*Renewable Agriculture and Food Systems: 26(1); 24–30* doi:10.1017/S1742170510000396

# Efficiency of an agrosystem designed for family farming in the pre-Amazon region

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**Accepted 28 July 2010; First published online 10 September 2010** **Research Paper**

## Abstract

In the humid tropics, the continuous use of the same area reduces nutrient availability and increases the incidence of weeds. To circumvent these obstacles, farmers practice itinerant agriculture associated with slashing and burning with negative effects on the local and global environment. In search for a suitable system for humid tropical agriculture, the objective of this study was to investigate the performance of no-till alley cropping in conjunction with the use of annual legume crops grown during the off-season. The experiment was implemented in a one-hectare alley cropping system in which the leguminous tree clitoria (*Clitoria fairchildiana* R.A. Howard) was used. The experimental design consisted of randomized blocks with four replications of the following treatments: Stylosanthis (*Stylosanthis capitata*), showey rattlebox (*Crotalaria spectabilis*), sunn hemp (*Crotalaria juncea*), jack bean (*Canavalia ensiformis*) and a control with clitoria alone, without an annual legume. In January 2007 and 2008, maize was planted in each alley. One hundred and twenty days after annual legumes were sown, the total biomass was recorded. Weed incidence was assessed 35 days after maize planting. Analyses of the C, N, P, K, Ca and Mg contents of the legumes were carried out. To assess soil organic matter (SOM), composite soil samples from the surface 0–5 cm were collected from experimental plots. Two adjacent areas were also sampled for comparison: a 10-year-old secondary forest and an area of conventional tillage. The SOM was fractionated using a densitometric and a granulometric method. Conventional systems reduce the silt and free light organic matter fractions more than no till. The use of annual legumes changes the composition of the weed community, replacing the more aggressive types with those less competitive. The use of showy rattlebox (*C. spectabilis*) may be an effective strategy for reducing weed density in the long-season crop. Furthermore, relative to the use of leguminous trees alone, higher yields of maize can be obtained with the use of showy rattlebox (*C. spectabilis*) and sunn hemp (*C. juncea*) without the application of additional N.

**Key words:** leguminous, weeds, soil organic matter, maize productivity

## Introduction

In the humid tropics, high temperatures and rainfall combined with soils derived from clastic sedimentary rocks result in unfavorable conditions for sustainable agrosystems. In particular, continuous use of the same area reduces the nutrient availability and may result in an increase of weed pressure[1,2]. To circumvent these obstacles, farmers in the pre-Amazon region practice itinerant agriculture associated with the slashing and burning of natural vegetation that grows during the fallow periods between slash and burn events. Under this system, the burnt ash increases nutrient availability, while the shifting of cultivation prevents the accumulation of weed seed banks, which become inexorable if successive cultivation is used[3]. Approximately 80,000 ha are slashed and burnt every year in the pre-Amazon region[4].

Unfortunately, with the growing number of farmers and the consequent reduction in fallow periods, this system no longer offers economic and social benefits to offset its negative effects on the local and global environment. In the local environment, the demand for farmable area leads to successive fires between ever-decreasing fallow periods, eliminating the species most susceptible to fire and allowing the most resistant species to predominate. This cycle reduces biodiversity and impoverishes ecosystems[5]. At the global scale, biomass burning contributes up to 1.1 Pg of carbon emissions each year, because approximately 95% of the total carbon of the biomass is released by burning. In Brazil (one of the five largest emitter countries), an estimated 70% of total $CO_2$ emissions is derived from uncontrolled burning of forests which emits approximately 69 tons of $CO_2$ for each hectare burned[6]. Thus, replacing the slash and burn system in the pre-Amazon region is justified first by the strong need to increase agricultural productivity and second by the need to reduce the environmental impact of burning tropical rainforests.

Besides the traditional focus on production, agricultural producers must also balance conflicting demands involving social, political, economic, technological and environmental issues[7]. Therefore, it is apparent that a farming system is needed, which does not rely on the application of fertilizers, which has a low cost, is consistent with the socio-economic and technological practices of the farmers and can sustain production and maintain soil fertility[8]. Several authors have recommended no-till farming of leguminous trees planted in alleys as an alternative to slash and burn methods in the humid tropics. Desirable characteristics of such a system include its ability to recycle nutrients[9], to improve soil fertility indicators[10] and to reduce weed incidence when combined with the use of annual legumes[3]. In addition, the high capacity of such a system to produce plant biomass makes it a viable alternative for increasing soil carbon stocks and reducing greenhouse gases[11].

