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Interactions among leguminous trees, crops and weeds in a no-till alley cropping system

E.G. Moura[a,*], E.S. Marques[a], T.M.B. Silva[a], A.R. Piedade[a], A.C.F. Aguiar[b]

[a]*Programa de Pós-Graduação em Agroecologia, Universidade Estadual do Maranhão, São Luís, Brazil.*
[b]*Programa de Pós-Graduação em Ciência Animal, Centro de Ciências Agrárias e Ambientais, Universidade Federal do Maranhão, Chapadinha, Brazil.*
*Corresponding author. E-mail: egmoura@elo.com.br

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Abstract

Trees improve the soil quality and their rapid growth in the tropics make agroforestry systems potentially effective for establishing low-input agricultural systems in this region. This study assessed the effects of the biophysical interactions among leguminous trees, weeds, cotton and maize in an alley cropping system. The experiment comprised six treatments: Clitoria + Gliricidia; Acacia + Gliricidia; Leucaena + Clitoria; Leucaena + Acacia; Leucaena + Gliricidia and Control and four replicates in randomised blocks. Cotton and maize were sown among the legumes. We analysed Ca, Mg, K, P and potential acidity and we measured the pH using $CaCl_2$ in the soil. Weeds were collected from within a square 0.5 m on a side in the cotton area. The application of the residues affected only the levels of Ca and Mg of the soil. The residues did not produce any differences in the density and richness of the weed species. The sensitivity of some crops to the allelopathic effects induced by the tree residues is evident mainly in root growth, in nutrient uptake and in the growth of the shoot. The results presented here support the view that the criteria for the choice of tree species for agroforestry systems must go well beyond the potential to enhance soil fertility to obtain the best results from agroforestry systems.

Keywords: Allelopathy; Cotton; Leguminous residue; Maize; Weed.

Introduction

The rapid growth of trees in the tropics makes agroforestry systems potentially effective for establishing low-input agricultural systems that are suitable for small holders. This approach has the advantage of bringing together crop cultivation and soil fertility regeneration in the same space and at the same time (Moura et al., 2009a). Trees improve the soil quality by providing organic matter, reducing weed populations, assisting in nutrient recovery from the deeper soil layers and adding nitrogen. However, trees have a major influence on crops owing to their perennial nature, large size and better adaptability. Trees also modify the biophysical environment to favour their own growth. In addition, a number of negative or antagonistic interactions, both competitive and allelopathic, may influence agroforestry systems. In view of this situation, the key to success in agroforestry is to minimise the negative interactions and maximise the positive interactions to obtain the best results (Thevathasan and Gordon, 2004).

In the cohesive low-fertility soil of the humid tropics, no-till alley cropping can be an efficient system to maintain maize productivity. However, to maximise the positive interactions, it is necessary to ensure an adequate release rate of nutrients and to maintain soil cover, thus improving the soil rootability, during the entire crop cycle (Moura et al., 2010). According to Aguiar et al. (2010), a good strategy is to use a combination of tree species that provide a combination of low-and high-quality residues. However, multispecies systems represent serious challenge for current agricultural research and, more specifically, for systemic agronomy because it is difficult to understand the effects of the different factors that interact within these systems (Malézieux et al., 2009). Therefore, although the mixture of residues offers some advantages, it may also increase the difficulty in understanding the ecological interactions between trees and crops in such intercropped systems. Such understanding is fundamental to the design of efficient systems having the potential for broader applicability. Furthermore, the occurrence of weeds is higher in this region and a no-till system may be undesirable for the farmer because this type of system increases the aggressiveness of weedy species (Araújo et al., 2007).

Although several other authors have noted that alley cropping can meet the need for rain-fed upland farming with low external chemical inputs, most of these authors were concerned with the positive interactions between trees and staple foods (Moura et al., 2010). Conversely, tree-crop interactions have been considered as a source of damage. These considerations are almost always associated with the effect of trees on the growth of crops through competition for moisture, light and nutrients (Imo and Timmer, 2000). Less attention has been given to antagonistic interactions between trees, weeds and crops in diversified systems, including systems that produce fibre or oil.

