Evaluation of *Inga edulis* and *I. samanensis* for firewood and green-mulch production in an organic maize alley-cropping practice in the humid tropics

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Ideally, a tree species used in alley cropping should create a suitable micro-environment for the companion crop and provide additional income. *Inga edulis* and *I. samanensis* were evaluated for firewood and green mulch production in an organic maize (*Zea mays* L.) alley-cropping practice in the humid tropics of Costa Rica. In 2001, trees were pruned and leaves plus twigs were distributed evenly in the alleys for green mulch and the branches were removed for firewood. Phosphate rock was applied at a rate of 90 kg P ha^{-1} to half of the treatments one week after pruning. Maize was planted in the alley- and mono-cropping plots immediately after P application, and was harvested 120 days later. The experiment was repeated three months after the first maize harvest. There was no response to P applications. At first harvest, both tree species were similar for green mulch and firewood production, averaging 6.2 and 9.5 Mg ha^{-1}, respectively, for 2001 and 2002. Nitrogen content in the green mulch averaged 168 kg ha^{-1}. Maize grain yields in the monocropping plots averaged 3.5 Mg ha^{-1} compared to 1.9 Mg ha^{-1} in the alley-cropping plots. At second harvest, maize grain yields in the monocropping plots declined to 1.9 Mg ha^{-1}, and were statistically similar to the alley-cropping plots at 1.7 Mg ha^{-1}. Because the alley-cropping plots produced both maize and firewood, they were more productive by the second harvest. Alley cropping maize with *I. edulis* or *I. samanensis* could provide tropical farmers with much needed firewood while maintaining maize yields.

Keywords: Organic agriculture; Biomass; Low-input agriculture; Phosphate rock

Alley cropping is a promising practice for sustainable low-input soil management ventures in the humid tropics (Oyetunji *et al*., 2003). One of the most important decisions in designing an alley-cropping practice is the selection of a tree species. The tree species should match the site conditions and create a micro-environment suitable for the companion crop (Garrett and McGraw, 2000). Trees should also provide additional income. Using trees of high economic value, such as black walnut (*Juglans nigra* L.) or pecan [*Carya illinoinensis* (Wangenh.) K. Koch], to produce added income in alley-cropping practices is well established in North American agro-forestry. In tropical agro-forestry, research has focussed on selecting N_2-fixing trees due to poor soil fertility and socio-economic conditions associated with small tropical farms. Trees that fix N_2 contribute significantly to the nutrient cycle, and can be used to create green mulch when pruned. In organic agriculture, chemical fertilizer is not permitted, so alternative sources of N_2 are necessary. However, often the N_2-fixing trees are not used to produce a harvestable product that can increase profits. One harvestable tree product is firewood, which is a valuable energy source for small tropical farms.

Trees in the genus *Inga* may have potential for producing firewood while creating a suitable micro-environment for alley cropping. *Inga* trees are used for shade in coffee and cacao plantations (León, 1998) and can produce large amounts of wood biomass (Pen-

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nington, 1998). The wood of *Inga* species is good for use as firewood due to its high gross calorific value. In a study conducted in Ecuador, *I. edulis*, *I. ilita*, *I. punctata*, *I. oerstediana, and I. vera*, produced wood with calorific values similar to or greater than values reported for fast-growing *Eucalyptus* species (440 Gj ha^{-1} yr^{-1}) and substantially higher than values reported for loblolly pine (*Pinus taeda* L.) (168 Gj ha^{-1} yr^{-1}) or aspen [*Populus tremula* subsp. *tremuloides* (Michx.) Á. Löve & D. Löve] (63 Gj ha^{-1} yr^{-1}) (Murphy and Yau, 1998).

