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EFFECT OF LEGUME MULCHES AND COVER CROPS ON EARTHWORMS AND SNAILS

[EFECTO DE MANTILLOS Y CULTIVOS DE COBERTERA DE LEGUMINOSAS EN LOMBRICES DE TIERRA Y CARACOLES]

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SUMMARY

We evaluated the effect of leguminous mulches and cover crops on earthworms and snails in Leptosol within a tropical dry climate. Treatments were: 1) Leucaena, - fresh mulch of *Leucaena leucocephala*; 2) Lysiloma - fresh mulch of *Lysiloma latisiliquum*; 3) Mucuna - cover crop of *Mucuna deerengianum;* 4) Canavalia - cover crop of *Canavalia ensiformis*; and 5) Control with only maize (*Zea mays*) as a crop. Samples were collected 14, 70 and 84 days after crop planting. Additionally, the decomposition of mulch, biomass production of the two cover crops, leaf quality and changes in microclimate were examined. Earthworm biomass increased in the first sample of Mucuna (29.39 g m^{-2}), Leucaena (36.85 g m^{-2}) and Lysiloma (12.94 g m^{-2}) treatments, due to the application of mulch of *L. latisiliquum* and *L. leucocephala* and to accumulated *M. deerengianum* mulch before crop planting. Control and Canavalia treatments had 3.64 g m^{-2} and 7.5 g m^{-2} of earthworm biomass, respectively. Seventy days after crop planting, foliage quality positively affected the density and biomass of earthworms. Cover crops increased the density and biomass of snails under adverse climatic conditions and mulch of *L. leucocephala* and *L. latisiliquum* reduced the density and biomass of snails. Compared to snails, earthworms were more affected by soil moisture and plant litter quality, while snails were present for longer periods of time than earthworms.

Key words: Snails, earthworms, crop, microclimate, litter quality.

RESUMEN

Se evaluó el efecto de mantillos y cultivos de cobertera de leguminosas en lombrices y caracoles en un Leptosol bajo condiciones climáticas de trópico subhúmedo seco. Los tratamientos fueron: 1) Leucaena - mantillo fresco de *Leucaena leucocephala* (Lam.); 2) Lysiloma - mantillo fresco de *Lysiloma latisiliquum*; 3) Mucuna - cobertera de *Mucuna deerengianum;* 4) Canavalia- cobertera de *Canavalia ensiformis*; y 5) Control - sin mantillo ni cobertera, solo maíz. Se muestreó lombrices y caracoles a: 14, 70 y 84 días después de la siembra (dds). Se estudió la descomposición de los mantillos, la producción de biomasa de los cultivos de cobertera, la calidad del follaje de las leguminosas y el efecto de mantillos y cultivos de cobertera en el microclima. A los 14 dds del maíz, la biomasa de lombrices con respecto al Control aumentó con Mucuna (29.39 g m^{-2}), Leucaena (36.85 g m^{-2}) y Lysiloma (12.94 g m^{-2}). La biomasa de lombrices en Control y Canavalia fue de 3.64 g m^{-2} y 7.15 g m^{-2}, respectivamente. A setenta dds la calidad de follaje afectó positivamente la densidad y la biomasa de las lombrices. Los cultivos de cobertera aumentaron la densidad y la biomasa de caracoles en condiciones climáticas adversas y el mantillo de *L. leucocephala* y *L. latisiliquum* redujeron la densidad y la biomasa de caracoles. Comparado con los caracoles, las lombrices fueron más afectadas por la humedad de suelo y la calidad de la hojarasca, mientras los caracoles estuvieron presentes durante períodos más largos de tiempo que las lombrices.

Palabras clave: Lombrices, caracoles, cultivos, microclima, calidad de la hojarasca.