The identification of allelopathy as the potential cause of vegetation patterning however, proved difficult due to the dynamic nature of soil and complex ecosystem interaction. Therefore, some controversial experimental results and the coexistence of allelopathy and resource competition in the natural environment make scientists sceptical about the possibility of distinguishing allelopathy from resource competition under field conditions (Albuquerque et al., 2011). Undoubtedly, the potential positive or negative allelopathic effects of tree residues on crops under field conditions still have not been properly addressed. Therefore, more information about the interactions among trees, crops and weeds is needed to move towards low-input systems, diversified and sustainable over the long term that will be adequate for smallholder agriculture in the humid tropics.

To contribute additional information about the correct use of trees in the sustainable management of tropical diversified agrosystems, this study assessed the effects of biophysical interactions among leguminous trees, weeds, cotton and maize in an alley cropping system.

Methods

Experimental area

The experiment was conducted at Maranhão State University, 2°30′S, 44°18′W. The region has a hot and semi-humid equatorial climate with a mean precipitation of 2,100 mm year^{-1} and two well-defined seasons: a rainy season that extends from January through June and a dry season with a marked water deficit from July through December. The soil was classified as Arenic Hapludult and contained 260 g kg^{-1} coarse sand, 560 g kg^{-1} fine sand, 80 g kg^{-1} silt and 100 g kg^{-1} clay. The area was limed in January 2002 with a surface application of 1 Mg ha^{-1} hydrated calcium, corresponding to 279 and 78 kg ha^{-1} of Ca and Mg, respectively. The alley cropping system was initiated six months after liming. The results of the chemical analysis of the soil before and one year after the application of lime can be found in

Moura et al. (2009b). Full details of the experimental design are given in Aguiar et al. (2010) and Moura et al. (2009b).

The alley cropping system experiment comprised six treatments and four replicates in randomised blocks. We tested four leguminous species. Two of these species, *Leucaena leucocephala* (leucaena) and *Gliricidia sepium* (gliricidia), have high-quality residues. The other two, *Clitoria fairchildiana* (clitoria) and *Acacia mangium* (acacia), have low-quality residues. It is noteworthy that of these legumes, only the clitoria is a native species. The trees were planted with 0.5 m spacing in 21×4 m parcels and in mixed rows so that each parcel received both types of residue. This design resulted in the following treatments, each consisting of a combination of two legumes: Clitoria + Gliricidia (C+G); Acacia + Gliricidia (A+G); Leucaena + Clitoria (L+C); Leucaena + Acacia (L+A), Leucaena + Gliricidia (L+G) and Control (no residues). Maize was sown every January between 2002 and 2009, with a 90 cm inter-row space and a 20 cm interplant space and was treated with 250 kg ha^{-1} of a fertiliser whose composition was N-P-K 10-25-15+0.05% Zn.

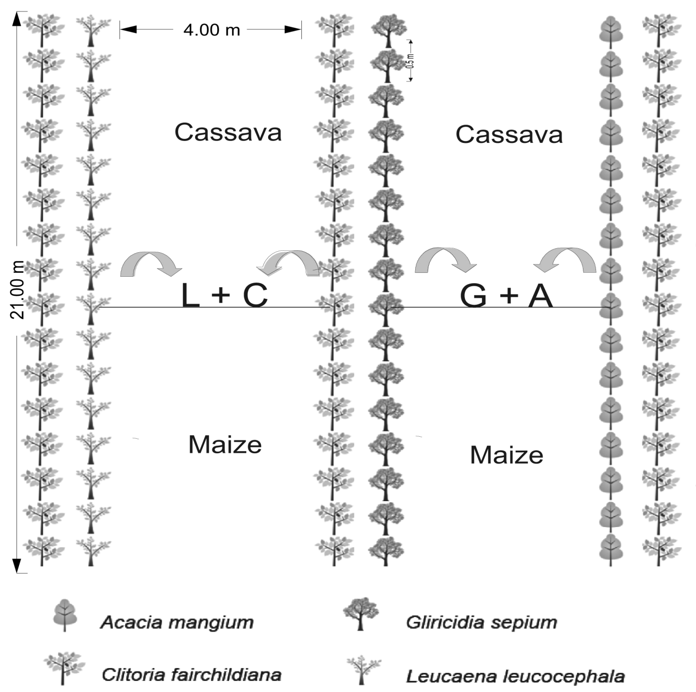

Figure 1. Diagram of two experimental plots showing the double row of trees that was divided in the treatments, with maize and cassava.