One promising species, *Inga edulis* Mart survives in acidic soils high in Al and Mn (Palm *et al.*, 1992). It also produces more biomass than other species commonly used in tropical agro-forestry such as *Gliricidia sepium* (Jacq) Steud and *Erythrina poeppigiana* (Walp.) Skeels. (Fahretti and Fisher, 1998). The capacity of *I. edulis* to produce high biomass in acidic and toxic aluminum soils in the humid tropics was also demonstrated by Kanmegne *et al.* (2000). It was found that *I. edulis* produced 26 Mg ha^{-1} of leaf biomass after nine months of regrowth when planted at a density of 3333 trees ha^{-1} (Kanmegne *et al.* 2000). Another *Inga* species, *I. samanensis* Uribe grows naturally near rivers and at the borders of wet forests in Costa Rica and may have potential as a shade tree in agro-forestry (Zamora and Pennington, 2001). Biomass production research information on these species was not found to enable the development of recommendations for managing them for use in alley-cropping practices with respect to their ability to produce green mulch and firewood.

The objectives of this study were to (1) measure the green mulch and firewood production of *I. edulis* and *I. samanensis*, (2) determine the N content of the green mulch, (3) compare maize (*Zea mays* L.) grain production in an organic maize alley-cropping practice using *I. edulis* and *I. samanensis* to a maize monocropping practice, and (4) determine if the addition of phosphate rock would improve the productivity of these cropping practices at this location.

Materials and Methods

The experiment was conducted at the Organic Farm at EARTH University, which is located 75 km from the Caribbean coastal plain of Costa Rica (10°10′ N, 83°37′ W, 95 m above sea level). EARTH University is in a climatic zone classified as a premontane wet forest basal belt transition. Annual rainfall averages 3464 mm (evenly distributed) and the annual mean temperature is 25.1°C. The soil is classified as Thaptic Hapludand with the following characteristics: pH, 5.1; exchangeable acidity, 0.3 meq 100 g^{-1}; Ca, 4.2 cmol kg^{-1}; Mg, 1.4 cmol kg^{-1}; K, 0.15 cmol kg^{-1}; P, 14.2 mg kg^{-1} (modified Olsen); Cu, 28.1 mg kg^{-1}; Fe, 109 mg kg^{-1}; Zn, 18 mg kg^{-1}; and Mn, 5.8 mg kg^{-1}. The experimental area was previously used for banana [*Musa* (group AAA) sub group 'Cavendish' 'Valery'] and ginger (*Zingiber officinale* Roscoe) production. However, the land was fallowed for approximately 10 years prior to this study. The vegetative cover on the research site, which consisted of small trees, shrubs, grasses, and herbaceous forbs, was hand-cleared using a machete.

Thirty plots measuring 25 m × 25 m were established in 1998. Each plot was separated by a 0.5-m deep by 1-m wide ditch. The total experimental area covered 2 ha. Seeds of *I. samanensis* and *I. edulis* were collected from trees grown near the university campus in 1998. Seeds were planted in pots and grown until seedlings were approximately 0.5-m tall. In 1999, seedlings were transplanted into 20 plots. Six rows of seedlings were established in each plot in an east-to-west orientation. Rows were spaced 4 m apart with 0.5-m spacing between seedlings within a row, giving a planting density of 5000 trees ha^{-1}.

Trees reached approximately 2 m in height in April 2000 and were pruned to 1.5-m high by 1-m wide at that time. Trees were pruned again in April 2001 so that approximately 5–10% of the foliage remained. Roots from several trees in each replicate were examined for nodules and all trees were determined to be well nodulated.

In October 2001, all plots were hand-weeded. After weeding, branches were pruned so that approximately 5–10% of the foliage remained. The pruned material was separated into green mulch which consisted of leaves plus twigs <1 cm in diameter, and firewood which were branches >1 cm in diameter. The green mulch was distributed evenly in the alleys between the tree rows and the firewood was removed from the plots. Pruned material was collected from five trees in each of three central rows within each plot to determine green mulch and firewood biomass. Biomass was not measured in the plots fertilized with phosphate rock in 2001, because P was not applied until one week after pruning. The green mulch and firewood from each of the 5 trees row^{-1} in each plot were pooled and weighed to determine fresh weight. Sub-samples of approximately 250 g of green mulch and firewood were dried at 60°C for 72 h and 120 h, respectively. To determine N content of the green mulch, sub-samples from each plot were ground to pass through a 686-micron screen. Nitrogen concentration was determined using standard Kjeldahl techniques. Nitrogen accumulation was calculated by multiplying the N concentrations by the corresponding dry weight.