INTRODUCTION

The edaphic and agronomic benefits of increased macroinvertebrate abundance in soils include: mineralization of N; P availability; recycling of nutrients such as Ca and K; greater aggregate stability; and better plant growth (Brown et al., 1995; Mba, 1993, 1997; Barois et al., 1999). Among soil macroinvertebrates, earthworms have the highest biomass and are the most responsive to management (Senapati et al., 1999; Brown et al., 2001; Fragoso, 2001). Inoculation of earthworms improves fertility in degraded soils (Lavelle, 1988; Lavelle et al., 1989; Tian et al., 1993; García and Fragoso, 2002), in microcosms under controlled conditions and in hot houses (García and Fragoso, 2002; Senapati et al., 1999). Further support is provided by field studies in different global regions showing a trend for improved soil fertility and increased plant productivity with earthworm inoculation (Stockdill, 1982; Springett, 1985; Curry and Byrne, 1992; Ketterings et al., 1997; Marinissen and Hillenaar, 1997; Brown et al., 1999; Fragoso et al., 1999; Senapati et al., 1999). However, field research on earthworm management for improved soil fertility lags far behind that on fertilizer management. This can be particularly noteworthy in field studies of earthworm management in Leptosol and in the subhumid tropics. In general, existing field studies indicate that increases in earthworm density and biomass can be promoted by improving both microclimate (lowering temperature and increasing soil moisture content) and soil organic matter quality (Tian et al., 1993).
Another macroinvertebrate group, land snails, has received less attention from an ecological standpoint (Mijail et al., 1996). Snails are extremely sensitive to variations in moisture and to availability of calcium, refuge and food (Alvarez and Willig, 1993; Naranjo, 1994), and thus, can be considered good soil quality indicators. Land snails are abundant in calcareous zones such as in the Yucatan Peninsula and Cuba.

Agronomic management of foliage (such as tree branches and leaves) as surface mulch in crops favors microclimate regulation and provides food for macroinvertebrates, thus promoting increased soil fertility and agricultural crop yields. Cover crops of herbaceous plants preserve soil moisture, lower soil temperature and add organic matter to the soil (Bennie and Hensley, 2001; Kwabiah et al., 2001).

Approximately 170,000 ha in the state of Yucatan, Mexico, are cultivated using the traditional Mayan slash-and-burn technique (INEGI, 2000). This generally consists of choosing an area and then clearing the vegetation during the dry season by cutting both low vegetation and trees, allowing plant remains to dry after which these are burned before the first rains. The cleared area is cultivated for two years and then left fallow because of increasing difficulties for weed control and to allow soil fertility to recover. The recommended fallow period in the region is 20 years (Hernández et al., 1995; Terán and Rasmunssen, 1994; Bautista et al., 2005), However, current fallow periods are of about four years. This shortened period directly affects maize (*Zea mays* L.) production, which is less than 1000 kg ha^{-1} the first year and about 500 kg ha^{-1} in the second year. If this tendency continues, productive lands in the region will soon be insufficient to supply enough food for the human population in the area.

Since 1994, researchers at the Biological and Agricultural Sciences Campus of the Universidad Autonoma de Yucatan (UADY) have been studying the use in maize production and for weed control of two legume tree species as mulches: *Leucaena leucocephala* (Lam.) De Witt and *Lysiloma latisiliquum* (L.) Benth.; and of two herbaceous legumes as cover crops: *Mucuna deerengianum* (L.) Medic. and *Canavalia ensiformis* (L.) D.C. (Caamal et al., 2001). The leguminous trees are widely distributed and abundant in the low Karstic plain of Yucatan (Flores and Espejel, 1994; Bautista et al., 2003b), and the two herbaceous legumes, though not native, are being managed with agricultural techniques and are adapting to influences from local farming. Other studies include detailed characterization of the Karstic-origin Leptosol in the region (Bautista et al., 2003a; Díaz et al., 2005).

Laboratory, hothouse and experimental field research performed at the UADY on these four species has produced a number of results: a) *L. leucocephala*, *L. latisiliquum*, *C. ensiformis* and *M. deerengianum* foliage contain compounds that reduce weed root growth and the survival of phytopathogenic nematode larvae, without adversely affecting crop growth (Caamal et al., 2001); b) *M. deerengianum* and *L. leucocephala* decrease the survival of *Spodoptera frugiperda* (Lepidoptera: family) larvae, a significant pest of the Solanaceae (Caamal et al., 2001); c) *C. ensiformis* and *M. deerengianum* decrease the presence of phytopathogenic nematodes on tomato roots (Caamal et al., 2001); d) field experiments show weed biomass reductions during the first years of cultivation of the legumes, in the following descending order of reduction, *M.*

deerengianum > *L. Latisiliquum* > *C. ensiformis* = *L. leucocephala* = Control (Caamal et al., 2001); e) maize production of 1.0 and 1.5 t ha^{-1} can be sustained for more than four years (Caamal et al., 2001).