If an agrosystem is to become established for use in humid tropical conditions, it must not only be environmentally appropriate but also attractive to farmers for its environmental and agricultural functions, such as reducing the incidence and aggressiveness of weeds, producing a sufficient quantity of residues for soil coverage and increasing the availability of soil nutrients and organic carbon through recycling[12]. In the search for a suitable system for humid tropical agriculture, the objective of this study was to investigate the performance of no-till alley cropping in conjunction with the use of annual legume crops grown during the off-season. Specifically, we sought to assess the ability of the system to increase the fractions of soil organic matter (SOM), suppress weeds that produce seeds at the end of the rainy season and sustain maize productivity in a dystrophic Plinthosol in the pre-Amazon region.

## Materials and Methods

The experiment was conducted between 2006 and 2008, encompassing two annual crop harvests in north-central Maranhão state (3°36″ south latitude, 45°24″ west longitude) at an altitude of 60 m. The local soil was classified as a typical silty and loamy dystrophic Plinthosol with the following characteristics in the 0–20 cm layer: $K = 2.7$ $\text{mmol}_c\ \text{dm}^{-3}$; $Ca = 11.0$ $\text{mmol}_c\ \text{dm}^{-3}$; $Mg = 7.0$ $\text{mmol}_c\ \text{dm}^{-3}$; (H + Al) (a proxy for total acidity) = 56.0 $\text{mmol}_c\ \text{dm}^{-3}$. Sand = 230.0 g $\text{kg}^{-1}$; silt = 680.0 g $\text{kg}^{-1}$; clay = 90.0 g $\text{kg}^{-1}$. pH ($H_2O$) = 4.3. BS (percent base saturation) = 27.0%; P = 8.0 mg $\text{dm}^{-3}$; bulk density = 1.3 Mg $\text{m}^{-3}$. The experiment was implemented in a one-hectare alley cropping system in which the leguminous tree clitoria (*Clitoria fairchildiana* R.A. Howard) was planted at a spacing of 2.60 m × 0.50 m. During 6 years prior to the experiment, the clitoria plants were pruned at the beginning of the rainy season and its branches were applied between the rows of the annual crops of cassava, maize or rice.

The experimental design consisted of randomized blocks with five treatments and four replications. Each block consisted of two alleys with a row of *C. fairchildiana* in the center and five plots of 5.2 m × 5.0 m planted with the following treatments: *Stylosanthis capitata* (stylosanthis), *Crotalaria spectabilis* (showy rattlebox), *Crotalaria juncea* (sunn hemp), *Canavalia ensiformis* (jack bean) or a control (clitoria alone, without an annual legume).

The annual legumes were sown in continuous rows with 0.5-m spacing between plants at a rate of 7.7 g $\text{m}^{-2}$ for the stylosanthis, showy rattlebox and sunn hemp. The jack bean was sown at a spacing of 0.50 m × 0.30 m, with three seeds per hole. Sowing took place in June 2006 and 2007, a period coinciding with the planting of off-season crops, in order to suffocate weeds that grow during this phase and that produce seeds that germinate at the same time as the main crop in the following year.

In January 2007 and 2008, at the beginning of the rainy season, four rows of maize (*Zea mays* L.), cultivar AG 5020, were planted in each alley at a spacing of 0.70 m × 0.30 m, with two seeds per hole. Maize seedlings were later thinned to five plants per linear meter. Fertilizer was applied during maize planting (20 kg $\text{ha}^{-1}$ N, 80 kg $\text{ha}^{-1}$ P, 60 kg $\text{ha}^{-1}$ K and 2 kg $\text{ha}^{-1}$ Zn), according to the most commonly used Brazilian fertilizer handbook[13]; side-dressing fertilization was not applied.

One hundred and twenty days after annual legumes were sown, their total biomass was cut and applied on the soil surface. Weed incidence was assessed 35 days after maize planting. Weed species of the family Commelinaceae were evaluated separately during the second year only. To assess weeds and legumes, samples were taken using a 50 × 50-cm iron square at four random locations per plot. Thirty days before maize planting, clitoria branches were pruned at a height of 0.50 m, weighed and evenly distributed on the soil in each plot mixed with residues of the annual leguminous crops. A sample of leaves and twigs was removed for chemical analysis. The weed, annual legume and clitoria samples were dried in a forced-air ventilation oven at 60°C until a constant weight was attained.