In December 2009, the biomass resulting from the pruning of the legume trees was distributed homogeneously throughout all of the plots representing the same treatment. Table 1 shows the quantities of dry biomass produced by these treatments.

Table 1. Quantities of dry biomass applied by treatments in 2010.

	G+C	L + G	G+A	L+C	L+A
Dry biomass (Mg ha^{-1})	24	16	30	22	39

G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

In January 2010, cotton was sown among the legumes. The cultivar 7MH brown (*Gossypium hirsutum* L.) was sown in sub-plots of 10×4 m using a 90 cm inter-row space and a 20 cm interplant space. The basic fertilisation applied to the cotton was 22 kg ha^{-1} urea, 180 kg ha^{-1} P_2O_5 and 70 kg ha^{-1} K_2O. A side dressing of 40 kg ha^{-1} urea was applied 30 days after emergence. In the same plots, maize (cultivar AG 7088) was sown with a 90 cm inter-row space and a 20 cm interplant space in sub-plots of 10×4 m and was fertilised with 250 kg ha^{-1} of N-P-K 10-25-15+0.05% Zn. In addition, 30 kg ha^{-1} of N was applied in the form of urea when the fourth pair of leaves appeared.

Evaluation and statistical analysis

Three samples per plot were taken to a depth of 20 cm for soil chemical analysis. We analysed Ca, Mg, K, P and H + Al and we measured the pH using $CaCl_2$ (IAC, 2001). We also determined the cation exchange capacity (CEC) using the formula [SB + (H + Al)], where SB= Ca, Mg, K. We determined the base saturation using the formula (SB / CEC) × 100).

Weeds were collected from within a square 0.5 m on a side in the cotton area. The square was placed randomly at three points within the plot. The identification of plants was performed according to Kissmann (1997). After identification, the plants were counted and dried at 70 °C to constant weight. The population dynamics of the weeds was evaluated by calculating the absolute and relative densities, richness, biomass and species diversity. The species diversity was obtained from the Shannon-Wiener index (Pinto-Coelho, 2000), given by=1 pi Σsi ln pi, where s is the number of species, pi is the ratio of the density of species i to the total density of all species and ln is the natural logarithm.

The cotton roots were sampled at the stage of the first appearance of the boll. An auger with a volume of 475.2 cm^3 was used. Samples were taken from each row of cotton. Three samples were taken from each plot at a depth of 0-20 cm. The samples were prepared by passing them through sieves. A 2 mm sieve was used on top and a 1 mm sieve was used at the bottom, as specified in Bohm (1976). The soil was separated from the roots using water jets. The impurities were then separated from the roots. The roots were counted using the Newman line intersection method as modified by Tennant (1975). The roots obtained from each volume of soil were placed in ruled petri dishes. The rulings system in the humid tropics system in the humid tropics formed a grid of 0.5×0.5 cm. Each root that intersected a row of the grid was tallied using a manual counter. The cumulative total was converted into the root length density (RLD) using the formula RLD=(11/14 * Number of intersections (N) * Unit squared) / 475.2 (cm cm^{-3}).

Samples of cotton plants were collected at two stages of growth. Ten plants per plot were removed at the flowering stage and at the stage of physiological maturity of the whole plant. The samples were placed in paper bags, transferred to the laboratory and dried using forced air at 65 °C. After drying, the samples of whole plants were weighed on an analytical balance to estimate the dry mass accumulated in the shoot. The materials were then ground. The total N, P, K, Ca and Mg concentrations in the cotton plants were determined following H_2SO_4-H_2O_2 digestion according to the standard method described by Tedesco et al. (1995).