The present study evaluated the effect on the abundance and biomass of earthworms and snails, and on soil microclimate, of two leguminous trees as mulch (*L. leucocephala* and *L. latisiliquum*) and of two herbaceous legumes as cover crops (*M. deerengianum* and *C. ensiformis*).

MATERIALS AND METHODS

Study area

The experiment was performed at the Biological and Agricultural Sciences Campus, UADY, in Merida, Yucatan, Mexico (20° 52' 3.86" N; 89° 37' 20.05" W) (Fig. 1). A long-term experiment on the effect in maize cultivation of tree and herbaceous legumes as mulch and cover crops has been performed here since 1994.

The study area is located on the low plain of the Yucatan Peninsula, near the coast, at less than 10 masl, an area of karstic origin (Lugo and García 1999; Bautista et al., 2003b). The area has an undulating microrelief with small mounds about 1 m high and shallow broad depressions covering less than 100 m^2. This creates microcatenas with Lithic Leptosol (LPli) and Hyperskeletic Leptosol (LPhsk) on mounds, and with LPli, Eutric Leptosol (LPeu) and Chromic Cambisol (CMcr) occupying the depressions. The vegetation is composed of secondary growth of low deciduous forest and the climate is warm subhumid (AWo), with summer rains, an average annual temperature of 26ºC and an average annual precipitation of 998 mm (Orellana et al., 1999).

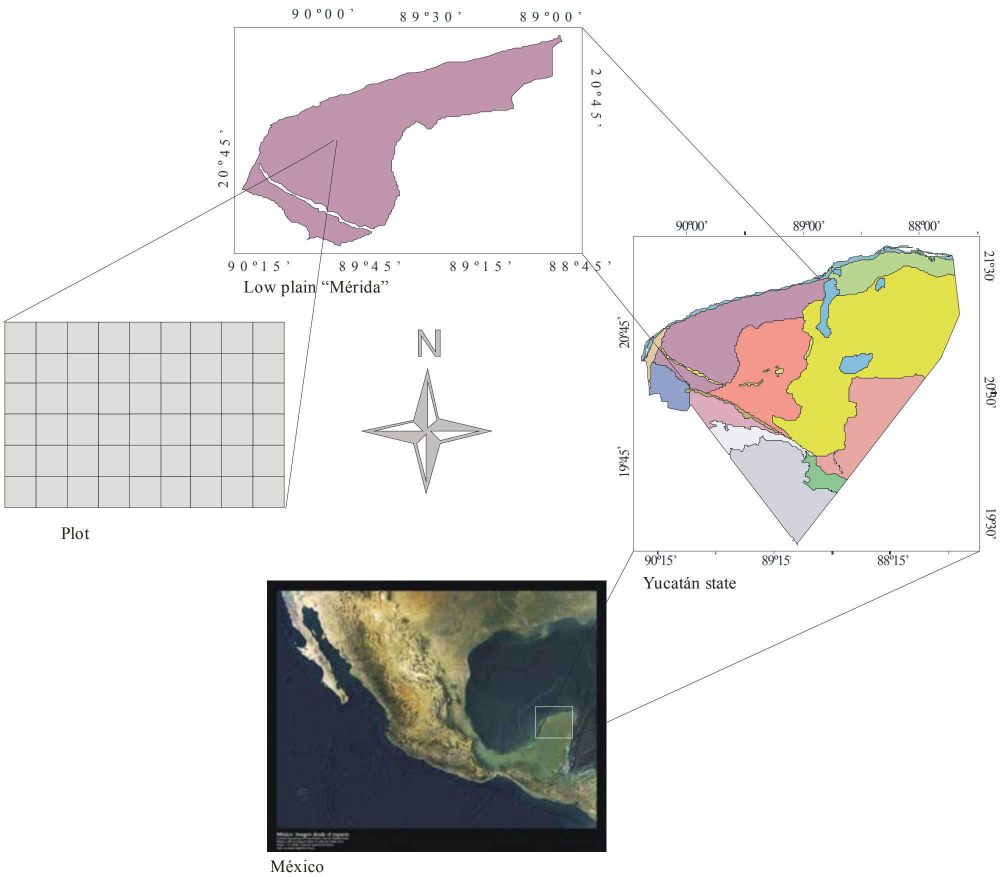

Figure 1. Study area.

