Review Articles

THE USE AND INTEGRATION OF *INGA EDULIS* IN AGROFORESTRY SYSTEMS IN THE AMAZON – REVIEW ARTICLE

LOJKA B.[1], DUMAS L.[2], PREININGER D.[1], POLESNY Z.[1], BANOUT J.[1]

[1]*Institute of Tropics and Subtropics, Czech University of Life Sciences, Czech Republic*
[2]*Ecole Nationale Supérieure Agronomique de Montpellier, Montpellier, France*

Abstract

In Latin America this fast growing, acid-soil tolerant tree, which improves soil fertility through nitrogen fixation, is traditionally used to shade perennial crops such as coffee and cacao, provide firewood and charcoal, and produce a sweet pulp suitable for human consumption. I. edulis is also useful as a green manure with its high biomass production and helps control weeds and erosion, in alley cropping and other agroforestry systems. It has a great potential for restoring degraded soils as a part of agroforestry system. The information about the physiology, the use by local farmers, the silvicultural management and integration into agroforestry systems were collected. The species is commonly used in a large variety of agroforestry systems, however, it is surprising that it is still not the object of any improved breeding program and scientific information about this species are still rather scarce.

Key words: Peruvian Amazon, slash-and-burn farming, small farmers, weed control

INTRODUCTION

The genus Inga (*Leguminosea: Mimosoideae: Ingeae*) comprises c. 300 species of trees restricted to tropical America. It is and ubiquitous component of lowland and montane rainforest throughout the humid tropical zones from Mexico to Uruguay. The highest species diversity is concentrated it the Andean foothills of Peru, Ecuador, Colombia and in southern Central America (Pennington, 1997). *Inga edulis* Mart. is one of the most widely distributed and economically useful in the whole Amazon region. Sotelo-Montes and Weber (1997) investigated farmers' preferences for agroforestry tree species in the Peruvian Amazon and identified I. edulis as a high priority species for agroforestry research and development. This fast growing, acid-soil tolerant tree, which improves soil fertility through nitrogen fixation, is traditionally used to shade perennial crops such as coffee and cacao, provide firewood and charcoal, and produce a sweet pulp suitable for human consumption (Pennington and Fernandes, 1998). *I. edulis* is also useful as a green manure with its high biomass production and helps control weeds and erosion (Lawrence, 1995). It has a great potential for restoring degraded soils as a part of agroforestry system. Its presence throughout the Amazon basin sparked interest of scientists in further exploring the potential of this species for agroforestry and other environmental improving systems (Weber et al., 2001).

Several researchers have described *I. edulis* as an agroforestry tree with an important role for farmers and with a great adaptability for agroforestry systems (Szott 1987; Alegre 1991; Salazar and Palm 1991; Fernandes et al., 1991; Ricse and Szott, 1993; Flores 1997; Weber et al., 1997; Labarta and Weber 1998; Pennington and Fernandes, 1998). In the study of Labarta and Weber (1998) of economic valuation of agroforestry species in the Peruvian Amazon, *I. edulis* was ranked as a second most important trees species used by local farmers. In other study of agroforestry species prioritization (Villachica, 1995) *I. edulis* was generally cited as a tree with facilities to integrate agroforestry systems and with excellent characteristics to develop its use in agroforestry. The objective of this review was to collect most relevant information about the integration and use of this species in agroforestry systems.

Physiology and adaptation

The native range of *I. edulis* is in Amazonian Brazil, Bolivia, Peru, Ecuador and Colombia. The species has also been introduced across most of tropical South America, Panama and Costa Rica (Lawrence, 1993). It grows in hot, humid climates between 26°S and 10°N, and up to 2000 m elevation and it is most wide-spread in areas without a dry season or with a dry season of three to four months and annual rainfall of around 1500 mm (900–3500 mm). It can tolerate short droughts, although in its natural range some rain falls every month.

I. edulis thrives on all the kind of soils presented in Amazon from fertile alluvial Entisols to strongly-acid, infertile Ultisols. Sanchez (1987) described *I. edulis* as an excellent species for acid soils in the tropics. However, its growth is better on the non-flooding fields (TCA, 1997). Rapid growth of this species is also reported on highly acidic soil, low in nutrients and high in aluminum toxicity of abandoned pasture in Amazonian Ecuador (Neill and Nixon, 1998). Leblanc et al. (2005) have studied the N_2-fixing symbiosis with *I. edulis*. The four strains of symbiotic bacteria were closely related to *Bradyrhizobium japonicum* and to *Bradyrhizobium liaoningense*. The estimate of the percentage of N fixed from atmosphere out of total N in *I. edulis* seedlings was about 40% in the sand media treatments and 10% in the native soil.