In cotton, the yield parameters evaluated were the number of bolls, the weight of the seeds, the percentage of fibre and the weight of the bolls. The yield parameters for maize were evaluated at the final harvest. The weight of the ears, the number of ears, the 100 grain weight and the weight of grains were determined.

The data were statistically analysed using STATISTICA software. The analysis of variance was applied to the results of the chemical analyses; to the data on root density, dry weight, species diversity, plant density and biomass; and to the yield parameters of cotton and maize. The comparison of means was performed using the Tukey test at a significance level of 5%. The Sigma Plot 11.0 program (Systat Cabinet Software Inc.) was used to produce the graphics.

Results

The application of the residues affected only the levels of Ca and Mg of the soil. These effects were reflected in small increases in the Sum of Bases and Percent Base Saturation in the cover soil compared with the control (Table 2). However, this modification was not sufficiently large to affect the critical levels of the chemical indicators (Ribeiro et al., 1999).

Table 2. Chemical characteristics of soil after the experiment in 2010.

	G+C	L+G	G+A	L+C	L+A	Control
Ca ($cmol_c$ kg^{-1})	7.2^a	7.3^a	7.4^a	8.1^a	8.6^a	4.1^b
Mg ($cmol_c$ kg^{-1})	1.6^a	2.0^a	1.8^a	2.2^a	2.4^a	1.0^b
K ($cmol_c$ kg^{-1})	0.4^a	0.5^a	0.5^a	0.5^a	0.3^a	0.7^a
P (mg kg^{-1})	13.6^a	13.2^a	20.6^a	14.0^a	8.1^a	15.7^a
Sum of Bases ($cmol_c$ dm^{-3})	9.2^a	9.8^a	9.6^a	10.8^a	11.3^a	5.8^b
Potential acidity ($cmol_c$ dm^{-3})	35.5^a	38.1^a	32.7^a	36.2^a	39.0^a	38.2^a
CEC ($cmol_c$ kg^{-1})	44.7^a	47.9^a	38.5^a	47.0^a	50.3^a	44.0^a
pH ($CaCl_2$)	4.1^a	4.1^a	3.8^a	4.1^a	4.0^a	4.0^a
Base saturation percentage %	20.1^a	19.3^a	16.6^{ab}	22.5^a	21.8^a	13.1^b

Different letters in the same row indicate difference at the 5% level by Tukey test.
G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

The residues did not produce any differences in the density and richness of the weed species (Table 3). In all, 16 species were recorded in the total area examined in the experiment. In addition, the diversity index values of approximately 0.5 found in all treatments indicate that the diversity and abundance were not affected by the different mixtures of residues used. However, the amount of weed biomass in (C+G) was more than twice that found in (L+A). The weed biomass did not differ significantly among the other treatments or between these treatments and the control.

Table 3. Effects of coverage on density, species richness, Shannon-Winer index and biomass weed.

	G+C	L+G	G+A	L+C	L+A	Control
Density, plants m^2	61.0^a	52.0^a	60.0^a	51.0^a	41.0^a	63.0^a
Richness, species m^2	22.0^a	18.0^a	19.0^a	19.0^a	16.0^a	17.0^a
Shannon-Winer Index	0.6^a	0.5^a	0.5^a	0.6^a	0.5^a	0.5^a
Biomass, g m^2	110.0^a	67.2^{ab}	68.9^{ab}	62.3^{ab}	44.8^b	88.6^{ab}

Different letters in the same row indicate difference at the 5% level by Tukey test.
G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

The 10 weeds observed most frequently in the experiment only appeared together in the treatments with clitoria (Table 4). Of these species, *Cleome affinis* DC., *Spigelia anthelmia* L. and *Croton lobatus* L. did not appear in (L+G) and *Mollugo verticillata* L. and *Synedrellopsis grisebachii* Hieron did not appear in (L+A). Moreover, it is noteworthy that one of the most important weeds in tropical agriculture, *Commelina benghalensis* L., did not appear in (A+G) and appeared at a much lower density in (L+A), although it was the second most frequent weed in the treatments with clitoria.

