to other fallow vegetation components, little is known about root architecture, growth and biomass (RESTOM, 1998). This invisible compartment, also called "the hidden half" (WAISEL *et al.*, 1991) is difficult to be studied under field conditions. The need for a sampling scheme capable of capturing its natural variability and sample-cleaning process, is tremendously time consuming (DOWDY *et al.*, 1998; VOGT *et al.*, 1998).

In the present study, the fallow vegetation development started after the last weedings for the cassava, approximately in November of 1996. From this moment onward the new growth of spontaneous vegetation will start mixing in enrichment system with the planted leguminous trees. The differentiation between natural fallow and the enriched vegetation is more easily aboveground than belowground. Therefore, there was no separation between the planted species and the fallow vegetation, as root identification of different species was difficult. Thus, the root estimates refer to the root biomass of both, planted leguminous trees and spontaneous fallow.

The fine root production (FRP) and the standing root stock (SRS) were evaluated during a period of time, that began in the fifth month of the fallow period and continued for 12 months. The SRS estimates make no distinctions between live and dead or fine and thick roots, while the FRP limits the root diameter to < 1 mm (mesh size of bags). An underestimation of SRS related to *roots of bigger diameters is possible because auger cores of only 5 cm* diameter were used.

The study of FRP was made based on in-growth bags installed at depths of 0-15 cm and 15-30 cm. To minimize the alterations caused by this methodology, the same soil of the studied profile was used. When in-growth bags samples were placed in the field (T0), it was assumed that there were no roots inside the in-growth bags. The collections of the in-growth bags were made after 4 months (T4) and 12 months (T12). The SRS was evaluated to a depth of 0-30 cm using auger cores. The samples were collected at three times: at the beginning of the in-growth bags study (T0) and after 4 months (T4) and 12 months of growth (T12). The auger-core samplings, as well as the in-growth bags study, were restricted to the treatments of tree spacing of 1 m x 1 m and 2 m x 2 m.

4.3.5.1 Root growth

The ANOVA for the FRP estimates using the complete factorial model (blocks, leguminous tree, planting density, time of sampling and depth) showed that species ($F_{552964.05}=4.73$, $p<0.05$), time ($F_{552964.05}=12.17$, $p<0.001$) and depth ($F_{552964.05}=52.79$, $p<0.0001$) were significant. Furthermore, the interactions of depth x leguminous tree ($F_{552964.05}=3.11$, $p<0.05$) and depth x time of sampling ($F_{552964.05}=5.29$, $p<0.05$) were significant.

At each sampled time, on average, 70% of the root growth was concentrated in the first 15 cm of soil depth (Table 38). However, the estimated values of FRP for enriched fallow systems were higher at the later sampling time ($F_{552964.05}=12.17$, $p<0.001$).

Table 38: Averages of fine root production - FRP (kg ha^{-1}) and standard errors for different enriched fallow systems formed by planting the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium* as a function of time of sampling (4 and 12 months) and two depths (0-15 cm and 15-30 cm)

Time (months)	N	Depth (cm)	
		0-15	15-30
4	24	1430 ± 110 b	680 ± 40 c
12	24	2410 ± 320 a	960 ± 120 c

Date followed by the same letter are not statistically different; LSD test ($p<0.05$)

Significant statistical differences were observed for FRP values of the different species treatments between the two studied depths in first sampling T4 (Table 39) ($F_{27796.69}=132.84$, $p<0.0001$). The enriched fallow systems formed with *A. angustissima*, *I. edulis* and *A. mangium* were, respectively, 80%, 70% and 40% more efficient than the control, in developing a root net in the top soil layer The system formed with *C. racemosa* was not different from the control (Table 39). At the depth of 15-30 cm, the two enriched systems with Acacias presented around 65% more roots than the control. The other systems did not show differences in relation to the control (Table 39).

Considering the total FRP values in 0-30 cm of soil depth, the enriched fallow systems formed by *A. angustissima*, *I. edulis* and *A. mangium* provided, respectively, 74%, 61% and 45% more root growth than the control (Table 39) ($F_{87468.198}=7.31$, $p<0.01$).

Table 39: Comparisons of averages of fine root production - FRP estimates and standard errors estimated for enrichment systems formed by using four leguminous trees planted at 1 m x 1 m and 2 m x 2 m and the control, obtained at 4 months of fallow

Enriched Systems	Fine Root Production (kg ha^{-1} 4 months^{-1})		
	0-15 cm	15-30 cm	Total
A. angustissima	1770 ± 180	730 ± 140	2500 ± 320
I. edulis	1620 ± 90	680 ± 20	2300 ± 90
A. mangium	1380 ± 110	710 ± 80	2090 ± 90
C. racemosa	970 ± 130	600 ± 110	1570 ± 240
Control	960 ± 140	470 ± 70	1430 ± 200
LSD (0.05)	290		560

The estimated FRP values obtained at T12 showed, as observed in T4, a differentiated behavior of the enrichment systems studied. The largest growth continued being in the top 15 cm of soil (Table 40, $F_{470650.61}$=29.63, $p<0.0001$). Compared to the control treatment, the enriched systems with *I. edulis*, *A. mangium* and *A. angustissima* produced, respectively, 2.2, 1.5 and 1.5 times more fine roots biomass, while the system with *C. racemosa* was not different.

In the soil layer of 15-30 cm, significant differences were not observed between treatments, although in absolute values the system with *A. mangium* presented about 90% more roots than the other enriched systems, and about 3 times more than the control. The only significant differences between the two depths (0-15 cm and 15-30 cm) were found for the systems formed with *I. edulis* and *A. angustissima* (Table 40).

Table 40: Comparisons of averages of fine root production - FRP estimates and standard errors for enriched systems formed by using four leguminous trees planted at 1 m x 1 m and 2 m x 2 m and the control, obtained at 12 months of fallow

Enriched Systems	Fine Root Production (kg ha^{-1} 12 months^{-1})		
	0-15 cm	15-30 cm	Total
I. edulis	3400 ± 960	770 ± 290	4170 ± 980
A. mangium	2360 ± 730	1400± 270	3760 ± 870
A. angustissima	2340 ± 110	890 ± 30	3230 ± 140
A. racemosa	1540 ± 350	770 ± 290	2310 ± 630
Control	1520 ± 210	510 ± 150	2020 ± 320
LSD (0.05)	1180		1850

Evaluating the total FRP estimates for 0-30 cm of soil depth, the enriched system formed with *I. edulis* produced about two times more fine roots than the control. The other systems were not statistically different from the control, although all of them had FRP's superior to the control (Table 40).