Phosphate rock was applied one week after the October 2001 pruning at a rate of 90 kg P ha^{-1} to half of the *I. samanensis*, *I. edulis*, and monocropping treatments. Immediately following P application, the maize variety Guararé 8128 was planted in all plots at the seeding rate of 40 000 plants ha^{-1}. Maize rows were 1 m apart and 2 seeds were sown using a dibble every 50 cm within the row. In the plots with trees, there were four rows of maize in the alleys between each two rows of trees. Trees were lightly pruned six weeks after the maize was planted to reduce shading. Only small branches overhanging the alleys were removed and the material was left in the alleys.

Maize was harvested by hand 120 days after sowing in February 2002. To determine maize biomass (stover + ear maize) 25 maize plants in every treatment (5 $plot^{-1}$) were randomly harvested (cut at soil level without harvesting roots) from the two central rows. These plants were oven-dried at 60°C for 72 h for dry matter (DM) determination. Maize yields were determined by harvesting a 6-m length of row from the two central rows in all plots. Seeds were removed from the cob and weighed. A moisture tester (Dickey-John® Illinois, U.S.A.) was used to adjust yield to 14% moisture content.

After the maize harvest, plots were fallowed for three months. In May 2002, plots were hand-weeded, the trees were pruned, and maize was planted as described above for the October 2001 maize planting date. Additional P was not applied because of the slow P release of phosphate rock. A light pruning to reduce shading occurred six weeks after the maize was planted. Maize was harvested 120 days after sowing in September 2002, and yields were determined as previously described.

The experiment was established in a randomized complete block design with five replicates and six treatments: (1) *I. samanensis* without phosphate rock, (2) *I. samanensis* with phosphate rock, (3) *I. edulis* without phosphate rock, (4) *I. edulis* with phosphate rock, (5) no trees without phosphate rock, and (6) no trees with phosphate rock. Maize was seeded in all plots. All data were subjected to an analysis of variance and means were separated using the Duncan's Multiple Range Test and reported as different at the $P \leq 0.05$ level.

Results and Discussion

Phosphate rock

There were no significant differences for green mulch or firewood production when P was applied. One possible explanation for this lack of response is that the soils at this location are derived from volcanic ash and are acidic (pH 5.1). Acidic soils can cause Fe and Al concentrations to increase, forming insoluble Al-phosphate and Fe-phosphate compounds which make P unavailable. Another factor could be that the P was applied as phosphate rock. Phosphate rock was used because the research site is an organic farm. The rate of dissolution of phosphate rock in soil, and hence, the potential availability of P to plants depends on the properties of the phosphate rock and on soil factors such as pH and P sorption capacity (Saggar *et al.*, 1993). Phosphate rock releases P slowly into the soil and is more easily fixed in acid soils than more soluble P sources (Mokwuye and Hammond, 1992). It is possible that most or all of the P that was made available from the slow-release phosphate rock was fixed by the soils in this experiment and made unavailable for plant growth. The only report available in the literature on the response of *I. edulis* to P was Hand (1998) who referred to unpublished data in which an application of 100 kg P ha^{-1} increased the green mulch production in *I. edulis*.

Plants grown in soils low in available P can obtain up to 80% of P needed through arbuscular mycorrhiza hyphae (Marschner and Dell, 1994). *Inga* is known to form a mycorrhizal association (Fernandez, 1998). It is possible that the *Inga* trees obtained sufficient quantities of P for growth both with P and without P treatments because of their mycorrhizal association.

There were no statistical differences between plots fertilized with phosphate rock and unfertilized plots for N accumulation in the green mulch. One might expect the application of P to improve N_2 fixation (Graham, 1999) and increased N_2 fixation should increase the N accumulation of the plants. In a separate study using N^{15} isotope dilution techniques, it was found that N_2 fixation was not increased in *I. edulis* when the same rate of phosphate rock was applied to these soils (Leblanc, 2004).