For cotton, the greatest root length density (RLD) was found in the combination of clitoria and gliricidia (C+G). In the combinations of gliricidia with acacia (A+G) and leucaena (L+G), the root growth was lower. The treatments (L+C) and (L+A) showed intermediate results. The accumulation of dry matter (DMA) was lower in the mixed residues with acacia, (L+A) and (A+G), than in the other combinations of residues. No differences in DMA were found among these other combinations, which were not different between them. The difference between the (L+A) and (C+G) treatments was almost 100%. The lower RLD of (L+G) did not prevent this treatment from exhibiting a DMA value equal to that of (C+G) and much higher than that of (L+A), even though (L+A) and (L+G) had equal values of RLD. A higher DMA: RLD ratio was observed for the treatments that included leucaena except that with acacia (Figure 1).

Table 4. Relative (RD) and absolute (AD) densities of weeds.

Species	Treatments											
	G+C		L+G		G+A		L+C		L+A		Control	
	RD	AD	RD	AD	RD	AD	RD	AD	RD	AD	RD	AD
C. punctatum Cass	42.6	104	45.5	100	65.0	156	31.4	64	56.1	92	49.2	124
C. benghalensis L.	18.0	44	27.3	60	-	-	21.6	44	4.9	8	11.1	28
M. verticilata L.	4.9	12	7.3	16	5.0	12	11.8	24	-	-	14.3	36
A. tenella Colla	4.9	12	3.6	8	8.3	20	11.8	24	7.3	12	3.2	8
C. affinis DC.	4.9	12	-	-	5.0	12	5.9	12	14.6	24	3.2	8
S.anthelmia L.	8.2	20	-	-	3.3	8	3.9	8	4.9	8	1.6	4
C. lobatus L.	3.3	8	-	-	3.3	8	2.0	4	2.4	4	3.2	8
S. grisebachii Hieron	1.6	4	7.3	16	3.3	8	2.0	4	-	-	-	-
P. phaseoloides	1.6	4	5.5	12	1.7	4	3.9	8	2.4	4	1.6	4
Cyperus esculentus L.	1.6	4	1.8	4	1.7	4	3.9	8	2.4	4	-	-

G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

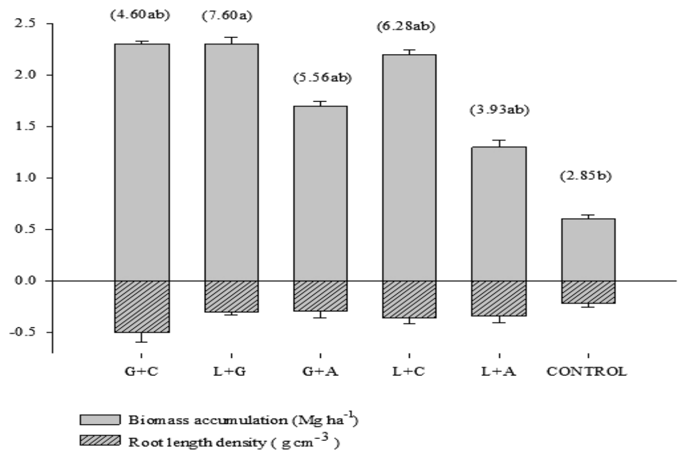

Figure 2. Cotton biomass accumulation, root length density (RLD) and ratio dry matter/RLD in brackets.

In cotton, the levels of the main nutrients did not differ among the residue treatments at the flowering stage (Table 5). In contrast, remarkable differences were observed in the N, K and Ca uptake at maturity. (C+G) showed over 50% more nitrogen than (A+G) and 33% more than (L+A). The differences in potassium uptake between the same treatments were 75% and 40%, respectively. The calcium uptake also varied significantly between these treatments, but the differences were smaller.

Table 5. Nutrient content at flowering and maturity of the cotton plant.