Tree can reach a height of 30m and a stem diameter (dbh) of 60 cm, but usually grows much lower (up to 15 m) and branches from below 1 m. The branches form a broad, flat and moderately dense canopy. The bark is pale grey and smooth, with pale elongated lenticels. The young twigs are angular in cross-section and covered in line short brown hair. The leaves are once pinnate, up to 24 cm long, with four to six pairs of opposite leaflets. The terminal pair of leaflets is larger than the basal pair and can be up to 18 cm long and 11 cm wide. Between each leaflet there is a nectary gland on the leaf rachis. The inflorescences are dense axillaries spikes of flowers, each consisting of a calyx tube with 5 lobes (4–9 mm long), a corolla tube with five lobes (13–25 mm long) and a large number of white stamens up to 4.5 cm long united in a tube in the lower half (Pennigton, 1997).

In observations made in Brazilian Amazon (Falcao and Clement, 2000) the majority of plants had four flowering periods during the year, with flowering peaks in March, May, August/September, October/December, with some trees presenting five flowering peaks, followed by fruiting periods in April, June, September/October, and November/January. Three to four year old trees produced 20 000–100 000 flowers (mean 50 000) and 200–800 fruits (mean 500). Fruit set varied from 0.4 to 1.8%, with a mean of 1.1%. Fruit is a large, cylindrical, ribbed pod (40–180 cm long), filled with 2–3 cm long, usually black, oval seeds, which are covered with white, cottony, edible pulp. Fruit weight varied from 250 to 600 g, with only 22 ± 4% of edible pulp (Falcao and Clement, 2000). The wood has white-grey colour, with density of 0.54 g per cm^3 it is used mainly as a fuel wood but also for rural construction.

The use

I. edulis has a wide range of uses among small farmers in Latin America (Pennington and Fernandes, 1998). Its major products are fruit and firewood, and its major service functions are shade and soil improvement. Its common uses are as a mulch supply in alley cropping system, a pasture or soil improver, a shade for perennial crops; its potential is as a fuelwood and timber producer and in improved fallows. Other uses are presented in the literature such as living fence or medicine properties (Weber et al., 1997). The seeds are valued as a natural purgative for human and cattle.

The pods of *Inga edulis* are widely marketed and eaten as a fresh fruit in the Amazon. The fruits of low quality are consumed by the livestock, pigs, poultry or fishes. The important content of proteins in the seed confers the potential as a source of animal alimentation (TCA, 1997). The pulp covering the seeds is sweet and tender, contains over 80% water, is rich in carbohydrates and contains a lot of energy. It is eaten usually fresh but juice can be prepared and it has also a potential for producing alcoholic beverages. The nutritive value of fresh pulp is low, but the embryos of this and other *Inga* species can be cooked and are more nutritious than the fruit. The cooking probably degrades trypsin inhibitors and enhances palatability (Leakey, 1997). The fruits, which can normally be kept for only three to four days, can be stored in a refrigerator for three weeks.

Concerning the use of *I. edulis* as a wood source, it is generally appreciated for three reasons (1) it is a fast-growing tree, (2) its management is easy, and (3) it has a short fruit production period (6–10 years). The wood is used as fuelwood or in the rural construction. (TCA, 1997). It has a high calorific content and its weak smoke derangement, however, the species is not usually cultivated specifically for fuelwood or other woody products (Lawrence, 1993).

Leblanc et al. (2005) have described *I. edulis* as tree used traditionally for shade in coffee and cacao plantations throughout tropical America. Indeed it is one of the most popular shade trees for coffee and cacao plantations in the humid Neotropics. In Costa Rica, *I. edulis* is chosen in preference to *Erythrina poeppigiana* (another commonly used species for coffee shade trees) because it retains its leaves in the dry season, while *E. poeppigiana* does not (Nichols, 1990). In pastoral systems, *I. edulis* can provide shade for livestock (Weber et al., 1997).

Because of the *Inga edulis* use as a soil fertility improvement, the production of biomass is an important

Tab. 1: Potential of biomass growth (in dry matter) of *I. edulis*

Age of tree (years)	Trees per ha	Prunning (%)	Spacing (m)	DM of leaves (kg/tree)	DM of wood (kg/tree)	DM of leaves (Mg/ha)	DM of wood (Mg/ha)	Total above-ground biomass (Mg/ha)
1	5000	0	1 × 2	0.4	0.3	2.10	1.65	3.75
2	2500	50	2 × 2	1.1	2.4	2.80	6.08	8.88
3	1250	75	2 × 4	3.0	17.7	3.78	22.11	25.89
4	625	88	4 × 4	4.3	35.9	2.69	22.43	25.12
5	313	94	4 × 8	5.8	65.4	1.82	20.48	22.29
6	156	97	8 × 8	6.1	73.0	0.95	11.39	12.34