There was no change in maize grain yield due to P in the mono- or alley-cropping treatments in either year. The lack of response in crop yields to P in tropical acid soils has been reported by Palm *et al.* (1992). Working with an Ultisol, no yield response was found with application of 25 kg of P ha^{-1} annually to rice (*Oryza sativa* L.) and beans (*Phaseolus vulgaris* L.) when alley-cropped with *I. edulis*, *Gliricidia sepium*, or *Senna reticulata* (Willd.) H.S. Irwin & Barneby (Palm *et al.*, 1992).

Because of the lack of difference between the unfertilized and P fertilized treatments, the tree prunings biomass and maize yield data collected were averaged over the P treatments.

Green mulch biomass and N content

Inga edulis and *I. samanensis* gave statistically similar yields of green mulch biomass, which averaged 7.4 and 5.0 Mg ha^{-1} for the October 2001 and May 2002 prunings, respectively (Table 1). Both prunings were taken following six months of tree regrowth at a plant density of 5000 trees ha^{-1}. Pennington (1998) reported a leaf biomass production of 4.4 Mg ha^{-1} for *I. edulis* after six months of regrowth when trees were planted at a density of 1111 trees ha^{-1}.

Sufficient green mulch was produced by both species to provide good ground cover. The N accumulated in the green mulch was similar in both species for both years and averaged 188.2 kg N ha^{-1} in 2001 and 142.0 kg N ha^{-1} in 2002. These values are similar to findings by Hand (1998), who found that *I. edulis* when grown in a fertile soil, accumulated 142 kg N ha^{-1}.

Giller and Wilson (1991) determined that the N content of 4 Mg ha^{-1} of leaves from a variety of trees is sufficient to meet the production of 2 Mg ha^{-1} of maize plus 3 Mg ha^{-1} of stover. The amount of N fertilizer recommended for maize production in the region of Costa Rica where this study was conducted is 100 kg N ha^{-1} (MAG, 1991). Thus, in this study, the N accumulated in the green mulch of both species should have been more than sufficient for maize production. However, not all the N accumulated in the green mulch was available to the maize crop. In a separate study, it was determined that in a 20-week period, *I. samanensis* released 47% of accumulated N and *I. edulis* 36% (Leblanc, 2004).

Maize grain

Maize grain yields were similar in the alley-cropping treatments when grown with either *I. edulis* or *I. samanensis*. This result is not surprising because both trees produced similar amounts of green mulch and had similar N contents.

In 2001, maize grain yields were greater in the monocropping plots (3.5 Mg ha^{-1}) compared to yields when grown with *I. edulis* and *I. samanensis* (2.0 Mg ha^{-1} average) (Figure 1). The poorer yields in the alley-cropping plots may have been due to competition between the trees and maize. Maize yields in the monocropping plots were relatively high due to the long fallow prior to planting, which may have resulted in good soil fertility.

In 2002, maize grain yield in the monocropping plots declined to 1.9 Mg ha^{-1} (Figure 1). This large reduction (46%) in grain yield is not surprising. It is well known that crop yields decline in the second or third year of cropping due to nutrient depletion if fertilizer is not applied to the soil. When maize was grown in an alley-cropping practice with *I. edulis* and *I. samanensis*, maize grain yields averaged 1.7 Mg ha^{-1}, which was not statistically different from the monocropping yields. In the second year, maize yield decline in the alley-cropping plots was only 15%; much less than the decline in the