WIESENMÜLLER (1999) evaluated the fine root growth of fallow vegetation of different ages in the present study area using in-growth bags. The production of roots measured per year was 2.7 and 3.0 t ha^{-1}, respectively, for a fallow vegetation of 3 and 8 years of age. Simultaneously, the rate of fine roots decomposition was of 1.4 t ha^{-1} for a 3-year-old fallow and of 2.1 t ha^{-1} for a 8-year-old capoeira.

As the enriched systems develop (samplings T4 and T12), the FRP maintains a vertical gradient, that means, there was a larger concentration of root growth in the top soil. After a year, the enriched system with *I. edulis* presented the largest root growth concentration (82%) restricted to the soil depth of 0-15 cm followed by the control (75%) (Table 41).

Table 41: Percentage of root biomass at 0-15 cm and 15-30 cm of soil depth, in relation to the total biomass obtained at 4 and 12 months of age for enriched fallow systems formed by planting the leguminous trees *I. edulis, A. mangium, A. angustissima, C. racemosa* at a spacing of 1 m x 1 m and 2 m x 2 m, and the control

Time	Enriched Systems				
(months)	*Inga edulis*	*Acacia mangium*	*Acacia Angustissima*	*Clitoria racemosa*	Control
			0-15 cm		
4	70%	66%	71%	62%	67%
12	82%	63%	72%	66%	75%
			15-30 cm		
4	30%	34%	29%	38%	33%
12	18%	37%	28%	34%	25%

ARUNACHALAM *et al.* (1996) studying disturbed subtropical humid forest in India found that 62% of the fine roots were in the soil top layer between 0-10 cm and 13% between 20-30 cm. Others, such as BERISH and EWEL (1988), NEPSTAD *et al.* (1991), KÄTTRER *et al.* (1995), TRUMBORE *et al.* (1995), RESTOM (1998), NEGREIROS *et al.* (1998) and WIESENMÜLLER (1999) also show a larger root growth in the top soil in studies realized under different environmental conditions.

The production of fine roots between 0-30 cm increased from T4 to T12 (Table 42). This response was to be expected and it was also reported by other authors (MAGALHÃES, 1979; NUNEZ, 1995 and WIESENMÜLLER, 1999), but how did growth rates change during the period of study ? Did fine roots growth show different growth rates between time T4 and T12 ?

Table 42: Total fine root biomass – FRP (kg ha^{-1}) (0-30 cm) and standard errors of T4 and T12 for different fallow enrichment systems composed by planting of leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium* and the control

Enriched Systems	Total of Fine Root Biomass (kg ha^{-1})	
	T4	T12
A. angustissima	2490 ± 320	3230 ± 140
Control	1430 ± 200	2020 ± 320
C. racemosa	1570± 240	2310 ± 630
I. edulis	2300 ± 90	4170 ± 980
A. mangium	2090 ± 90	3760 ± 870

To answer this question about growth dynamics, linear regressions (y = ax + b) were fitted using estimates of fine root production as a dependent variable of time (T4 and T12). The first analysis considered the growth period between the moment of in-growth bags placement - T0, and its first collection after four months - T4 (T0-T4). The second analysis covered the interval between T0 and the collection after one year - T12 (T0-T12). At the time of the in-growth bags installation T0 was considered without roots and, the "b" value is zero. The fitted equations for the two periods are shown in Tables 43 and 44. In the present case, larger values of "a" represent a fast growth of roots per month.

Table 43: Adjusted linear regression equations for root growth between T0-T4 for different fallow systems enriched by planting the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, and the control

Enriched Systems	Equations	r^2	p
A. angustissima	y = 623 x	0.96	0.000
I. edulis	y = 576 x	0.95	0.000
A. mangium	y = 521 x	0.99	0.000
C. racemosa	y = 392 x	0.94	0.000
Control	y = 358 x	0.99	0.000

Table 44: Adjusted linear regression equations for root growth between T0-T12 for different fallow enrichment systems enriched by planting the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *A. mangium*, and the control

Enriched Systems	Equations	r^2	p
I. edulis	y = 347 x	0.88	0.001
A. angustissima	y = 269 x	0.99	0.000
A. mangium	y = 313 x	0.88	0.001
C. racemosa	y = 192 x	0.84	0.002
Control	y = 168 x	0.94	0.000

The "a" values of the adjusted linear models for both situations discussed above are presented in Table 45. For the first interval T0-T4, the enriched systems with *A. angustissima*, *I. edulis* and *C. racemosa* grew, respectively, about 1.8, 1.6 and 1.5 times more roots than the control, while the system with *C. racemosa* was practically equal. For the second period T0-T12, root growth of the enriched systems with *I. edulis*, *A. mangium*, *A. angustissima* and *C. racemosa* produced fine roots at about 2.0. 1.8, 1.6 and 1 1 times the rate of the control, respectively.

Table 45. Coefficients of linear regression (y = ax + b) adjusted for fine root growth for two intervals of time (T0-T4 and T0-T12) obtained with different enriched fallow systems by planting the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium*, and the control

Enriched Systems	n	Coefficients of Linear Regression ("a")	
		T0-T4	T0-T12
A. angustissima	3	623	269
I. edulis	3	576	347
A. mangium	3	521	313
C. racemosa	3	392	192
Control	3	358	168

The values of "a" for the different enriched systems in T0-T4 were always larger compared to the one for the period T0-T12. Based on slope values it is possible to identify two groups of enriched systems. The first group is formed by the systems that yielded high values of "a" in the first interval T0-T4 with a drastic reduction in the period T0-T12. The enriched systems with *C. racemosa* and *A. angustissima*, and the control had lower "a" values by 48%, 43% and 46%, respectively. The second group, formed by the systems with *I. edulis* and *A. mangium*, maintained, during the entire T0-T12, about 60% of the growth of the first period, T0-T4 (Table 45).