characteristic. Lojka et al. (2005) have studied the correlation of aboveground biomass growth with other growth parameters in Peruvian Amazon. Using statistical tools, they have determined that the diameter of the trunk is a more useful indicator of growth and biomass production. Highest correlation for wood biomass was obtained for dependence between wood biomass and diameter at 10 cm above soil surface: $y = 0.0466\ x^{2.3713}$; $R^2 = 0.924$. Also for leaf biomass high correlation was obtained for dependence on the trunk diameter: $y = 0.1564\ x^{1.1817}$; $R^2 = 0.792$. Using these equations with high correlation the potential aboveground biomass growth for *I. edulis* can be assessed (Table 1.).

The highest biomass production rates reported in the literature (Szott et al., 1995) reached as much as 31 Mg. $ha^{-1}.yr^{-1}$on acid soils at experimental station near Yurimaguas, Peru. By two years of age, average tree diameter at 10 cm above soil surface ranged up to 10.7 cm and average tree height up to 9 m. However, even at lower production levels of 8–12 $Mg.ha^{-1}.yr^{-1}$, *I. edulis* produced more biomass than other non-*Inga* species (Lawrence et al., 1995).

Oglesby and Fownes (1992) describe the patterns of *I. edulis* leaves decomposition. Cumulative N mineralization was negatively correlated with polyphenol content for earlier time periods (1 through 8 weeks) and with lignin for later time periods (4 through 12 weeks). Initial percent N and lignin/N ratio were not strongly correlated with N mineralization. The best chemical index of N release was the initial polyphenol/N ratio. General characteristics about *I. edulis* green mulch decomposition are also given by Leblanc et al. (2005). Hemicelluloses disappeared almost completely from the litter during the 20-week incubation period, while no significant lignin decay occurred. After a slow start, cellulose partially decayed following linear kinetics. The half-life of labile N, estimated as a Michaelis-Menten parameter, was 24 weeks. Polyphenol content in the biomass is usually higher and litter may be classified as low-quality, but long durable mulch. Due to the relatively large recalcitrant mulch fraction, the litter may promote carbon sequestration and long-term N accumulation in soil.

Because of these N-fixation characteristics, *I. edulis* is sometimes used to improve the soil fertility during fallows or in alley-cropping systems. Szott and Palm (1996) have studied the nutrient stocks in *I. edulis* fallows in Peruvian humid tropics during 53 months on a previously cultivated Ultisol (Acrisol). They concluded that total N stocks increased by 10% in the *I. edulis* treatment. Total stocks of P and K were 40–80% and 12% greater than initial values, but Ca and Mg stocks were reduced by 25–40%. Although there were net decreases of stocks of P, K, Ca and Mg in soil in all treatments during the fallow, storage of P and K in vegetation and litter in the *I. edulis* fallows offset losses of these nutrients from soil. These results suggest that leguminous biomass of *I. edulis* may increase N, P and K stocks, but that incomplete recuperation of Ca and Mg may limit the sustainability of short-rotation fallow-based systems on acidic, infertile soils.

According to the results of modelling study made by Lojka et al. (2008) in Peruvian Amazon, improved fallow with *I. edulis* has potential in increasing nitrogen levels in the soil, slightly increasing soil organic matter content, and maintaining soil phosphorus content compared to natural bush fallow.

Bishop (1983) describes a system developed in Amazonian Ecuador in which the fallow period in shifting cultivation sequences was intensified by the use of the Asian perennial forage cover crop *Desmodium ovalifolium* under *I. edulis*. In this case, both species improve soil fertility and reduce erosion. Alegre and Rao (1995) had studied the soil and water conservation by contour hedging of *I. edulis* in the Peruvian humid tropics. They concluded that contour hedgerow intercropping is recommended for moderate sloping lands, considering the long-term conservation of land resource and the potential for continuous cropping with minimal inputs. *I. edulis* has potential to restore degraded soils such as old pastures (TCA, 1997). There are examples of soil restoration in Latin America or in other countries such as in the Southern Cameroon (Kanmegne et al., 2003).

I. edulis is particularly interesting to control the weed development because, alone or in combination, this species can have an integral shade cover. Alegre et al. (1999), for instance, have found significant effect of weed reduction the association between *I. edulis* and *Centrosema* sp.