Analyses of the C, N, P, K, Ca and Mg contents of the legumes were carried out according to methods described in Tedesco et al.[14]. Lignin analysis was performed according to the methodology of Van Soest (1967)[15]. Phenolic compounds were analyzed using hot water and the Folin–Ciocalteu reagent. Polyphenol levels were expressed as gallic acid equivalents. The plant residue quality index (PRQI) of Tian et al.[16] was calculated using the formula $\text{PRQI} = [1 \div (a \times \text{C/N} + b \times \text{L} + c \times \text{P})] \times 100$, where *a*, *b*

**Table 1.** Nutrient contents and residue quality of the leguminous species used; average of 2 years.

| Parameter | Stylosanthis | Showy rattlebox | Sunn hemp | Jack bean | Clitoria |
|---|---|---|---|---|---|
| Nitrogen (g ha$^{-1}$) | 31.52 (± 2.90) | 32.28 (± 3.12) | 33.63 (± 3.00) | 26.81 (± 2.53) | 27.81 (± 2.40) |
| Phosphorus (g ha$^{-1}$) | 1.33 (± 0.14) | 1.57 (± 1.20) | 1.85 (± 0.20) | 2.20 (± 0.23) | 1.07 (± 0.13) |
| Potassium (g ha$^{-1}$) | 4.48 (± 0.47) | 7.53 (± 0.61) | 4.06 (± 0.32) | 2.08 (± 0.19) | 2.67 (± 0.32) |
| Calcium (g ha$^{-1}$) | 3.95 (± 0.45) | 4.45 (± 0.39) | 2.11 (± 0.15) | 1.77 (± 0.12) | 2.31 (± 0.25) |
| Magnesium (g ha$^{-1}$) | 0.46 (± 0.05) | 0.56 (± 0.43) | 0.51 (± 0.04) | 0.25 (± 0.03) | 0.47 (± 0.03) |
| C/N ratio | 9.38 (± 1.10) | 9.19 (± 0.86) | 8.59 (± 0.64) | 9.00 (± 0.86) | 9.03 (± 1.20) |
| Lignin (%) | 8.16 (± 0.89) | 10.27 (± 0.96) | 8.57 (± 0.69) | 6.75 (± 0.52) | 15.87 (± 1.70) |
| Polyphenols (%) | 0.64 (± 0.07) | 0.54 (± 0.08) | 0.28 (± 0.03) | 0.47 (± 0.53) | 1.282 (± 0.30) |
| Plant residue quality index | 13.27 (± 1.46) | 11.92 (± 1.50) | 13.50 (± 1.40) | 14.78 (± 1.65) | 9.76 (± 0.89) |

Figures in parenthesis indicate standard deviation.

and $c$ are coefficients of the content contribution of each compound, represented by the values 0.423, 0.439 and 0.138, respectively; C/N = Carbon/Nitrogen ratio and L and P = percentages of lignin and polyphenols, respectively. The residue quality measurements of each annual legume species used are shown in Table 1.

For soil analysis, samples were collected with a duty auger, from a 0 to 20 cm layer. Soil samples were analyzed for pH (0.01 M $CaCl_2$ suspension, 1 : 2.5 soil/solution, v/v), P and exchangeable K, Ca, Mg (resin) and H + Al (SMP method), according to standard methods used by the Agronomic Institute of Campinas[17]. CEC was determined as: K + Ca + Mg + H + Al. Sum of bases (SB) were calculated as: K + Ca + Mg and base saturation percentage (BSP) as SB/CEC × 100. We collected soil samples for the determination of soil bulk density with 100 cm$^3$ volumetric cylinders, with three replicates per plot. Each replicate was a core sample from 0 to 15 cm depth. The soil from each cylinder was dried in a lab oven at 105 °C. Bulk density (ρs) was calculated as w/v, where w is the soil weight in the dried sample and v is the core volume.

To assess SOM, soil samples were collected using an Eijkelkamp Edelman sand auger at a depth of 0–5 cm at the end of the maize cycle in the second year. In each plot, three composite samples, each made up of ten individual samples, were collected. For comparison, two adjacent areas were also sampled: a 10-year-old secondary forest and an area of conventional tillage where rice and corn had been cultivated for 2 years. Within these areas, 21 individual samples were collected using a zigzag pattern, from which four composite samples were obtained. After collection, the samples were air dried, broken up, homogenized and passed through a 2.0-mm sieve.

The SOM was fractionated using two methods: a densitometric method using a 1.8 g cm$^{-3}$ sodium iodide (NaI) solution and a granulometric method described by Machado[18]. Wet oxidation with potassium dichromate was used for carbon analysis of each soil fraction ($C_{sf}$) following the method described by Embrapa[19]. The C stocks were estimated as follows: Csf (Mg ha$^{-1}$) = carbon content (g kg$^{-1}$) × bulk density (g cm$^{-3}$) × 5 cm depth/10.

One hundred and thirty days after planting for two consecutive years, the maize was completely harvested from all plots and placed in the open air to dry. The harvested maize was weighed when its moisture content reached 16%.

Data were analyzed using the Statistica software[20]. Analysis of variance was performed, and means were compared using the Tukey test ($P \leqslant 0.05$).