The period T0-T4 refers to the root growth during the rainy season, whereas the T0-T12 interval included a rainy-and-dry period (Figure 2). The soil humidity is one of the main factors regulating root growth. BERISH and EWEL (1988) studying the root growth in different successions of ecosystems in Costa Rica, observed a rapid root development during the first 15 weeks and a decrease of 40% in the dry season. According to those authors, the fine-root growth decrease was evident during the first year of study, but was not so clear in the four following years. WIESENMÜLLER (1999) working in the area of the present study, found a decrease in the fine-roots stock during the transition of the rainy period to the end of the dry season, and an increase in the following rainy period. The fine-roots growth was also related to soil water supply as found by KÄTTERER *et al.* (1995).

There is controversy in the literature about the best methodology to estimate roots production (VOGT *et al.*, 1998). In-growth bags may have a micro-environment inside the bag which is different from the parent soil (natural conditions), and the root growth can therefore differ. However, the present work does not engage in this controversy and the fact that this methodology is widely used (PRIESS and FÖLSTER, 1994), makes it sufficiently safe for the local comparisons of systems.

Compared to the control, the enriched systems showed similar root growth, but with the same or superior magnitude. This fact is important, because it shows that the planting of fast growing trees to increase biomass production did not cause a negative impact on total root growth. This observation can also be affirmed from a comparison of the present work and the study carried out by WIESENMULLER (1999) in the same region. Although the root quantification has been made by different people, WIESENMÜLLER (1999) found a fine root production of 2700 kg ha^{-1} year^{-1} for a 3-year-old fallow vegetation and 3000 kg ha^{-1} year^{-1} for a 8-year-old fallow. Except the enriched system formed by planting *C. racemosa*, all the other systems showed larger FRP estimates than those values presented by WIESENMÜLLER (1999). Therefore, it is possible to predict that continuous regeneration ability of this important fallow vegetation component will be maintained. The enriched systems with *A. mangium* and *I. edulis* have the greatest ability to maintain the root system active during the period of less precipitation.

4.3.5.2 Root standing stock of biomass

The ANOVA of roots stock data using the complete factorial model (blocks, leguminous species, planting density and time of sampling) showed that the factor time ($F_{1984263.13}=30.26$, $p<0.0001$) and the interaction of leguminous tree x density of planting ($F_{1984263.13}=7.42$, $p<0.0001$) were significant.

Except for the enriched system with *A. angustissima* planted in 1 m x 1 m, all the systems increased the root stock from T0 to T4 followed by a decrease from T4 to T12 (Table 46). Between samplings T0 and T4 the major root stock variation was found for *C. racemosa* (57%) and the smallest (32%) for the control (Table 47; $F_{1471332.83}=26.86$, $p<0.0001$). Between T0 and the last sampling T12 the largest growth variation was observed in the system with *A. angustissima* (56%) and the smallest in the system with *C. racemosa*, which practically remained constant (Table 47).

Table 46: Standing root stock (kg ha^{-1}) and standard errors as a function of time of sampling in enriched fallow systems with leguminous trees *A. angustissima*, *I. edulis*, *A. mangium*, and *C. racemosa* at the densities 1 m x 1 m and 2 m x 2 m, compared with the control

Enriched Systems	Planting Density	Time (months)		
		T0	T4	T12
A. angustissima	1 x 1	2370 ± 150	6620 ± 300	7820 ± 300
	2 x 2	2980 ± 420	5770 ± 470	4340 ± 890
I. edulis	1 x 1	3620 ± 200	6700 ± 190	4340 ± 400
	2 x 2	2570 ± 500	5110 ± 470	4420 ± 650
A. mangium	1 x 1	1640 ± 200	4510 ± 480	3090 ± 520
	2 x 2	3380 ± 310	8320 ± 2480	5880 ± 1320
C. racemosa	1 x 1	3540 ± 170	5470 ± 210	2940 ± 380
	2 x 2	3070 ± 470	5980 ± 1420	3560 ± 1200
LSD (0.05)		1040	n.s.	2390
Control		1730 ± 230	5320 ± 1490	3140 ± 660

n.s. = not significant

Table 47: Standing root stock (kg ha^{-1}) and standard errors as a function of three samplings times for the enriched fallow systems by planting the leguminous trees *A. angustissima*, *I. edulis*, *A. mangium*, and *C. racemosa* at the densities 1 m x 1 m and 2 m x 2 m, compared with the control

Enriched Systems	Time (months)		
	T0	T4	T12
A. angustissima	2680 ± 140	6190 ± 350	6080 ± 300
I. edulis	3090 ± 350	5900 ± 310	4380 ± 300
A. mangium	2510 ± 130	6410 ± 1410	4480 ± 580
C. racemosa	3300 ± 230	5720 ± 790	3250 ± 770
Control	1730 ± 230	5320 ± 1490	3140 ± 660
LSD (0.05)		2030	

To compare the temporary fluctuation of SRS, a rate of relative root stock (RRS) was calculated that represents the change found between the samplings T4-T0 (RRS-T4T0), T12-T4 (RRS-T12T4) and between T12-T0 (RRS-T12T0).

The relative roots stock rate RRS-T4T0 reflected an accrual of SRS in all systems studied, with the largest value (3580 kg ha^{-1}) observed for the control and the smallest for the enriched system with *C. racemosa* (2420 kg ha^{-1}; Table 48).

The values of RRS-T12T4 were negative for all systems. Between T4 and T12, half the time fell in the dry period and half in the rainy period. The results of RRS-T12-T4 rate appears to be affected by the influence of the dry period causing a decrease in root stocks. The largest loss was observed for the enriched system with *C. racemosa* (-2470 kg ha^{-1}) and the smallest with *A. angustissima* (-110 kg ha^{-1}; Table 48). However, the a balance of growth (RRS-T12T0) over a whole year is positive for all enriched systems, excepting with *C. racemosa* (Table 46).

Comparing Tables 42 and 48, the production of the fine roots in T12 and the RRS-T12 value, it is observed that the studied systems favor growth of fine roots over root stock growth. The exception is the enriched system with *A. angustissima*.