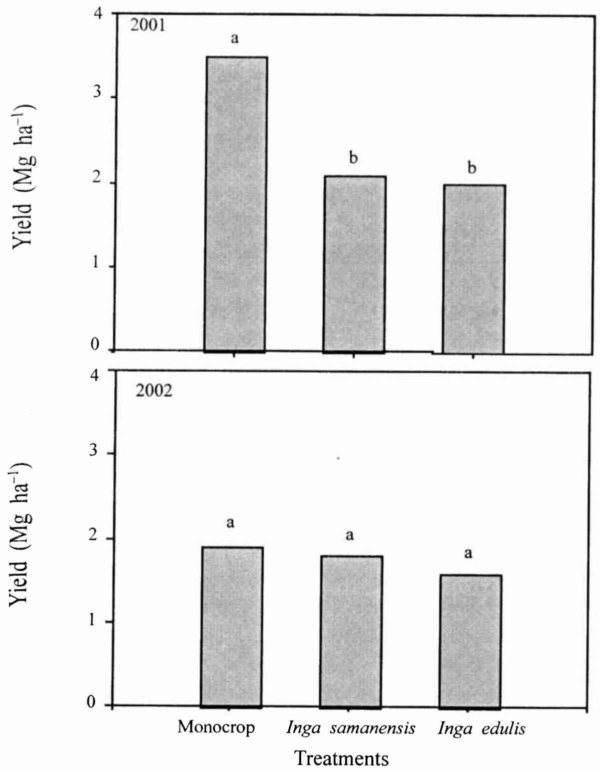

Figure 1 Maize grain yields planted as a monocrop and in an organic alley-cropping practice. Values with the same letter are not statistically different ($P \leq 0.05$)

monocropping plots. It is possible that N supplied by the legume trees helped maintain the maize yields in the alley-cropping plots.

Alley cropping, which allows for continuous cropping and soil fertility maintenance, has been proposed to replace traditional shifting cultivation (Sumberg and Atta-Krah, 1988). A practical example of this situation is reported in West Africa, where crop productivity declines rapidly following a shortened fallow period, below the minimal period of time needed to restore soil fertility to an acceptable level (Aihou *et al.*, 1999). To address this problem in a large part of West Africa, the development of cropping systems that allow sustainable crop production at an economically acceptable level with a minimal amount of external inputs, has been the focus of resource management research in recent years. Alley cropping is an example of a technique derived from that research (Kang *et al.*, 1981).

In organic agriculture, one way to maintain the fertility when producing a monocrop is to use organic fertilizers. However, for a low-value crop such as maize, these soil amendments would be too expensive for subsistence farmers in the humid tropics. Organic fertilizers, like compost, would best be used to fertilize crops of higher value such as organic vegetables.

Firewood

Inga edulis and *I. samanensis* were statistically similar for firewood production in 2001 and 2002 (Table 1). At the October 2001 pruning, which was prior to the first maize planting, firewood biomass averaged 9 Mg ha^{-1}. In 2002, prior to the second maize planting, firewood biomass averaged 10 Mg ha^{-1}. Pennington (1998) using a tree density of 1110 trees ha^{-1} found that *I. edulis* produced 24.9 Mg ha^{-1} yr^{-1} of stem biomass. This value is much higher than the 9–10 Mg ha^{-1}. However, in that study, all stem biomass produced in one year was collected, whereas in this case, only branches >1 cm in diameter were considered and the period of production was a mere six months.

Lemckert and Campos (1981) working with small farms (<25 ha) found that 54% of the farmers interviewed in the Caribbean region of Costa Rica use *I. edulis* as firewood. At that time, the average firewood use for small-family farms in Costa Rica was 19.8 kg family^{-1} day^{-1}. The average use per year of a family with six members was 7226 kg. In this study, both *I. edulis* and *I. samanensis* produced more firewood in six months than needed by a small family farm in one year. The extra firewood produced in one year could be sold for additional income.

Total harvested biomass

The total harvested product differences between the maize monocropping system and the alley-cropping practice was determined by a comparison of the yield of maize stover and maize grain in the monocropping system to the yield of maize stover, maize grain, green mulch, and firewood in the alley-cropping practice. The maize monocropping plots averaged for both years produced 6.6 Mg ha^{-1} of maize stover and maize grain (Figure 2). The alley-cropping plots averaged for both years produced 20.8 Mg ha^{-1} of total harvested biomass. The total biomass data clearly show the higher productivity of the *Inga* alley-cropping practice when compared to a monocropping system.