## Results and Discussion

### Residue quality and nitrogen recycling

In humid tropical agrosystems, the quality and quantity of cover residues strongly affect the rate of decomposition and the time during which the soil is covered. In turn, the availability and the N and K use efficiency rely heavily on the time of soil coverage which enhances the soil rootability[10]. In this experiment, the annual legumes that produced the greatest quantities of biomass were jack bean and sunn hemp, followed by showy rattlebox. In conditions of water stress (during the first year), jack bean outperformed the *Crotalaria* species, but in the second year, the *Crotalaria* species were more productive. The pruning of clitoria at the end of the rainy season in the first year decreased its productivity in the following year. On the other hand, all species except for stylosanthis had higher growth in 2008 than in 2007. This finding is probably due to the greater intensity and more uniform distribution of rainfall at the end of the second year. The highest biomass of the annual legumes compensated for the lower production of the clitoria biomass and increased the quality of residues in the second year compared to the first year (Table 2). In the second year, the clitoria and clitoria + stylosanthis treatments did not provide enough biomass for soil coverage.

Soil coverage buffers sudden changes in temperature and humidity in this region. This is important because the local soils have a fragile structure and are generally prone to cohesion. Thus, moisture retention makes the soil less hard and improves rooting ability and nutrient use efficiency[10]. The levels of recycled nitrogen followed the normal trend in biomass production. However, potassium recycling was highest with *Crotalaria* species. The efficient use of nitrogen and potassium under humid tropical conditions

**Table 2.** Dry biomass, nutrient contents and residue quality of the mixture (clitoria + annual species) and of the clitoria, applied to each treatment; average of 2 years.

| Parameter | Stylosanthis | Showy rattlebox | Sunn hemp | Jack bean | Clitoria |
|---|---|---|---|---|---|
| Year I | | | | | |
| Dry biomass (Mg ha$^{-1}$) | 6.20 (± 0.58) | 6.90 (± 0.86) | 7.70 (± 0.65) | 8.51 (± 0.91) | 5.61 (± 0.65) |
| Nitrogen (kg ha$^{-1}$) | 174.85 (± 6.90) | 197.34 (± 12.91) | 225.61 (± 19.32) | 233.72 (± 18.85) | 155.70 (± 13.90) |
| Potassium (kg ha$^{-1}$) | 17.41 (± 1.89) | 24.65 (± 3.00) | 17.71 (± 1.90) | 20.43 (± 2.54) | 14.61 (± 1.51) |
| C/N ratio | 9.03 (± 1.23) | 9.11 (± 0.87) | 8.97 (± 0.78) | 9.05 (± 1.00) | 9.09 (± 1.10) |
| Lignin (%) | 15.00 (± 1.17) | 14.84 (± 1.20) | 13.94 (± 1.45) | 12.73 (± 1.30) | 15.76 (± 1.45) |
| Polyphenols (%) | 1.25 (± 0.15) | 1.16 (± 0.12) | 1.00 (± 0.98) | 1.13 (± 0.08) | 1.30 (± 0.15) |
| Plant residue quality index | 9.33 (± 0.10) | 9.55 (± 1.11) | 10.21 (± 1.50) | 10.53 (± 0.98) | 9.24 (± 0.12) |
| Year II | | | | | |
| Dry biomass (Mg ha$^{-1}$) | 2.03 (± 0.19) | 5.50 (± 0.76) | 6.90 (± 0.71) | 5.15 (± 0.47) | 1.65 (± 0.11) |
| Nitrogen (kg ha$^{-1}$) | 57.05 (± 4.98) | 173.16 (± 16.87) | 187.74 (± 16.78) | 138.76 (± 12.43) | 44.96 (± 3.70) |
| Potassium (kg ha$^{-1}$) | 5.84 (± 0.62) | 34.27 (± 2.98) | 25.25 (± 2.58) | 11.27 (± 1.42) | 4.07 (± 0.56) |
| C/N ratio | 9.17 (± 1.09) | 9.07 (± 1.32) | 8.66 (± 1.11) | 9.04 (± 0.87) | 9.05 (± 0.83) |
| Lignin (%) | 14.58 (± 1.56) | 11.84 (± 1.43) | 10.37 (± 0.98) | 9.77 (± 0.74) | 15.24 (± 1.23) |
| Polyphenols (%) | 1.26 (± 0.12) | 0.83 (± 9.23) | 0.58 (± 0.61) | 0.79 (± 0.86) | 1.23 (± 1.71) |
| Plant residue quality index | 9.74 (± 1.43) | 10.92 (± 1.56) | 12.14 (± 1.15) | 12.34 (± 1.35) | 9.17 (± 1.00) |

Figures in parenthesis indicate standard deviation.

depends on optimal root functioning and the availability of these nutrients during the growth period[21,22]. In a region where rainfall can reach 1200 mm during the crop growth period, nutrient availability is reflected in resistance to vertical movement of surplus water. Therefore, the best coverage treatments for growing crops are those that provide the best rooting conditions and greatest N and K recycling and uptake from residues[10].