Table 48: Relative root stock (RRS) (kg ha^{-1}) obtained among samplings at different time (T0, T4 and T12 months) for enriched fallow systems formed by planting the leguminous trees *A. angustissima*, *C. racemosa*, *I. edulis* and *C. racemosa* and the control

Enriched Systems	Time (months)		
	T4-T0	T12-T4	T12-T0
A. angustissima	3520	-110	3400
A. mangium	3900	-1930	1980
Control	3580	- 2180	1400
I. edulis	2810	-1530	1280
C. racemosa	2420	- 2470	-50

A higher root biomass accumulation was also observed by BERISH and EWEL (1988) in Costa Rica in a 5-year-old enriched vegetation succession (through a shower of seeds). Those authors found a root stock to a depth of 85 cm, of 13700 kg ha^{-1} for enriched succession and of 8000 kg ha^{-1} for the control. ARUNACHALAM *et al.* (1996) report root stocks of 14700 kg ha^{-1} and of 7600 kg ha^{-1} for vegetation with 16 and 7 years of age, respectively, in forest re-growths in humid subtropical, India.

Compared to the control treatment, the enriched fallow systems did not cause a reduction in root system vitality. The root stock found at T12 showed that enriched systems with *A. angustissima*, *I. edulis* and *A. mangium* produced, respectively, 1.9, 1.4 and 1.4 times more roots than the control, while the *C. racemosa* system was similar to the control.

5. General Discussion and Conclusions

The motivation for this work was the possibility to overcome the effects of shortening the fallow period in slash-and-burn agriculture. The knowledge generated has importance for the Bragantina region and it has the potential to be used in other areas of the Brazilian Amazon region.

The question initially asked was: is it possible to shorten fallow periods as currently practiced by farmers, while maintaining fallow vegetation biomass vitality and with that, the system's carbon stock ? The answer depends on some factors observed during the undertaking of the study and these will be discussed below.

5.1 The effect of tree density on productivity of simultaneous crops

The agricultural system used as the basis for fallow vegetation enrichment was maize and cassava. Maize remained on the field during the first four months without competition from the recently burned fallow vegetation. Therefore, its cultivation can be considered as monocropping.

Cassava shared site resources with trees planted during eight months until its harvest one year after planting. The different trees, averaged over spacing, did not differ in their impact on the dry weight of cassava tubers. In fact, on average for all enrichment species, the spacing of 2 m x 2 m appeared to enhance the cassava crop. A significant reduction in cassava tuber dry weight was observed when the spacing of 1 m x 1 m (10000 trees ha^{-1}) was compared with the spacing of 2 m x 2 m.

Those results show that crop productivity can be maintained with enrichment of fallow vegetation by leguminous trees. In practice, farmers could be attracted to use this new technology because there were no changes in crop production. However, as the farmer can not reduce his expectation of cassava harvest, tree planting at the spacing of 1 m x 1 m should be avoided and 2 m x 1 m or 2 m x 2 m could be recommended.

5.2 Leguminous trees

During the development of the enriched fallow system, planted trees and cassava grew together for as long as eight months and later on, after crop harvest, trees competed with the regenerating natural fallow vegetation. This competition did not have a negative impact on the survival of trees neither to plant spacing. The values of tree survival (> 90%) at 24 months were comparable to those in to commercial plantations levels.

The trees studied were ranked by calculating the average monthly growth in height. *Acacia mangium* grew fastest followed by *S. paniculatum*, *I. edulis*. *Acacia angustissima* was classified as of intermediary growth and *C. racemosa* as of slow growth.

The dynamics of tree growth, evaluated by monthly average height increment - MHI - during the study period, showed the same tendency for all species. Four phases of tree development could be distinguished: seedling adaptation, growth explosion, competition and stability. In selecting new species, attention should be paid that during the competition phase, trees are established and can withstand natural fallow competition.

After 24 months of growth, the planted trees showed different height and Dbh growth. Plant spacing did not influence growth in height, but significantly affected growth in Dbh. The slowest Dbh growth for all species was at the spacing of 1 m x 1 m, followed by 2 m x 1 m and 2 m x 2 m.

The wood volume produced by the different trees planted may also be a criteria for selection because the sale of wood (firewood, charcoal or stakes) can represent an opportunity for the farmer to earn income. At the end of the experiment, *A. mangium* had produced the largest wood volume followed by *I. edulis*, *A. angustissima*, *S. paniculatum* and *C. racemosa*. An increase of volume was observed by increasing the number of trees planted per hectare for all species, although the average Dbh decreased.

At the end of the fallow period the success of enrichment planting may only be measured in the total biomass produced.

Some desirable seed attributes are easy availability-, access- and absence of dormancy. This will facilitate the technology dissemination to a large number of users. Nitrogen fixing may be preferable to help compensate for loss of N to the atmosphere when the fallow vegetation is burned. Useful attributes of trees for enrichment in the study region are: i) species flowering during the fallow period and specially in the dry period can contribute additional food for bees and this particular comments has importance because in Bragantina region honey production is becoming a growing market; ii) straight growth permits another use as a stake for passion fruit for example; and iii) another possible utilization of wood for charcoal or energy should also be considered an advantage.

5.3 Biomass accumulation

All enrichment systems accumulated more aboveground biomass than the control with no enrichment (Table 49). Based only on this verification, all enriched systems could be recommended.

At the end of the experiment, biomass accumulation and transfer processes had occurred at different intensities in the various enriched system. Therefore, to recommend the best option, it is necessary to break down the produced biomass into the two main compartments, the spontaneous fallow vegetation and the planted leguminous trees.

Table 49: Total aboveground biomass (kg ha^{-1}) of different compartments (litter, leguminous trees and fallow vegetation) of enriched fallow using *A. angustissima*, *C. racemosa*, *I. edulis*, *A. mangium*, *S. paniculatum* planted at 10000, 5000 and 2500 trees per hectare and the control plot

Enriched Systems	Total Aboveground Biomass			Average (kg ha^{-1})
	10000 trees ha^{-1}	5000 trees ha^{-1}	2500 trees ha^{-1}	
A. angustissima	29390	35650	35520	33520
C. racemosa	26320	29470	25880	27220
I. edulis	30040	30270	29760	30020
A. mangium	61890	50190	54700	55600
S. paniculatum	-	32150	-	32150
Control				23970

The percentage reduction of spontaneous vegetation biomass in each enriched system was calculated in relation to the control. Furthermore, using the control biomass treatment as a reference, the percentage of total biomass accumulated for each enrichment system was calculated. The results are presented in Figure 18.