Table 1 Yield of firewood, green mulch, and total prunings and N content of green mulch of *Inga samanensis* and *I. edulis* in an organic alley-cropping practice in the humid tropics of Costa Rica

	I. samanensis	*I. samanensis* + P	*I. edulis*	*I. edulis* + P	$\bar{x}$
Biomass (Mg ha^{-1})					
2001					
Firewood	9.1	n/a	9.0	n/a	9.0
Mulch	8.6	n/a	6.1	n/a	7.4
Total	17.7	n/a	15.1	n/a	16.4
2002					
Firewood	10.2	8.6	11.0	10.4	10.0
Mulch	4.8	5.2	5.3	4.6	5.0
Total	15.0	13.8	16.3	15.0	15.0
Nitrogen content (kg ha^{-1})					
2001					
Mulch	212.8	na	163.6	na	188.2
2002					
Mulch	139.2	153.0	151.2	123.0	142.0

na, Not measured in 2001

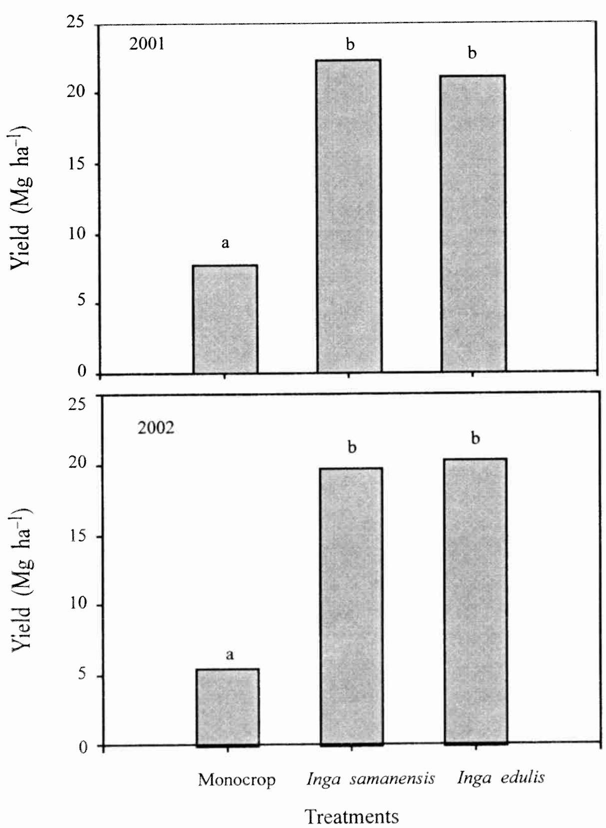

Figure 2 Maize biomass in a monocrop compared to maize plus tree biomass in alley-cropping. Values with the same letter are not statistically different ($P \leq 0.05$)

Economically harvestable products

The harvestable products that have economic value in this experiment are maize grain and firewood. In 2001, the maize monocrop averaged 3.5 Mg ha^{-1} of grain, whereas the alley-cropping practices averaged 11.0 Mg ha^{-1} of maize grain plus firewood (Figure 3). In 2002, the monocrop averaged 1.9 Mg ha^{-1} of grain, whereas the alley-cropping treatments averaged 11.7 Mg ha^{-1} of maize grain plus firewood. By the second year, maize grain yields were similar for the two cropping systems, and the alley-cropping practice was producing enough firewood for home use and for sale. In addition, the *Inga* trees may provide extra benefits such as weed control and soil erosion control from the application of green mulch.

Conclusions

The application of phosphate rock did not affect green mulch production, N accumulation of green mulch, firewood production, or maize grain yield in either the mono- or alley-cropping treatments. This lack of response could be due to the slow release of phosphate rock and the formation of Al-phosphate and Fe-phosphate in the soil making P unavailable.