## Effect on soil organic matter

SOM levels were reduced by the soil management in alley cropping systems with annual legumes relative to the secondary forest area, but the decrease in SOM was even greater in the conventionally tilled area. The largest reductions in the conventionally tilled area were in the clay and silt fractions, with the latter reduced by more than five fold compared to annual legume treatments and by more than eight fold compared to the conventional tillage (Fig. 1). According to Feller and Beare[23], changes in carbon stocks in agriculturally managed soil are dependent on soil texture. In silty soils such as those found in this experiment, greater changes are expected to occur in the silt fraction.

The light fraction supposedly represents an intermediate pool between non-decomposed residues and humified SOM and therefore is not only the less stable fraction, but also the most sensitive to changes in management practices mainly in humid tropical conditions[24]. Several authors[25,26] have reported the high sensitivity of the light fraction to changes caused by management of tropical soils. On the other hand, according to Christensen[27], variations in the light fraction depend primarily on factors that alter the balance between the production and decomposition of residues. Soil tillage in the conventional system and biomass quality in annual legume treatments decreased the SOM light fraction levels in this experiment. The free light fraction is important in tropical silty and loamy soils because of its effect on what Shepherd et al.[28] called the *ephemeral stability of aggregates*, which is reflected in improved physical indicators such as infiltration rate and aeration capacity. These effects can be extremely important in the humid tropics, especially during periods of higher levels of rainfall, when excess water limits plant growth[29]. There were no differences in humified organic matter among any of the treatments. Environmental factors, such as the ready availability of water, oxygen, nutrients and high temperatures, all of which were present in this experiment, can eliminate the differences that varying systems of soil management have on these fractions of organic matter[30].

## Capacity to suppress weeds

The lack of effective weed management practices is widely reported to be a major constraint in alternative agriculture[31]. Under Brazilian humid tropical conditions, no-till farming without herbicides is feasible only if farmers can reduce the incidence of weeds that grow from May to August after the long-season crop is harvested. The high growth of the weeds in this period might produce seed banks that infest the crops sown at the beginning of the next rainy season[3]. In this experiment, the presence of annual legumes sown in the first year was not enough to reduce weed incidence in the primary crops in the following year (Table 3). The lack of rain, which discourages the growth of the legumes and the high coefficient of variation, may have been the primary causes of the lack of significant differences between weed biomasses from areas with residues versus the control area.

Several other factors may contribute to the variation of weeds in alley cropping systems, including shading of the area during tree growth, which reduces the abundance of

**Table 3.** Density and biomass of monocotyledons and dicotyledons, years I and II, and ratio biomass of *Commelina* sp.:total year II in the treatments the mixture (clitoria + annual species) and clitoria alone 30 days after sowing.

| | **Stylosanthis** | **Showy rattlebox** | **Sunn hemp** | **Jack bean** | **Clitoria** |
|---|---|---|---|---|---|
| Year I | | | | | |
| Monocotyledons | | | | | |
| Density (plant $m^{-2}$) | 33.5 | 25.5 | 52.5 | 25.2 | 25.8 |
| Biomass (kg $ha^{-1}$) | 1352 | 822 | 1398 | 982 | 1692 |
| Dicotyledons | | | | | |
| Density (plant $m^{-2}$) | 68.0 | 25.0 | 52.0 | 15.2 | 19.8 |
| Biomass (kg $ha^{-1}$) | 560 | 525 | 495 | 505 | 385 |
| Total | | | | | |
| Density (plant $m^{-2}$) | 101.5 | 50.5 | 104.5 | 40.5 | 45.5 |
| Biomass (kg $ha^{-1}$) | 1912 | 1348 | 1892 | 1488 | 2078 |
| Year II | | | | | |
| Monocotyledons | | | | | |
| Density (plant $m^{-2}$) | 70.0 | 44.0 | 51.0 | 46,5 | 103.0 |
| Biomass (kg $ha^{-1}$) | 485 | 440 | 415 | 490 | 740 |
| Dicotyledons | | | | | |
| Density (plant $m^{-2}$) | 51.0 a | 16.0 b | 25.0 ab | 23.5 ab | 34.0 ab |
| Biomass (kg $ha^{-1}$) | 190 | 100 | 80 | 110 | 60 |
| Total | | | | | |
| Density (plant $m^{-2}$) | 121.0 ab | 60.0 b | 76.0 ab | 70.0 ab | 137.0 a |
| Biomass (kg $ha^{-1}$) | 675 | 540 | 495 | 600 | 800 |
| Ratio *Commelina* sp.:total biomass (%) | 62.2 | 58.3 | 70.7 | 61.6 | 53.1 |

Different letters indicate significant differences calculated by Tukey test ($P < 0.05$).