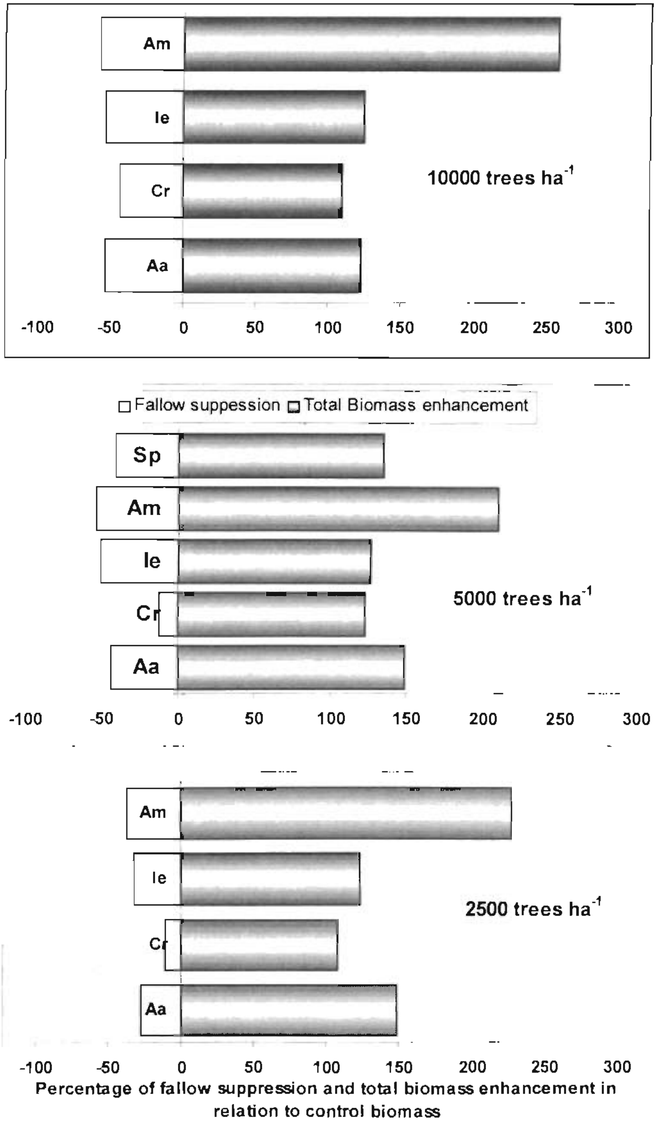


Figure 18: Spontaneous fallow suppression and total biomass enhanced in relation to control for enriched systems with *A. mangium* (Am), *A. angustissima* (Aa), *I. edulis* (Ie), *C. racemosa* (Cr) and *S. paniculatum* (Sp) at 10000, 5000 and 2500 trees per hectare

Enrichment altered the fallow vegetation biomass, as adding a new component to fallow ecosystem increased competition for site resources. The fallow enrichment system with 10000 planted trees per hectare produced the largest aboveground biomass and wood volume, but caused substantial fallow vegetation suppression. The largest biomass reduction was observed in the enrichment system with *A. mangium* (57%) at the spacing of 1 m x 1 m (10000 trees ha^{-1}). The smallest reductions were registered in the systems with *C. racemosa* planted at the spacing of 2 m x 1 m (5000 trees ha^{-1}) (12%) and 2 m x 2 m (2500 trees ha^{-1}) (11%).

A reduction in biomass accumulation of fallow vegetation as a function of increasing the number of trees planted was also reflected in the litterfall from the spontaneous fallow over a period of one year. The ratio of litterfall biomass from planted leguminous trees and spontaneous vegetation was 3:1 for 1 m x 1 m enrichment systems formed with *A. angustissima*, *I. edulis* and *A. mangium*. However, for *C. racemosa* the ratio was 1:1 Therefore, besides the spacing, each species influenced the composition and the accumulated biomass differently.

The biomass reduction of spontaneous fallow was in part a function of the crown architecture of the different trees planted and of their interaction with the spontaneous vegetation. Light quality studies of SÁ *et al.* (1998) and the study of dynamics of floristic composition accomplished by WETZEL *et al.* (1998), in the same experimental plots, confirm the strong competition in fallow vegetation caused by the species *A. mangium* and *I. edulis* planted at the spacing of 1 m x 1 m. Although increasing the number of planted trees has caused biomass reduction of fallow vegetation, one should consider that there was a gain of total biomass. Therefore, two points have to be discussed.

The first one is: is it useful to look for a fallow system which is enriched but still maintains a base of natural fallow or why should one not give up the natural fallow vegetation and replace it by a planted fallow with highest amounts of biomass ? It can be assumed that maintaining the fallow vegetation makes sense, and there are reasons for this assumption such as:

a) the natural fallow vegetation maintains a deep root system. It can relatively fast establish a functioning fallow vegetation with nutrient root uptake by the roots. The establishment of an artificial active cover would demand a high planting density. In this case, costs of seedling production and planting must be considered;

b) to maintain the original biodiversity could be advantageous not only from a biological point of view, but also for economically purposes as energy, construction, utensils, tools, medicines, among others; and

c) uncertainty with regard to the long term effects, for instance, the continuing impoverishment of the fallow vegetation due to the dominant enriched species.