Silvicultural management

I. edulis is easily propagated by the seeds, which readily germinate inside the pod. The fruits are indehiscent and embryos viviparous. The seeds cannot be stored and must be planted immediately after opening the pot. Germination starts since the third day and reaches the rate of 90% (Villachica, 1996). Farmers usually selects the best pods and use direct sowding, making a small hole by the stick and putting 2–4 seeds inside. Concerning the seeds selection, farmers prefer to sow black-coloured seeds of these varieties in their experience; black seeds develop into so called “female” trees with abundant, annual fruit production while yellow seeds develop into “male” trees which do not produce much fruit (Weber et al., 1997). The preparation of seedling in the nursery and transplanting when they reach the height of 40–60 cm to the definitive place is also possible. One farmer in Ucayali region of Peruvian Amazon explained how he annually planted *I. edulis* in his crop field with seed from his home garden, but also collected seed from neighbours’ trees and from fruit bought in the market in a more haphazard rather than planned fashion. Selection for specified traits is often opportunistic (Brodie et al*.,* 1997).

For planting the species as fallow enrichment farmers establish *I. edulis* in their annual crops by direct sowing at approximately 5 × 5 m density (Brodie et al., 1997). After the crop harvest, the *Inga* trees are allowed to grow and form a closed canopy. The farmer estimates that 2–3 years is needed to suppress weeds and restore the fertility sufficiently to be able to sow annual crops. However, farmers often decide to establish some fruit trees under the canopy of *Inga* trees, but they must be pruned or thinned to avoid excessive shade. As a shade trees for coffee and cacao the distance of 10–15 m among the trees is used, while for hedgerow intercropping 4 m between hedges and 0.5 m between the trees inside the hedge is used (Villachica, 1996). There are also some experiences of establishment of pure plantation and it is expected to maintain the distances of 3–6 m. The trees can reach the height of 2–4.5 m in 12 months, depending on the soil fertility (Villachica, 1996).

Fructification starts in the second year with few pods and increases till the fifth year, when the production of one tree can reach as much as 300 pods (TCA, 1997). Mature fruits do not fall down the tree, but must be collected or shake-off by wooden sticks. The expected time for production is about 20 year, but farmers typically managed trees for fruit production for only 6–10 years, after which they are cut for firewood. Some farmers coppice the trees for firewood in a two-year rotation (ICRAF, 1996).

Integration into agroforestry systems

I. edulis is described as a tree which can be integrated in the agroforestry systems easily (Weber et al. 1997). The examples of this integration are particularly numerous from Peruvian Amazonian, and also from several other countries in Latin America. *I. edulis* and also other *Inga* species are most often associated with coffee or cacao trees as shade tree (Brack, 1993).

The cultivation of *I. edulis* is also adapted to wide variety of agroforestry association. It is possible to plant *I. edulis* with several annual, semi-perennial or perennial species. In alley-cropping, the potential associated crops are cassava (*Manihot esculenta*), banana (*Musa* spp.), pineapple (*Ananas comosus*), caimito (*Pouteria caimito*), carambola (*Averrhoa carambola*), avocado (*Persea americana*), coconut (*Cocos nucifera*), citrus trees (*Citrus* spp.), tropical cedar (*Cedrela odorata*), Brazilian nut (*Bertholletia excelsa*), moena (*Aniba* sp.) and mahogany (*Swetenia macrophylla*) (TCA, 1997). The practice of managing a fallow by small farmers in the Peruvian Amazon actually begins at the time the forest is cleared for cultivation, when valuable species such as palms, and those used later for timber, are spared during cutting. As the swidden is being cultivated, perennial species such as pineapple (*Ananas comosus*), banana (*Musa* spp.) and fruit and palm trees such as umarí (*Poraqueiba sericea*), uvilla (*Pouroma cecropiaefolia*) and peach palm (*Bactris gasipaes*), among others *I. edulis* is planted, interspersed among annual crops such as cassava (*Manihot esculenta*) or maize (*Zea mays*) (Unruch, 1988).

It can also be integrated in the crops succession. For example, near the city of Pucallpa (Peruvian Amazon), in the non-flooding land, the annual crops are establishment for 1–3 years (rice, maize, cassava and other associated crops: beans, chickpea, squash, etc.) followed by 1–5 years of perennial crops, typically plantain (*Musa* sp.), with associated fruit trees. As plantain yields decline between the sixth and eighth years, they are substituting plantains with fast producing fruit trees, most commonly *I. edulis*, which are then succeeded by longer living marketable fruit trees such as citruses (*Citrus* spp.)

and peach palm (*Bactris gasipaes*). These are often intercropped with pineapple, tree densities are low and management extensive (Brodie et al., 1997). Other example of integration is 30-year multistrata systems (Weber et al., 1997), that could provide a diverse and sustainable source of income to farmer: fruit and firewood from *I. edulis* beginning in year two; firewood, pulp and small poles from bolaina (*Guazuma crinita)* and charcoal and small poles from capirona (*Callycophylum spruceanum)* beginning in year three; fruit, seed and "heart of palm" from peach palm beginning in year five; lumber and large poles for construction from bolaina and capirona beginning in year ten; and high-value lumber from tornillo (*Cedrelinga cateniformis)* in year 30. The tree species could be sequentially interplanted in secondary forests, or planted separately in spatially distinct patches, strips, depending of the soil conditions.