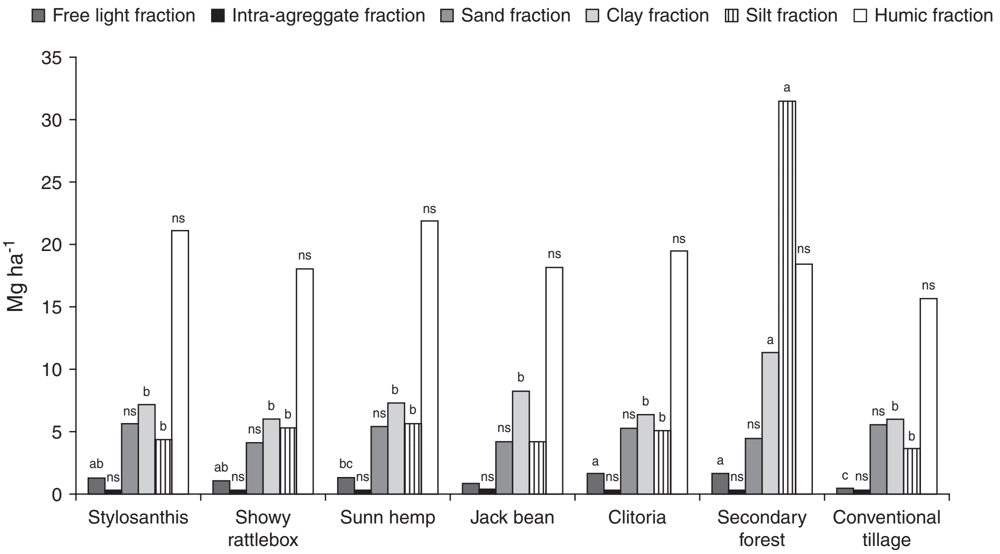

**Figure 1.** Carbon fraction quantities of the soil under the mixture (clitoria + annual species), clitoria alone, secondary forest and conventional tillage, at a depth of 0–5 cm. Different letters indicate significant differences calculated by the Tukey test ($P < 0.05$). ns = not significant.

species that are sensitive to shade. Also, the improvement in soil fertility indicators resulting from the decomposition of residues applied over time alters the competitiveness of the crop and the composition of weeds[32]. The change in the composition of the weed community in this experiment is evident by comparing these results to those of Araújo et al.[3]. The previous study took place in the same location in 2004 and found more than 60% dominance of weedy Poaceae species, especially *Leptochloa virgata* and *Panicum laxum*. Four years later, in the second year of this experiment, *Commelina* species predominated, comprising more than 58% of weed species in all treatments and

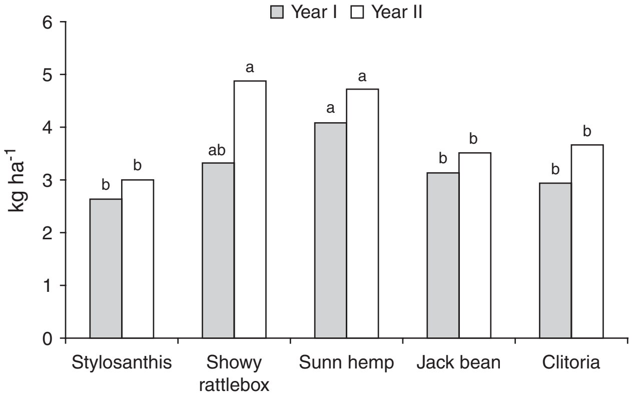

**Figure 2.** Maize yield in the years I and II and in the treatments the mixture (clitoria + annual species) and clitoria alone. Different letters indicate significant differences by the Tukey test ($P < 0.05$).

reaching as much as 70% in the *C. juncea* treatment. Changes in species composition often occur when management practices and crop rotation systems are altered. Organic carbon levels and nutrient availability are the primary factors that influence the changes in species composition of weeds in cultivated fields[33].

During the second year, although there was greater growth of legumes, the overall weed density was reduced only in the *C. spectabilis* treatment. With this treatment, weed density was reduced to less than half that of the control (Table 3). The impact of soil coverage on weed density is probably related to biological effects of allelopathic products derived from residue decomposition and the physical weed barrier brought about by the presence of the material used for covering the soil surface. The inhibitory effect of *Crotalaria* species on weeds has also been shown[34].