The second point is: if it is considered meaningful to maintain a fallow-based land use system, one looks for a compromise between optimal biomass production and optimal survival rate of the natural fallow vegetation. When coexistence of fallow vegetation and enriched species is wanted, the planting density 1 m x 1 m does not need to be discussed. The results show clearly that this density is beyond consideration. On the contrary, one might even consider the possibility of still wider spacing of 3 m x 1 m or 4 m x 1 m. With those two spacings, there is a greater distance between rows, and that may provide a better environmental situation for the fallow vegetation (light incidence for example), and the number of planted trees per hectare would provide a possibility to accumulate biomass. Fast and moderate growing species such as *A. mangium*, *I. edulis* and *A. angustissima* could be preferably planted in wider spacing (2500 trees ha^{-1}), whereas slow growth species such as *S. paniculatum* and *C. racemosa* would be planted in tight spacing (5000 trees ha^{-1}). Planting of tall seedlings can be tested to overcome the problem of slow initial growth as was observed in *S. paniculatum* and *C. racemosa*. In this case, seedlings are produced using tall plastic bags, and at the time of planting these could better withstand competition from fallow vegetation. The disadvantage of this method is that seedlings would need more time in the nursery and with that, production *cost would be higher.*

Besides the ecological aspects of safeguarding the fallow vegetation component, also technical and economic aspects have to be discussed.

Slash-and-mulch agriculture is another possibility that has been evaluated at the study area. All biomass produced during the fallow is cut and chopped to serve as soil cover (KATO, 1998a and KATO, 1998b). A riding bush chopper has been developed for mulch production to be used only in situations where the diameter of trees planted for fallow enrichment did not exceed the machine capacity of about 5-8 cm (DENICH *et al.*, 1998). In situations where the species *planted for enrichment exceeded the maximum dimensions* to use the bush chopper, an alternative could be to harvest the larger trees (only wood), but leaving leaves and branches to contribute as mulch.

The economic aspect of fallow vegetation enrichment refers to production and planting cost of leguminous trees. A density of 10000 trees ha^{-1} produced the largest biomass, but comes with the highest planting cost. According to a preliminary estimate, production and planting of 2500, 5000 and 10000 trees seedlings would cost per hectare, about US$ 520, US$ 980 and US$ 2090, respectively. The extend to which these costs can be lowered, is difficult to envisage. A compensation may be feasible at the end if the produced wood is sold as firewood or charcoal. Under this cost aspects, one might consider the alternative of choosing even wider spacing of the trees planted.

5.4 Carbon pools

The sequestration and dynamics of carbon are important issues of global warming. From land use in tropical areas, cropping is credited to be the largest carbon source to the atmosphere, making research on carbon stocks and growth rates of secondary forest a matter of high priority (GRACE, manuscript; RICHTER *et al.*, 1999).

The enriched systems and control treatment in this study provided a comparison of total carbon stocks. The accumulated aboveground carbon varied according to enriched systems. In the case of enrichment with *A. mangium*, this accumulation was 1.3 times greater than the control (Table 50). Compared to the total carbon stock, the enriched systems with *A. angustissima*, *C. racemosa* and *I. edulis* accumulated around 30% of the carbon aboveground, whereas *A. mangium* 40% and the control 20% (Table 50). The aboveground carbon stock represents a constant potential of manipulating carbon sequestration. The belowground carbon could be considered a real stock, since the system is maintained. The carbon released with the burn during land preparation, could be sequestered in the fallow period, and over time, if the system continues, the balance is stable.

The annual capacity of carbon sequestration of the enriched fallow systems varied from 5 to 10 t ha^{-1} $year^{-1}$ (Table 50), but GRACE (manuscript) citing FEARNSIDE (1995) estimates only 5 t ha^{-1} $year^{-1}$ are sequestered in fallow vegetation derived from abandoned farm land. When one considers the existing 800 thousand properties in the Brazilian Amazon region practicing slash-and-burn agriculture (IBGE, 1996) and, on average, at least two hectares are burned for crop production, the present enrichment could facilitate an annual carbon sequestration of the order of 8 to 16 million tons. Given that about 2×10^9 t yr^{-1} of carbon are released to the atmosphere, mainly by clearing of world's forest (RICHTER *et al.*, 1999), the studied enriched systems have a compensation potential of 0.5% to 1.0%.

Table 50: Average carbon stock (kg ha^{-1}) of different compartments of enriched fallow system and control after 2- 2.5 years of growth

Compartments		Carbon Stock (kg ha^{-1})				
		Acacia angustissima	*Clitoria racemosa*	*Inga edulis*	*Acacia mangium*	Control
Tree	leaves	130	40	130	1780	-
	wood	6640	3140	5260	14540	-
Fallow	leaves	1220	1400	930	960	1910
	wood	2800	3930	2180	2280	5410
Litter	tree	1510	240	1650	2350	-
	fallow	1590	2140	2130	1640	2190
Total Aboveground		**13890**	**10890**	**12280**	**23550**	**9510**
Root	0-30 cm	2740	1460	1970	2020	1410
Mineral soil	0-50 cm	33440	33750	32220	34260	36160
Total Belowground		**36180**	**35210**	**34190**	**36280**	**37570**
Total System		**50070**	**46100**	**46470**	**59830**	**47080**

5.5 Impact on land requirement and sustainability

Projections of population growth and food production indicate that by the year 2025 a great effort will be necessary to solve the problem of world hunger (VLEK and KOCH, 1992). To meet world food demand, more productive and sustainable systems with low environmental impact must be sought. The transfer to enriched fallow systems may meet part of this goal.

This question remains to how much fallow time could be saved by the fallow enrichment technique ? If it is assumed that the efficiency of a fallow in restoring soil fertility, or the capacity to produce another crop, is a function of its biomass, one can answer the question by means of the presentation in Figure 19.

A linear regression equation was estimated ($y = 0.54 + 6.52\ x$; $r^2 = 0.91$; $p = 0.008$ and $n = 10$), for biomass production (y) of fallow vegetation as a function of age (x), based on data of several authors obtained in the same region as the present study (DENICH 1989; NUNEZ 1995; DIEKMANN 1997; KATO 1998a and 1998b; WIESENMÜLLER 1999). Since the control plot data of the present experiment were not consistent with the various fallow development measurements on surrounding plots, done in the past, it was normalized the present data to fit the estimated regression line by multiplying with a "site factor" of 0.6. The more vigorous growth of fallow vegetation in the present experiment may have been related to site history and recently soil fertility status, but also to relatively small study plots with more favorable growth conditions regarding light intensity and reduced competition at the plot borders. The results of the regression and the normalization of all fallow systems studied are presented in Figure 19.