Following the cropping cycle, many farmers in the Peruvian Amazon Basin plant Inga edulis into their woody fallows (Brodie et al., 1997; Sotelo-Montes and Weber, 1997). The use of I. edulis green manure for fallow improvement is well developed in some idingenous farming communities: they can maintain sustainable crop production for 5 years following a 5-year fallow enriched with selected I. edulis (Brodie et al., 1997). In the trial of Alegre et al. (2005) *I. edulis* was used as a fallow tree. An experiment was conducted at Yurimaguas (Peruvian Amazon) evaluating planted tree fallows of *I. edulis* and colubrina (*Colubrina glandulosa*), with and without centrosema (*Centrosema macrocarpum*) cover, compared with the traditional bush fallow in terms of weed suppression, their ability to increase subsequent crop production and overall economic benefits. The planted trees grew faster and accumulated more biomass than those in natural fallow. The trees effectively suppressed weeds, but the tree fallows did not increase crop yields compared with natural fallow and resulted in significantly lower yields in the third post-fallow season. The *Inga* and *Inga*+centrosema systems had the highest net present value; however, natural fallow had the highest benefit/cost ratio, due to its lower costs relative to the more intensive fallow systems. Long-term simulation and economic assessment of the use of *I. edulis* as improved fallow species compared to traditional bush fallow in Peruvian Amazon (Lojka et al. 2008) has shown that *Inga* fallow system can provide improvements to a range of soil biophysical measures and enables higher levels of farm outputs to be achieved. The economic analysis has also demonstrated higher profitability of this system, but only in long term. This can be attributed to improved soil fertility (thus higher crop yields), and to the additional product (firewood). But in adopting the *Inga* fallow system, smallholders will incur lower profits in the first years, because of the higher establishment and managements costs. It could take up to ten years for smallholders to begin making a profit above that achievable with the traditional fallow system.

Another study conducted at Yurimaguas by Fernandez et al. (1993) included double hedgerows of *I. edulis* were established and an annual rotation of upland rice and cowpea provided the test crops over several years. The effects of prunings applied as a mulch, application of fertilizers and repeated root pruning were investigated. Mulching increased rice grain yields and reduced seed yields of cowpeas. Recommendations included alley widths >4m, intense hedgerow pruning, incorporation of prunings into the soil, moderate fertilizer use, and use of species less prone to competition than rice. The species is also used in the contour hedgerows.

The home gardens are other example of agroforestry systems where *I. edulis* is often planted. As Padoch and Jong (1991) concluded from their study of species diversity of a riverside village near Iquitos (Peruvian Amazon), *I. edulis* was the most widely distributed tree species. The tree is also used in the silvopastoral systems in order to improve the soil physical and chemical characteristics (and thus the forage production) and also to produce shade for cattle and marketable products. Weber et al. (1997) described, for instance, the case of pastures diversified by planting timber species capirona (*Calycophyllum spruceaneum*) and *I. edulis* in low density or as live fence around the pastures.

In other regions of Latina America, most examples of integration of *I. edulis* in the agroforestry systems can also be found as shade tree for coffee or cacao (Brazil: Miranda et al., 1999; Costa Rica: Beer, 1991; Somarriba and Beer, 1999; Venezuela: Escalante et al., 1987). In Brazil, Brienza et al. (1998) described a change of traditional slash-and-burn farming to improved fallow system with the use of *I. edulis,* which was associated with the maize and cassava. The tree biomass production was accelerated after cassava harvest. Cassava yield was not influenced negatively by tree growth, nor were the trees affected by the crop. Example of alley cropping in Brazil is given by Ferraz et al. (2001): cowpeas and rice were grown in rotation in alleys of *I. edulis* and other leguminous tree species, but cowpea seed yield did not respond to the legume crop residues. Jardin et al. (2004) evaluated the initial behaviour of a 32-month-old agroforestry system, where copoacú trees (*Theobroma grandiflorum*) are intercropped simultaneously with forest species, *I. edulis* used for permanent shading and with different varieties of banana (*Musa spp*.) for temporary shading. *I. edulis* presented a very rapid initial growth; however, it may become inconvenient for use as a shade species, because of its horizontalized and very dense type of crown which produces excessive shading. Nonetheless, they conclude, that if employed with adequate spacing and guided by pruning, it may be appropriate as a component of agroforestry systems, due to the large quantity of biomass produced, which functions to protect and enrich the soil. Miranda et al. (1999) studied the performance of coffee plants shaded by *I. edulis*, compared to plants exposed to full sun. The results of two harvests of coffee showed that the yield in full sun was significantly higher.