### *Maize productivity*

Despite the low productivity of the annual legumes, used as the green manure, only the residue application of sunn hemp affected maize productivity during the first year (Fig. 2). Productivity increased during the second year in all treatments, but the highest yields were attained with *Crotalaria*. According to Moura et al.[10], the productivity of maize under the conditions of this experiment is determined by the efficiency of absorption and remobilization of N and K, which depend on their availability and the rooting ability conditions provided by soil coverage.

Because side-dressing fertilization was not used, the differences in productivity in this experiment can only be explained by the greater nutrient availability and nutrient use efficiency derived from the annual legumes. In a study in the same region[9], different coverage residues were compared. Those authors concluded that for maize productivity, the application of greater quantities of N and K from high-quality leucaena residues was equivalent to long-term coverage with low-quality residues for the leguminous trees *Inga edulis* and *C. fairchildiana*, both of which produced 48% more than the control treatment without residue application.

Over the 2 years of this experiment, the *Crotalaria* treatments produced more biomass, N and K and produced 30% more grain than control treatments. This indicates that soil covered with lower-quality clitoria residue was less productive than the mixture of residues. Some studies[11] have reported that an appropriate combination of different quality residues can improve uptake from N recycling and that the combination of leucaena (higher quality) with *Acacia mangium* (low quality) grown in alleys can produce up to four times more grain of maize than soil without residues. In this experiment, mixtures of residues with sunn hemp and showy rattlebox performed better in the second year, even with the low quantities of clitoria, because they provided greater quantities of N and six times more K than the control.

## Conclusion

Under humid tropical conditions, soil used for farming experiences rapid decreases in total levels of organic matter relative to areas of secondary forest, primarily by decreasing levels of silt and clay fractions. However, the use of legumes in no-till systems may be more environmentally appropriate for compensating for these decreases than conventional systems that reduce the silt and free light organic matter fractions of the soil. Moreover, the soil management in this system changes the composition of the weed community, replacing the more aggressive types (such as the Poaceae species) with those less competitive (such as the *Commelina* species).

From an agronomical point of view, the use of *C. spectabilis* sown at the end of the rainy season seems to be an effective strategy for reducing weed density in the long season crop. Furthermore, relative to the use of leguminous trees alone, there is some evidence that higher yields of maize can be obtained with the use of showy rattlebox and sunn hemp without the application of additional N. In order to design an agrosystem that is appropriate for humid tropical conditions, further research that addresses the sustainability of the beneficial effects of various systems is needed.

## References

1 Lal, R. 2009. Soils and food sufficiency. A review. Agronomy for Sustainable Development 29:113–133.

2 Affholder, F., Scopel, F., Neto, J.M., and Capillon, A. 2003. Diagnosis of the productivity gap using a crop model. Methodology and case study of small-scale maize production in central Brazil. Agronomie 23:305–325.

3 Araujo, J.C., Moura, E.G., Aguiar, A.C.F., and Mendonça, V. 2007. Supressão de plantas daninhas por leguminosas anuais em sistema agroecológico na Pré-Amazônia. Planta Daninha 25:267–275.

4 Ferreira, L.V., Venticinque, E., and Almeida, S. 2005. O desmatamento na Amazônia e a importância das área protegidas. Estudos Avançados 19:157–166.

5 Moura, E.G., Araújo, J.R.G., Monroe, P.H.M., Nascimento, I.O., and Aguiar, A.C.F. 2009. Patents on periphery of the Amazon rainforest. Recent Patents on Food, Nutrition and Agriculture 1:142–148.

6 Fearnside, P. 2002. Fogo e emissão de gases de efeito estufa dos ecossistemas florestais da Amazônia brasileira. Estudos Avançados 16:99–123.

7 Hendrickson, J.R., Hanson, J.D., Tanaka, D.L., and Sassenrath, G. 2008. Principles of integrated agricultural systems: introduction to processes and definition. Renewable Agriculture and Food Systems 23(4):265–271.

8 Ogunlana, E.A. 2004. The technology adoption behavior of women farmers: the case of alley farming in Nigeria. Renewable Agriculture and Food Systems 19(1):57–65.

9 Leite, A.A.L., Ferraz Junior, A.S.L., Moura, E.G., and Aguiar, A.C.F. 2008. Comportamento de dois genótipos de milho cultivados em sistema de aléias preestabelecido com diferentes leguminosas arbóreas. Bragantia 67:875–882.

10 Moura, E.G., Moura, N.G., Marques, E.S., Pinheiro, K.M., Costa Sobrinho, J.R.S., and Aguiar, A.C.F. 2009. Evaluating chemical and physical quality indicators for a structurally fragile tropical soil. Soil Use and Management 25:368–375.

11 Aguiar, A.C.F., Amorim, A.P., Coelho, K.P., and Moura, E.G. 2009. Environment and agricultural benefits of a management system designed for sandy loam soils of the humid tropics. Revista Brasileira de Ciência do Solo 33:1473–1480.