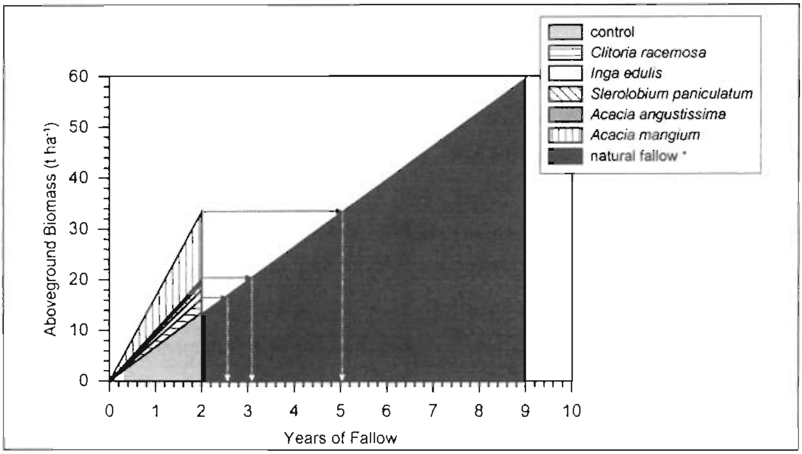


Figure 19: Aboveground biomass (kg ha^{-1}) of enriched fallow vegetation by planting *A. angustissima*, *C. racemosa*, *I. edulis*, *S. paniculatum* and *A. mangium* and control compared to natural fallow data analyzed by different authors in the same region ($^{+}$DENICH, 1989; NUNEZ, 1995; DIEKMANN, 1997; KATO, 1998a; KATO, 1998b; WIESENMÜLLER, 1999)

The normal fallow vegetation would take approximately five years to accumulate the same biomass as the enriched system with *A. mangium* in two years (Figure 2). This would imply that 3 years fallow could be saved. For the other enriched species, less time is saved: about one year for the system enriched with *A. angustissima, I. edulis*, and *S. paniculatum*, and down to 0.6 years for *C. racemosa*.

From this extrapolation, it seems obvious that the enrichment technique offers advantages. Even if one assumes that part of the increased biomass of the system with *A. mangium* could not remain on the field (energy and charcoal exploitation), a fallow reduction by one or two years would be a gain, if this can be attained without a lowering in crop productivity.

However, at this stage one should not indulge into speculations about the future consequences of fallow enrichment. It is necessary to keep in mind that so far, only one cycle of the system has been studied. In order to be positive about the sustainability of a system, one has also to study the impacts of changes on consecutive cycles. Attention should be paid to the following:

a) there is a lack of information on the amount of fallow biomass required for sustainability of the system. HÖLSCHER et al. (1997) in his study of the nutrient balance of a 9-year cycle, demonstrated the deficit character of the system. One can doubt, therefore, that the common 2 + 4 year cycle is sustainable. If it is accepted that farmers today are not in a position to prolong the fallow period, other ways have to be found to supplement nutrient deficits. Fallow enrichment may be one way but it can probably not be the only one;

b) not all aims of the fallow system are met by the accumulation of biomass. NYE and GREENLAND (1960) mention as equally important to eliminate the weeds and their seed bank during the crop period. CLAUSING (1994) showed that the weed control is a function of fallow time. This point is important because of the labor requirement of weeding and the weed impact on crop production.

The results of the present enrichment studies are encouraging but the approach has to be continued in long-term experimentation, and under consideration of additional measures (fertilizers) and possibly also alternative strategies.

5.6 Conclusions

The present study was motivated by the search for an alternative to natural fallow vegetation that would promote biomass accumulation, allow a shorter fallow period as currently practiced in the studied area, with minimum impact on crop production and the spontaneous fallow vegetation. Based on present results with enrichment of fallow vegetation, the following conclusions may be drawn:

a) the different species planted for enrichment, regardless of plant spacing, did not have negative impacts on dry and fresh weights of cassava roots. This fact will help stimulate farmers to adopt this new technology. However, planting trees for enrichment at the spacing of 1 m x 1 m should be carefully considered when food production is the main goal;

b) the crop and natural fallow vegetation did not suppress the survival of planted trees. After the cropping period, the initial fallow vegetation development influenced planted tree growth, showing that it is necessary during this period, that the trees are protected or already well established and able to support compete with the fallow vegetation;

c) in enriched fallows the spontaneous vegetation biomass was a function of tree-planting spacing and decreased when the number of planted trees increases, indicating competition for site resources. However, the systems with enrichment of the fallow vegetation were able to accumulate biomass in a shorter period of time. In addition, the wood produced by the trees may be used commercially, mainly in areas with high demand of wood for construction, energy or charcoal; and

d) considering the traditional system of one year cropping followed by a three years of fallow, the biomass accumulation of enriched fallow in 2 years of fallow, by planting trees, was equivalent up to 5 years of natural fallow, representing a 3 years gain for the farmer.

6. Summary

The agricultural system used in sequence with fallow vegetation was maize and cassava. In the experimental timetable, maize grew essentially as monocrop, subject only to interactions with the slashed and burned re-growth. The maize yield was 1890 kg ha^{-1}, larger than what is generally obtained in the area studied. Cassava divided site resources with planted trees for enrichment during eight months until its harvest at the age of one year The different trees planted for enrichment, regardless of spacing, did not have a negative impact on the dry weight of cassava root. The values of dry weight of cassava root varied as per the following: *S. paniculatum* (7120 kg ha^{-1}) > *A. angustissima* (6750 kg ha^{-1}) > *I. edulis* (6560 kg ha^{-1}) > *A. mangium* (6320 kg ha^{-1}) > *C. racemosa* (6100 kg ha^{-1}) > control (6060 kg ha^{-1}). The spacing of trees planted, regardless of species, showed a significant reduction of cassava dry root-weight at the spacing of 1 m x 1 m (10000 trees ha^{-1}) only, when compared to tree spacing of 2 m x 2 m. There appeared some advantage in having a light enrichment as seen from the following sequence: 2 m x 2 m (7140 kg ha^{-1}) > 2 m x 1 m (6660 kg ha^{-1}) > control (6060 kg ha^{-1}) > 1 m x 1 m (5610 kg ha^{-1}). These results show the possibility to maintain crop productivity in enriched fallow vegetation systems by planting leguminous trees. However, when food crops are the main goal, tree planting at the spacing of 1 m x 1 m should be carefully considered.