	Nutrient contents at flowering					
	G+C	L+G	G+A	L+C	L+A	Control
N g kg^{-1}	39.0^{a}	36.8^{a}	34.5^{ab}	38.1^{a}	34.6^{ab}	25.6^{b}
P g kg^{-1}	2.4^{a}	2.4^{a}	2.2^{a}	2.1^{a}	2.2^{a}	1.8^{a}
K g kg^{-1}	10.3^{a}	9.3^{a}	8.9^{a}	8.8^{a}	9.6^{a}	7.8^{a}
Ca g kg^{-1}	5.88^{a}	5.63^{a}	5.43^{a}	5.89^{a}	5.21^{a}	5.36^{a}
Mg g kg^{-1}	1.69^{a}	1.66^{a}	1.56^{a}	1.82^{a}	1.67^{a}	1.26^{a}
	Nutrient contents at maturity					
	G+C	L+G	G+A	L+C	L+A	Control
N g kg^{-1}	69^{a}	63^{ab}	45^{c}	64^{ab}	54^{bc}	14^{d}
P g kg^{-1}	6^{a}	7^{a}	4^{ab}	7^{a}	5^{ab}	2^{c}
K g kg^{-1}	14^{a}	12^{ab}	08^{c}	11^{b}	10^{b}	2^{d}
Ca g kg^{-1}	13.90^{a}	13.99^{a}	10.32^{c}	13.62^{a}	11.59^{b}	3.50^{d}
Mg g kg^{-1}	4.93^{a}	5.30^{a}	3.32^{a}	4.49^{a}	3.41^{a}	0.77^{b}

Different letters in the same row indicate difference at the 5% level by Tukey test.
G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

The interactions of corn and cotton with the mixtures of residues differed markedly. The greatest difference was found between (L+A) and (C+G) (Table 6). The cotton was negatively affected by leucaena if leucaena was not combined with clitoria, but the damage was very high if leucaena was combined with acacia. The yield of fibre was almost three times smaller in (L+A) than in (C+G). Clitoria dampened the negative effect of leucaena, but gliricidia did not do so. Thus, the cotton yields in (C + L) and (G + C) were much higher than that in (L + A). All of the parameters of productivity of the cotton evaluated were negatively affected by the combination of leucaena plus acacia. Conversely, for maize, the (L+A) treatment was superior, with a yield 26% higher than to (C+G). (C+L) was also superior to all of the other treatments. The yield parameters of the maize did not differ significantly among the treatments.

Table 6. Yield parameters of cotton and corn.

	Yield parameters of cotton					
	G+C	L+G	G+A	L+C	L+A	Control
Yield fibre kg ha^{-1}	566.8^{a}	291.8^{bc}	464.4^{ab}	463.9^{ab}	191.7^{c}	25.8^{d}
Number of bolls m^{2}	24.0^{a}	14.6^{ab}	14.9^{ab}	17.9^{ab}	7.5^{b}	2.3^{c}
Weight of seeds kg ha^{-1}	448.30^{a}	349.90^{ab}	274.20^{ab}	325.43^{ab}	124.80^{b}	16.50^{c}
Fiber percentage %	35.8^{a}	26.7^{b}	34.5^{ab}	34.6^{ab}	34.3^{ab}	34.5^{ab}
	Yield parameters and dry matter of corn					
	G+C	L+G	G+A	L+C	L+A	Control
Dry matter kg ha^{-1}	6001.3^{a}	5257.5^{a}	4457.5^{b}	4607.5^{b}	4657.5^{b}	1574.4^{c}
Weight of ears g	95.3^{a}	89.1^{a}	72.3^{ab}	81.1^{a}	82.9^{a}	47.2^{b}
Weight of 100 grains g	23.5^{a}	21.1^{a}	23.5^{a}	22.4^{a}	22.2^{a}	19.7^{a}
Grain Yield kg ha^{-1}	3486.3^{a}	3257.5^{a}	2457.5^{b}	2607.5^{b}	2757.5^{b}	1174.4^{c}

Different letters in the same row indicate difference at the 5% level by Tukey test.
G+C=Gliricidia + Clitoria; L+G=Leucaena + Gliricidia; G+A=Gliricidia + Acacia; L+C=Leucaena + Clitoria; L+A=Leucaena + Acacia.