12 Aguiar, A.C.F., Bicudo, S.J., Costa Sobrinho, J.R.S., Martins, A.L.S., Coelho, K.P., and Moura, E.G. 2009. Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the pre-Amazon region of Brazil. Nutrient Cycling in Agroecosystems 25:1–12.

13 van Raij, B., Cantarela, H., Quaggio, J.A., and Furlani, A.M.C. 1997. Recomendações de adubação e calagem para o Estado de São Paulo. Boletim técnico, 100. Instituto Agronômico, Campinas.

14 Tedesco, M.J., Gianello, C., Bissani, C.A., Bohnen, H., and Volkweiss, S.J. 1995. Análise de solos, plantas e outros materiais. UFRGS, Porto Alegre.

15 Van Soest, P.J. 1967. Development of a comprehensive system of feed analysis and its application to forages. Journal of Animal Science 26:119–128.

16 Tian, G., Brussaard, L., and Kang, B. 1995. An index for assessing the quality of plant residues and evaluating their effects on soil and crop in the (sub-) humid tropics. Applied Soil Ecology 2:25–32.

17 IAC. 2001. Análise química para avaliação da fertilidade de solos tropicais. IAC, Campinas.

18 Machado, P.L.O.A. 2002. Fracionamento físico do solo por densidade e granulometria para a quantificação de compartimentos da matéria orgânica do solo – um procedimento para a estimativa pormerizada do sequestro de carbono pelo solo. Embrapa, Rio de Janeiro.

19 Embrapa. 1997. Manual de métodos de análise de solos. Centro Nacional de Pesquisas de Solos, Rio de Janeiro.

20 Statsoft. 2007. Electronic Statistics Program. StatSoft, Tulsa, OK.

21 Sawyer, J.E. and Mallarino, A.P. 2002. Corn leaf potassium deficiency symptoms. In The Integrated Crop Management Newsletter. IC-488 (15). Iowa State University Extension.

22 Yang, X.E., Liu, J.X., Wang, W.M., Yez, Q., and Luo, A.C. 2004. Potassium internal use efficiency relative to growth vigor, potassium distribution, and carbohydrate allocation in rice genotypes. Journal of Plant Nutrition 27(5): 837–852.

23 Feller, C. and Beare, M.H. 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma 79:69–116.

24 Tan, Z., Lal, R., Owens, L., and Izaurralde, R.C. 2007. Distribution of light and heavy fractions of soil organic carbon as related to land use and tillage practice. Soil and Tillage Research 92:53–59.

25 Pinheiro, E.F.M., Pereira, M.G., Anjos, L.H.C., and Machado, P.L.O.A. 2004. Fracionamento densimétrico da matéria orgânica do solo sob diferentes sistemas de manejo e cobertura vegetal em Paty do Alferes (RJ). Revista Brasileira de Ciência do Solo 28:731–737.

26 Souza, E.D., Carneiro, M.A.C., Paulino, H.B., Silva, C.A., and Buzetti, S. 2006. Alterações nas frações do carbono em um neossolo quartzarênico submetido a diferentes sistemas de uso do solo. Acta Scientiarum Agronomy 28:305–311.

27 Christensen, B.T. 1992. Physical fractionation of soil and organic matter in primary particle size and density separates. Advances in Soil Science 20:1–89.

28 Shepherd, M.A., Harrison, R., and Webb, J. 2002. Managing soil organic matter – implications for soil structure on organic farms. Soil Use and Management 18:284–292.

29 Moura, E.G., Albuquerque, J.M., and Aguiar, A.C.F. 2008. Growth and productivity of corn as affected by mulching and tillage in alley cropping systems. Scientia Agricola 65:204–208.

30 Christensen, B.T. 2000. Organic Matter in Soil: Structure, Function and Turnover. Dias, Tjele.

31 Kristiansen, P., Sindel, B.M., and Jessop, R.S. 2008. Weed management in organic Echinacea (*Echinacea purpurea*) and lettuce (*Lactuca sativa*) production. Renewable Agriculture and Food Systems 23(2):120–135.

32 Maclean, R.H., Litsinger, J.A., Moody, K., Watson, A.K., and Libetario, E.M. 2003. Impact of *Gliricidia spectabilis* hedgerows on weeds and insect pests of upland rice. Agriculture, Ecosystems and Environment 94:275–288.

33 Koocheki, A., Nassiri, M., Alimoradi, L., and Ghorbani, R. 2009. Effect of cropping systems and crop rotations on weeds. Agronomy for Sustainable Development 29:401–408.

34 Inderjit, Weston, L.A., and Duke, S.O. 2005. Challenges, achievements and opportunities in allelopathy research. Journal of Plant Interactions 1:69–81.