During the development of enriched fallow system planted trees and cassava grew together for as long as eight months and later on, after crop harvest, trees developed with the natural vegetation. In this chronosequence the values of tree survival at 24 months of age were as follows: *C. racemosa* (99%), *A. angustissima* (98%), *I. edulis* (97%), *A. mangium* (91%) and *S. paniculatum* (90%). At 24 months of age, trees planted to enrich fallow vegetation showed different behaviors relating to height- and Dbh growth. *Acacia mangium* presented the best performance (7.1 m height and 5.6 cm Dbh) followed by *I. edulis* (4.7 m and 3.5 cm), *A. angustissima* (4.5 m and 3.2 cm) and *C. racemosa* (3.4 m and 3.0 cm). Increased plant spacing did not influence growth in height, but caused significant reductions in growth in Dbh. The lowest diameters were observed at the spacing of 1 m x 1 m (3.2 cm) followed by 2 m x 1 m (3.9 cm) and 2 m x 2 m (4.3 cm).

The annual dynamics of tree growth, evaluated by average height increment - MHI during the study period, were similar for all species. These growth dynamics demonstrate the existence of four phases of tree development. The first phase was characterized as seedling "adaptation" and occurred during the first six months after planting. MHI values are small, and this phase coincided with a period of low precipitation. The second phase, called "growth explosion", began with the start of the first rainy season, between the sixth and the eighth month of growth, when the highest MHI values were observed for all species planted. "Competition" characterized the third phase and occurred from the eighth to tenth month. MHI values decrease due to fallow vegetation development, showing competition for site growth resources to exist. The last phase, denominated "stability" characterizes the maturation of the enriched fallow vegetation system. This phase, occurred between the 10th and the 24th month, and MHI values of trees planted tended slowly to decrease.

The trees studied were ranked by calculating the average monthly growth in height. *A. mangium* was considered as fast grower (32 cm month^{-1}), followed by *S. paniculatum* (22 cm month^{-1}), *I. edulis* (22 cm month^{-1}), and *A. angustissima* (17 cm month^{-1}) classified as of intermediary growth and the slow growing *C. racemosa* (11 cm month^{-1}).

The wood volume produced by the different trees planted is also an issue to be considered, because of the potential sale of wood (firewood, charcoal or stakes) which can represent an opportunity for the farmer to earn income. At the end of the experiment, when trees planted were 2.5 years old, wood volumes were: 60 m^3 ha^{-1} (*A. mangium*), 26 m^3 ha^{-1} (*I. edulis*), 20 m^3 ha^{-1} (*A. angustissima*), 18 m^3 ha^{-1} (*S. paniculatum*) and 15 m^3 ha^{-1} (*C. racemosa*). Considering the spacing, regardless of species, an increase of volume was observed by increasing the number of trees planted per hectare but at the expense of Dbh. In this case, the registered values were: 40 m^3 ha^{-1} (10000 trees ha^{-1}), 30 m^3 ha^{-1} (5000 trees ha^{-1}) and 20 m^3 ha^{-1} (2500 trees ha^{-1}).

All systems studied with enrichment accumulated more aboveground biomass than the control with no enrichment, and all enrichment systems reduced the biomass of fallow vegetation. The enriched fallow systems formed by planting *A. mangium, A. angustissima, S. paniculatum, I. edulis* e *C. racemosa* accumulated respectively 55600 kg ha^{-1}, 33520 kg ha^{-1}, 32150 kg ha^{-1}, 30020 kg ha^{-1} and 27220 kg ha^{-1} and the control 23970 kg ha^{-1}. The fallow enrichment system with 10000 trees per hectare produced the largest aboveground biomass accumulation and wood volume, but caused substantial fallow vegetation suppression. The largest biomass reduction was observed in the enrichment system with *A. mangium* (57%) at the spacing of 1 m x 1 m (10000 trees ha^{-1}). The smallest reductions of accumulating biomass for fallow vegetation of 12% and 11% were registered in the systems with *C. racemosa* planted at 2 m x 1 m (5000 trees ha^{-1}) and 2 m x 2 m (2500 trees ha^{-1}). This biomass accumulation reduction of fallow vegetation as a function of increasing the number of trees planted was also confirmed during evaluation of litterfall of one year In this case, the total circulated biomass within the systems, 17%, 29% and 47% were related to fallow vegetation developed in the enrichment systems of 1 m x 1 m, 2 m x 1 m and 2 m x 2 m, respectively.

The litterfall biomass composition between planted leguminous trees and fallow vegetation showed a ratio of 3:1 for enrichment systems formed with *A.*

angustissima, *I. edulis* and *A. mangium* and of 1:1 for *C. racemosa*. Thus, both spacing and type of species influenced the composition and the accumulated biomass circulation.

The annual primary productivity of roots (0-30 cm) in enrichment systems with *I. edulis*, *A. mangium* and *A. angustissima* was, respectively, 100%, 80% and 60% larger than in the control treatment without enrichment. In general, the enrichment systems concentrated about 70% of primary productivity in the first 15 cm of soil depth and the other 30% between 15-30 cm. Over a period of 17 months of fallow, systems with *A. angustissima*, *I. edulis* and *A. mangium* produced, respectively, 90%, 40% and 40% more root biomass than the control treatment without enrichment, while *C. racemosa* was practically the same as the control.

The enriched fallow systems presented the annual capacity of carbon sequestration varying from 10 to 30 t ha^{-1}. This represents an annual carbon sequestration of the order of 16 to 40 million of tons for the 800 thousand properties existing in the Brazilian Amazon region practicing slash-and-burn agriculture (IBGE, 1996) when, on average, at least two hectares are used annually with this type of agriculture.

The analysis of the impact of enrichment on fallow time reduction showed that when a linear biomass accumulation of the control treatment in the first nine years was considered as a reference, the enriched fallow systems provide in a total of 3 years (1 year of cropping + 2 years of enriched fallow) a biomass accumulation equivalent to up to five years of traditional fallow time.

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