Inga edulis and *I. samanensis* produced similar green mulch biomass and N accumulation in the green mulch. The amount of N accu-

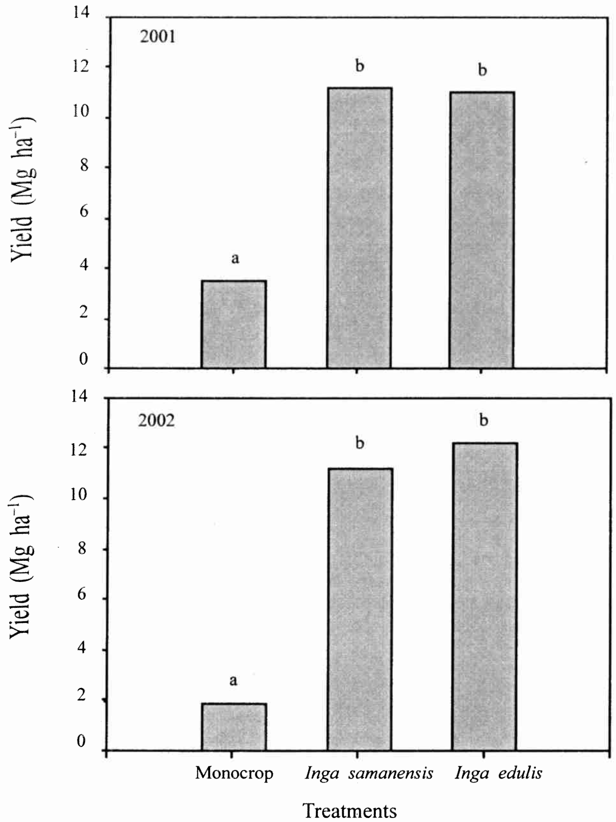

Figure 3 Yield of products with economic value: maize grain from monocropping and maize grain plus firewood from alley cropping. Values with the same letter are not statistically different ($P \leq 0.05$)

mulated in the green mulch should be more than sufficient for maize production if it were all available; however, not all the green mulch will decompose and release the accumulated N during a crop cycle. Maize grain yields in 2001 were greater in the monocropping plots compared to the alley-cropping plots. The poorer yields from the alley-cropping plots may be due to competition between the trees and maize. In 2002, maize grain yield in the monocropping plots declined 46%, probably due to nutrient depletion in the soil. Maize grain yields in the alley-cropping plots were similar to those in the monocropping plots in the second year. In addition to the maize grain, the alley-cropping plots also produced firewood. Both tree species produced more firewood in six months than is typically required for a small family farm and the extra firewood could be sold to provide additional income. The alley-cropping practice with either *I. edulis* or *I. samanensis* produced more total biomass and had a greater economic yield using the same land area as the monocropping practice. By the second year, the alley cropping practice produced similar maize grain as the monocropping plots and also produced a considerable amount of firewood. The present data support the premise that an alley-cropping practice using *I. edulis* or *I. samanensis* with maize may be a good alternative for sustainable subsistence farms in the humid tropics.

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References

Aihou, K., Sanginga, N., Vanlauwe, B., Lyasse, O., Diels, J. and Merckx, R. (1999) Alley cropping in the moist savanna of West-Africa: I. Restoration and maintenance of soil fertility on “terre de barre” Soils in Béning Republic, *Agrofor. Syst.* **42** 213–227

Fahretti, T. and Fisher, R.F. (1998) Tropical leguminous species for acid soils: studies on plant form and growth in Costa Rica, *Forest Ecol. Mgmt* **108** 175–192

Fernandez, E.C.M. (1998) Nodulation and N fixation in the Genus *Inga,* in: *The Genus* Inga *Utilization* (eds Pennington, T.D. and Fernandez, E.C.M.), Kew, London, England, The Royal Botanic Gardens, pp. 14–52

Garrett, H.E. and McGraw, R.L. (2000) Alley cropping practices, in: *North American Agroforestry*: *An Integrated Science and Practice* (eds Garrett, H.E. *et al.*), Madison, Wisconsin, U.S.A., pp. 149–188

Giller, K.E. and Wilson, K.J. (1991) *Nitrogen Fixation in Tropical Cropping Systems*, Wallingford, U.K., CAB International

Graham, P.H. (1999) Biological dinitrogen fixation: symbiotic, in: *Principles and Applications of Soil Microbiology* (eds Sylvia, D.M., Fuhrmann, J.J., Hartel, P.G. and Zuberer, D.A.), New Jersey, U.S.A., Prentice Hall, pp. 322–345