Several examples of the use of I. edulis in agroforestry systems take place in Costa Rica. Kettler (1997) studied the effects of enriched fallows systems with I. edulis and other leguminous tree species. Biomass production of the fallow vegetation was of better quality and quantity in all fallow enrichment treatments. However, bean yields did not show a significant response to the fallow enrichment treatments. In other study from Costa Rica, timber species *Terminalia amazonia* was planted alone, and interplanted with *I. edulis* (Nichols and Carpenter, 2006). Measurements at 4, 8, and 11 years showed that *T. amazonia* grew significantly better when mixed with *I. edulis*. They analyzed the standing crops of vegetation and their nitrogen content and the data were consistent with the hypothesis that improved nitrogen nutrition accounts for improved growth of *T. amazonia* when interplanted with *I. edulis*.

A system being developed in Amazonian Ecuador is described (Bishop, 1983) in which the fallow period in shifting cultivation sequences is intensified by the use of the Asian perennial forage cover crop *Desmodium ovalifolium* under *I. edulis*. Both species improve soil fertility and reduce erosion. *I. edulis* produced fuelwood and charcoal in less than six years, produced fruit and provided good bee forage. The system was compatible with traditional patterns of cultivation, forming a six-year fallow in an eight-year field rotation with maize, beans and cassava. Pech and Bishop (1992) also recommended an improved tree fallow for soil restoration following production of short-cycle subsistence crops. *I. edulis* was seeded directly at 5 × 5 m spacing with *D. ovalifolium* establishment vegetatively or by seed. In three years, *Inga* grows to a height of 10–12 m. During this improved fallow, the *Inga/Desmodium* was successfully grazed with tropical hair sheep.

CONCLUSION

The actual situation in humid tropics of Latin America take aware the importance to develop agricultural systems which are able in the same time to reduce the land and population pressure and to increase local people income. By its physiological characteristics, *Inga edulis* appears to be a potential species to be used. It is easily adapted into agroforestry systems, it can be a good source of income by the fruit or wood sales for farmers and it is able to maintain and improve soil fertility. It is surprising that this widely used tree species in Latin America is still not the object of any improved breeding program and scientific information about this species are still rather scarce.

REFERENCES

Alegre J.C., Fernandes E.C.M. (1991): Runoff and erosion losses under forest low-input and alley-cropping on slopes: Y-433B. In: TropSoils Technical Report 1988–89. Raleigh, North Carolina State University, NC (USA), pp. 227–228.

Alegre J.C., Rao M.R. (1995): Soil and water conservation by contour hedging in the humid tropics of Peru. Agr. Ecosyst. Environ., 57: 17–25.

Alegre J.C., Arevalo L., Rao M.R. (1999): Barbechos mejorados para un manejo intensivo de los suelos en los trópicos húmedos. Seminario No 1 del Centro Ecorregional, Pucallpa 15 de julio de 1999.

Alegre J.C., Rao M.R., Arevalo L.A., Guzman W., Faminow M.D. (2005): Planted trees fallows for improving land productivity in the humid tropics of Peru. Agr. Ecosyst. Environ., 110: 104–117.

Beer J. (1991): Implementing on-farm agroforestry research: lessons learned in Talamanca, Costa Rica. Special issue: On-farm agroforestry research, based on an international workshop “Methods for participatory on-farm agroforestry research” Nairobi, 1990. Agroforestry Syst., 15: 229–243.

Bishop J.P. (1983): Tropical forest sheep on legume forage/fuelwood fallows. Agroforestry Syst., 1: 79–84.

Brack E.A. (1993): Plantas nativas utilizadas en el Perú en agroforesteria. Sistemas agroforestales, una opcion para el agro. Bosques y desarrollo, 4 (8): 22–34.

Brienza J.S., Santos W.E.S., Costa R.F.R., Vielheurer K., Denich M., Vlek P.L.G. (1998): Changing the slash-and-burn agriculture in Brazilian Eastern Amazonia by enriching the fallow vegetation. Proceedings of the Third SHIFT-Workshop, Manaus, Brazil, 15–19 March, 1998. A German-Brazilian Research Program.

Brodie A.W., Labarta-Chavarri R.A., Weber J.C. (1997): Tree germoplasm management and use on farm in the Peruvian Amazon: a case study from the Ucayali region, Peru. Research report, Overseas Development Institute, London and ICRAF, Nairobi.