Discussion

Even though large amounts of residues and fertilisers were applied during the seven years following the establishment of the plantation, the analyses of the soil used in the experiment showed that the levels of all of the chemical indicators analysed were less than those established for fertile tropical soil (Ribeiro et al., 1999). In addition, the application of different residues did not produce significant variations in the chemical indicators that would account for the differences among the treatments observed with respect to the performance of the cash crops or for the weeds. The design and management of the experiment aimed to avoid above-ground competition between the trees and the crops. Therefore, to explain the results of this experiment, the non-resource interactions among the components of the alley cropping system must be considered.

The residues affected the growth of weedy species more than the occurrence of these species in the community. The effect of residues was primarily observed in the plots with acacia and leucaena. This finding may be important in light of the observation that the weeds were much more aggressive in (C+G) than in (L+A) treatment. According to Maclean et al. (2003), alley cropping offers three ways to reduce the competition between crops and weeds. Green manuring can improve the physico-chemical properties of the soil and alter the species composition of the weed community, shade can reduce the growth of weed species that are sensitive to shading and mulching can prevent weed germination. In this experiment, only the mulching effect could potentially serve to explain differences among the treatments. Furthermore, the physical weeds suppression resulting from mulching was not important, because the control did not differ from some treatments (A+G and L+G) in which the plots were totally covered. Hence, the variation in the impact of the mulching on the density and growth of weeds may be associated more with the biological effects of the allelopathic products released by the decomposition of the residues. In this context, the opposite effects on weed occurrence and biomass exhibited by clitoria, a native legume and by acacia and leucaena, both exotic species, show that the tree species chosen for the alley cropping system may modify the interactions between the components of the system and increase or decrease the competitiveness of the weeds. The high weed biomass for the (C+G) treatment indicates that the weeds in those plots benefitted from nutrient release but were not affected by allelopathic substances.

The suppressive effect of leucaena on weeds is well known (Williams and Hoagland, 2007) and is attributed to at the release of mimosine, which is a non-protein amino acid that occurs in its leaves and seeds. In acacia, Luz et al. (2010) have reported the presence of the substance lupenone, which is a triterpenoid that has allelopathic effects on the germination of seeds of several weed species. Conversely, it is important to note the antagonistic effect of the residues of clitoria on the suppression of weeds by leucaena residues. Aguiar et al. (2010) have reported that the composition of the weed community changed after four years in an alley cropping system with clitoria. These changes resulted mainly from the increase of such species as *Commelina benghalensis* L. In both cases, the weeds took advantage of improvements in soil fertility produced by the residues of native plants in the absence of overt antagonism. These antagonistic effects are more commonly caused by exotic plants, as described by Bais et al. (2003).

The root growth of the cotton in this experiment was shown to depend on the physical improvement of the rootability of the soil produced by the mulch and the antagonistic effect of the residues on the growth of the roots. This finding is consistent with the idea that the lower root length density (RLD) in the plots without residues resulted from the hardening of the soil. Such soil hardening affects root growth after only four days without rain in uncovered plots (Becher et al., 1997). However, the RLD of the cotton was higher in the (C+G) treatment than in the (A+G), which someone could not wait, from the data of Moura et al. (2009b). These authors found major improvements in the soil rootability in plots with acacia in the same experiment three years ago. Moreover, even under the same conditions, Moura et al. (2012) found that the RLD of maize was higher in (A+G) plots than in (C+G) plots. These results confirm that the improvement in the soil properties caused by the residues from trees cannot be generalised to all cash crops without considering the antagonistic effects that may occur. Such antagonistic effects on cotton probably result from the release of allelopathic substances during the decomposition of the residues, as also reported by Moran and Greenberg (2008) that found out antagonist effect of Vinegar on cotton.

The treatments involving leucaena, acacia and clitoria in combination with gliricidia clearly indicated that both the acacia and leucaena were detrimental to the growth of cotton roots. According to Luz et al. (2010), in several species, the effects of lupenone, which is a substance produced by *Acacia mangium*, may result in decreases in radicle growth of as much as 40%. Root growth inhibition caused by the mimosine present in leucaena has been associated with reductions in the phenylalanine and peroxidase activities and the lignin content, according to Andrade et al. (2008). The inhibitory effect of leucaena on root growth, combined with the increased release of nutrients, may have been the reason that the DMA: RLD ratio tended to be higher in the (L + G) and (C+L) treatments.