Hand, M.R. (1998) The uses of *Inga* in the acid soils of the rainforest zone: alley-cropping sustainability and soil-regeneration, in: *The Genus* Inga *Utilization* (eds Pennington, T.D. and Fernandez, E.C.M.), Kew, London, England, The Royal Botanic Gardens, pp. 53–86

Kang, B.T., Wilson, G.F. and Sipkens, L. (1981) Alley cropping maize (*Zea mays* L.) and *Leucaena*

(*Leucaena leucocephala* Lam) in Southern Nigeria, *Plant Soil* **63** 165–179

Kanmegne, J., Bayomoch, L.A., Duguma, B. and Ladipo, D.O. (2000) Screening of 18 agroforestry species for highly acid and aluminum toxic soils of the humid tropics, *Agrofor. Syst*. **49** 31–39

Leblanc, H.A. (2004) Evaluation of *Inga* spp for dinitrogen fixation and nitrogen release in humid-tropical alley cropping, *Ph. D. dissertation*, Univ. of Missouri, Columbia, MO, U.S.A.

Lemckert, L. and Campos, C. (1981) Producción y consumo de leña en las fincas pequeñas de Costa Rica, *Proyecto Leña y Fuentes Alternas de Energía*, CATIE-ROCAP # **596-0089**, p. 54

León, J. (1998) *Inga* as shade for coffee, cacao and tea: historical aspects and present day utilization, *in: The Genus* Inga *Utilization* (eds Pennington, T.D. and Fernandez, E.C.M.), Kew, London, England, The Royal Botanic Gardens, pp. 101–115

MAG (1991) *Aspectos Técnicos Sobre Cuarenta y Cinco Cultivos Agrícolas de Costa Rica*, Ministerio de Agricultura Y Ganadería, Dirección General de Investigación y Extensión Agrícola, Costa Rica, 560 pp.

Marschner, H. and Dell, B. (1994) Nutrient uptake in mycorrhizal symbiosis, *Plant Soil* **159** 89–102

Mokwuye, A.U. and Hammond, L.L. (1992) Myth and science of fertilizer use in the tropics, in: *Myths and Science of Soils of the Tropics* (ed. Sanchez, P.A.), Madison, Wisconsin, U.S.A., SSSA, No. **29**, pp. 121–134

Murphy, R.J. and Yau, P.Y. (1998) Calorific value, basic density and ash content of *Inga* species, in: *The Genus* Inga *Utilization* (eds Pennington, T.D. and Fernandez, E.C.M.), Kew, London, England, The Royal Botanic Gardens, pp. 29–39

Oyetunji, O.J., Osonubi, O. and Ekanayake, I.J. (2003) Contributions of an alley cropping system and arbuscular mycorrhizal fungi to maize productivity under cassava intercrop in the derived savannah zone, *J. Agric. Sci*. **140** (3) 311–316

Palm, C.A., Salazar, A.A., Szott, L.T. and Fernandez, E.C.M. (1992) Long-term performance of alley cropping on acid soils of the Amazon basin, in: *Proceedings of International Conferance on Alley Farming* (eds Kang, B.T., Osiname, A.O. and Larbi, A.), Nigeria, pp. 379–392

Pennington, T.D. (1998) Growth and biomass production of *Inga* species, in: *The Genus* Inga *Utilization* (eds Pennington, T.D. and Fernandez, E.C.M.), Kew, London, England, The Royal Botanic Gardens, pp. 15–28

Saggar, S., Hedley, M.J., White, R.E., Gregg, P.E.H., Perrott, K.W. and Cornforth, I.S. (1993) Assessment of the relative agronomic effectiveness of phosphate rocks under glasshouse conditions, *Fertil. Res*. **34** 141–151

Sumberg, J.E. and Atta-Krah, A.N. (1988) The potential of alley farming in humid West Africa— a reevaluation, *Agrofor. Syst*. **6** 163–168

Zamora, N. and Pennington, T.D. (2001) *Guabas y Cuajiniquiles de Costa Rica*, INBIO, 200 pp.