Escalante F.E.E., Aguillar A.R., Lugo R.P. (1987): Identificación, evaluación y distribución espacial de especies utilizadas como sombra en sistemas tradicionales de café (*Coffea arabica*) en dos zonas del estado Trujillo, Venezuela. Venezuela forestall, 3 (11): 50–62.

FALCAO M.A., CLEMENT C.R. (2000). Phenology and productivity of inga (*Inga edulis*) in central Amazonia. Acta Amazonica, 30: 173–180.

FERRAZ A.S.L., SOUZA S.R., FERNANDEZ M.S. (2001): Cowpea production in alley cropping system with four leguminous species. Documentos – Embrapa Meio-Norte, No. 56 Avancos tecnologicos no feijao caupi. V Reuniao Nacional de Pesquisa de Caupi, Teresina, Brazil, 4–7 Dezembro.

FERNANDES E.C.M., DAVEY C.B., SÁNCHEZ J.A. (1991): Alley-cropping on an Ultisol in the Peruvian Amazon: mulch, fertilizer and hedgerow root-pruning effects: Y-433A. In: TropSoils Technical Report 1988–89. Raleigh, North Carolina State University, NC (USA), pp. 223–226.

FERNANDEZ E.C.M., DAVEY C.B., NELSON L.A. (1993): Alley cropping on an acid soil in the Upper Amazon: mulch, fertilizer, and hedgerow root pruning effects. Technologies for sustainable agriculture in the tropics: Proceedings of two international symposia held in San Antonio, TX and Denver, CO, 1990 and 1991 respectively.

FLORES S.P. (1997): Cultivo de frutales nativos Amazónico – Manual para el extensionista. TCA – Tratado de Cooperacion Amazonina. Lima, Peru.

ICRAF (1996). Annual report 1996. Internacional Centre of Reschearch in Agroforestry, Nairobi, Kenya.

JARDIN F.C.S., RIBIERO G.D., ROSA L.S. (2004): Preliminary evaluation of agroforestry system at the "Agua Verde" Project. ALBRAS, Barcarena, Para – I. Revista de Ciencias Agrarias, 41.

KANMEGNE J., BAYOMOCK L.A., DEGRANDE A., ASAAH E., DUGUMA B. (2003): Establishment of Inga edulis and Calliandra calothyrsus in improved fallow systems in southern Cameroon. Agroforestry Syst., 58 (2): 119–124.

KETTLER J.S. (1997): Fallow enrichment of a traditional slash/mulch system in southern Costa Rica: comparisons of biomass production and crop yield. Agroforestry Syst., 35: 49–57.

LABARTA-CHÁVARRI R.A., WEBER J.C. (1998): Economic valuation of tangible goods of agroforestry species in the Peruvian Amazon Basin. Revista Forestal Centroamericana 7.

LAWRENCE A. (1993): *Inga edulis*: A tree for acid soils in the humid tropics. NFT Highlights 93-04. Nitrogen Fixing Tree Association.

LAWRENCE A. (1995): Inga: Farmers knowledge and use of Inga species. In: Evans D.O., Szott L.T. (ed.): Nitrogen Fixing Trees for Acids Soils: 142–151. Proceeding of Workshop, July 3–8, 1994, Turrialba, Costa Rica. Nitrogen fixing tree special issue.

LAWRENCE A., PENNINGTON T.D., HANDS M.R., ZÚNIGA R.A. (1995): *Inga*: High diversity in the neotropics. In: Evans D.O., Szott L.T. (eds.): Nitrogen fixing Trees for Acid Soils: 130–141. Proceeding of Workshop, July 3–8, 1994, Turrialba, Costa Rica.

LEAKEY R.R.B. (1993): Potential for novel food products from agroforestry trees: a review. Food Chemistry, 66 (1): 1–14.

LEBLANC H.A., MCGRAW R.L., NYGREN P., ROUX C. (2005): Neotropical legume tree *Inga edulis* forms N2 fixing symbiosis with fast-growing Bradyrhizobium strains. Plant and soil, 275: 123–133.

LOJKA B., PREININGER D., LOJKOVA J., BANOUT J., POLESNY Z. (2005): Biomass growth and farmer knowledge of *Inga edulis* in Peruvian Amazon. Agricultura Tropica y Subtropica, 38: 44–51.

LOJKA B., LOJKOVA J., BANOUT J., POLESNY Z., PREININGE D. (2008): Performance of an improved fallow system in the Peruvian Amazon – modelling approach. Agroforestry Syst., 72: 27–39.

MIRANDA E.M., PEREIRA R.C.A., BEGRO C.L. (1999): Performance of six coffee lineages (*Coffea arabica* L.) in shade conditions and full sun in Acre state, Brazil. Ciencia e Agrotecnogia, 23.