The uptake of available nutrients by crops is closely related to the rootability of the soil. The uptake of N, K and Ca was therefore affected by the growth of the roots, but the (L+C) and (L+G) treatments also benefitted from the higher nutrient liberation rate of the leucaena residues. According to the results obtained by Moura et al. (2010) in the same area, the (L+A) and (L+C) treatments produced better conditions and a higher uptake of N and K by the maize by providing a good balance of low- and high-quality residues. This balance permitted an increase in the release time of N and K. Furthermore, it allowed the soil to remain covered during the entire crop cycle and thus improved the rootability of the soil.

In the cotton plants investigated in this experiment, other factors, beyond the root growth and nutrient availability, must have contributed to the large differences in the N, K and Ca contents between the (A+G) and (L+G) treatments. According to Zhang et al. (2010), phenolic acids are present at very high concentrations in *Acacia mangium,* which can alter the rate at which ions are absorbed by plants. Reductions in both macro-and micronutrients are generally encountered in the presence of phenolic acids. According to Glass (1974), one mechanism by which plant growth is inhibited by this class of allelochemicals may be an alteration in the membrane permeability. However, Brum and Gerig (2005) have suggested that some species can modify the concentration of active phenolic acids surrounding their roots and can influence the magnitude of the primary and secondary effects of phenolic acids. This suggestion indicates that phenolic acids may have different effects on maize and cotton roots. Cotton is also more sensitive to K fertiliser than corn and soybean, probably because the root system of cotton is less dense at depths of <0.3 m in the soil. K absorption is therefore highly dependent on root activity. Vigorous growth of root systems is required to intercept and absorb available K (Sawyer and Mallarino, 2002).

The comparison of the results for cotton and maize confirmed that the effects of the trees on productivity can be very different for different crops. Unfortunately, this effect can be independent of the capacity of the residues to release nutrients and of the levels of the indicators of enhanced soil quality. In this study, the maize was able to benefit from the improvements in nutrient release and soil rootability furnished by the beneficial combination of low- and high-quality residues in the (L+A) and (L+C) treatments. In contrast, the cotton did best in the (C+G) treatment, because the level of antagonistic substances was lower. This characteristic also promoted weed growth.

Furthermore, the effects of the (L+A) treatment on the growth and productivity of the cotton must have reflected the influence of antagonistic substances on the plant's metabolism because productivity was much lower, despite the higher potential for nutrient release and enhanced soil rootability. According to Batish et al. (2007), crops growth may suffer the effects of the residues of allelopathic plants. These effects include decreases in the amounts of total chlorophyll and the contents of water-soluble proteins and the total carbohydrates and area consequence of the degradation or reduced synthesis of these compounds.

Conclusions

The results presented here support the view that the criteria for the choice of tree species for agroforestry systems must go well beyond the demonstrated potential to enhance soil fertility and prevent resource competition. Therefore, information on the complex and specific interactions linking trees, cash crops and weeds is needed to take advantage of the relationships between trees and crops and to obtain the best results from agroforestry systems. Under field conditions, the sensitivity of some crops to the allelopathic effects induced by the tree residues is evident mainly in root growth, in nutrient uptake and in the growth of the shoot. Thus, the combined use of two allelopathic species, such as leucaena and acacia, may decrease the yield of the sensitive cash crops and cancel the positive effects of the trees on nutrient availability and soil rootability. Therefore, the inclusion of a non-allelopathic (perhaps a native) species having additional desirable characteristics in the mixture of residues could be a good potential strategy. This approach would help to mitigate the negative effect of species such as leucaena on the cash crops and would furnish a high potential for the release of nutrients throughout the crop cycle. The biological impact of residues on the occurrence of weeds is very specific, for this reason its successfull use depend on sensitivity of the principal weeds and of tolerance of the crop to allelopatic effect.

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