Neill A.D., Revelo N. (1998): Silvicultural trails of mahagony (Swietenia macrophylla) interplanted with two Inga species in Amazonian Ecuador. In: Pennington T.D., Fernandes E.C.M. (eds.): The genus Inga utilization. The Royal Botanic Gardens, Kew, UK, pp. 141–150.

NICHOLS J.D. (1990): *Inga edulis* with coffee in Peréz Zeledón, Costa Rica. Nitrogen Fixing Tree Research Reports: 145.

NICHOLS J.D., ROSEMEYER M.E., CARPENTER F.L., KETTLER J. (2001): Intercropping legume trees with native timber trees rapidly restores cover to eroded tropical pasture without fertilization. Forest Ecol. and Manage., 152: 195–209.

NICHOLOS J.D., CARPENTER F.L. (2006): Interplanting *Inga edulis* yields nitrogen benefits to *Terminalia Amazonia*. Forest Ecol. and Manage., 233: 344–351.

Oglesby K.A., Fownes J.H. (1992): Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. Plant and soil, 143: 127–132.

PADOCH C., DE JONG W. (1991): The house gardens of Santa Rosa: diversity and variability in an Amazonian agricultural system. Economic Botany, 45 (2): 166–175.

PECH R.B., BISHOP J.P. (1992): Management of secondary trees species in agroforestry systems to improve production sustainability in Amazon Ecuador. Agroforestry Syst., 17: 123–135.

PENNINGTON T.D. (1997): The genus Inga Botany. The Royal Botanic Gardens, Kew. London, UK.

PENNINGTON T.D., FERNANDES E.C.M. (1998): The genus Inga Utilization. The Royal Botanic Gardens, Kew, London, UK.

RICSE A., SZOTT L.T. (1993): Informe final Proyecto Inga/Perú III Centro de Investigación para el desarrollo (IDRC) Exploración del potencial del genero *Inga* y otras especies nativas de la Amazonia peruana como componentes en sistemas agroforestales para el trópico húmedo. INIA, Pucallpa, Peru.

SALAZAR A.A., PALM C.A. (1991): Alley-cropping on Ultisols: Y-425. In: TropSoils Technical Report 1988–89. North Carolina State University, Raleigh, NC (USA), pp. 221–22.

SÁNCHEZ P.A. (1987): Soil productivity and sustainability in agroforestry systems. In: Steppler H.A., Nair P.K.R. (eds.): Agroforestry: A decade of Development. ICRAF, Nairoby, Kenya.

SOMARRIBA E. BEER J. (1999): Sistemas agroforestales con cacao en Costa Rica y Panamá Cacao en Sistemas Agroforestales. Agroforestria en las Americas, 22 (6).

Sotelo-Montes C., Weber J.C. (1997): Priorización de especies arbóreas para sistemas agroforestales en la selva baja del Perú. Agroforestería en las Americas, 4 (14): 12–17.

SZOTT L.T. (1987): Improving the productivity of shifting cultivation in the Amazon basin of Peru through the use of leguminous vegetation. (A doctoral thesis), Dpt. of Soil Science, North Carolina State University, USA.

SZOTT L.T., PALM C.A. (1996): Nutrient stocks in managed and natural humid tropical fallows. Plant and Soil, 186: 293–309.

TCA (Tratado de Cooperacion Amazonica) (1997). Cultivo de frutales nativos amazonicos Manual para el extensionista.

UNRUCH J.D. (1988): Ecological aspects of site recovery under swidden-fallow management in the Peruvian Amazon. Agroforestry Syst., 7: 161–184.

VILLACHICA H. (1995): Priorizacion de árboles multiproposito para su mejoramiento. Informe de las cinco primeras etapas del proceso de priorizacion. Septiembre, Lima, Peru.

VILLACHICA H. (1996): Frutales y Hortalizas Promisorios de la Amazonia. Tratado de Cooperacion Amazonica, Lima, Peru.

WEBER J.C., SOTELO-MONTES C., LABARTA-CHÁVARRI R.A. (1997): Tree domestication in the Peruvian Amazon Basin – working with farmers for community development. Agroforestry Today, 9 (4): 4–8.

WEBER J.C., SOTELO-MONTES C., VIDAURRE H., DAWSON I.K., SIMONS A.J. (2001): Participatory domestication of agroforestry trees: an example from the Peruvian Amazon. Development in Practice, 11: 425–433.

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Corresponding author:

Ing. Bohdan Lojka, PhD.
Institute of Tropics and Subtropics
Czech University of Life Sciences Prague
Kamýcká 129
165 21 Prague 6-Suchdol
Czech Republic
email: lojka@its.czu.cz