Crop management and treatment establishment

The experimental plot (45 x 25 m) has been planted with maize, using legumes as mulch and cover crops since 1994. The data used in this study were generated in 1996. Before planting, the area was cleared of vegetation for all treatments. Soils had 15.9% organic matter and high calcium levels (Table 1). For maize sowing, a planting-stick was used to make holes in the soil and three seeds were placed in each hole. Maize was planted at a spacing of 50 cm between plants and 100 cm between rows, resulting in a planting density of 60 000 plants ha^{-1}. The maize seed used was V-528 with a three-month long life cycle.

Each treatment was applied in nine, 5 x 5 m experimental plots. The five treatments were: 1) Leucaena, maize with fresh *L. leucocephala* as mulch, 2) Lysiloma, maize with fresh *L. latisiliquum* as mulch, 3) Mucuna, maize with *M. deerengianum* as a cover crop, 4) Canavalia, maize with *C. ensiformis* as a cover crop, and 5) Control, using only maize.

Branches and leaves of the mulch plants were placed over the soil surface on the same day that maize was sown. We used the cut and carry system. Each mulch type required 12 t ha^{-1} fresh weight, equal to 3.6 t ha^{-1} dry weight for *L. leucocephala*, and 5.8 t ha^{-1} dry weight for *L. latisiliquum*. Cover crops were sown 15 days after the maize was sown, but between the maize plants, and in the same manner and density as the maize. The plot does have irrigation, but this was used only as a back-up. No fertilizers were used and no hoeing was performed in the mulch and cover crop treatments, although Paraquat was applied in the control treatment at 15 and 30 days after sowing (das) to control weeds and to approximate to local farming practices.

Cover crop foliage production

In the two cover crop treatments maize was grown along with *M. deerengianum* or *C. ensiformis*. The experimental design was totally random with four replicates, each replicate being an experimental unit within a 25 m^2 plot. An ANOVA and a Tukey test for comparison of means (α= 0.05) were performed using *Statistica* (StatSoft, 1995).

Biomass production was evaluated using two samplings: 1) one day before planting, the cover crop legumes that had emerged from remnant seeds from the previous crop were collected, and 2) at 84 days, when the maize was harvested. In both cases plants were counted and weighed wet and dry (constant weight at 60ºC for 48 h). In the second case, the biomass and plants collected from each experimental unit were measured for both legumes.

Foliage quality and mulch decomposition

Litter quality for *L. leucocephala, L. latisiliquum, M. deerengianum* and *C. ensiformis* was determined by taking mixed samples of branches and leaves that were dried at 60º C for 48 h, ground and sieved through a 60-mesh (<0.25 mm) screen. Nitrogen was analyzed using the Kjeldahl method, lignin, hemicellulose, cellulose and polyphenols were analyzed using the Folin-Denis method (van Soest, 1963; Anderson and Ingram, 1993), and all analyses were performed in duplicate. The (lignin + cellulose)/N ratio was calculated as a percentage, which is a modified version of the index reported by Anderson and Flanagan (1989) and by Vitousek et al. (1994).

Decomposition was measured using 315 fabric bags per mulch treatment, each bag filled with 17 g of leaves (dry weight). Bags were 750 cm^3 (25 x 10 x 3 cm) in size with square mesh openings of 2.25 mm^2. Filled bags were placed on the soil of the experimental units and nine bags per treatment were removed at 8, 20, 48, 65, 121, 175 and 314 days after placement. The plant material remaining in the bags was dried at 60º C for 48 h, weighed, and the N content measured using the Kjeldahl method.

Table 1. Means and standard deviations for chemical properties of Leptosols in the study area.

	pH	OM	NO_3^-	P	K	Na	Ca	Mg	Zn	Fe	Mn
		%	----------	----------	----------	----------	mg kg^{-1}	----------	----------	----------	----------
Mean	7.4	15.9	61.3	21.9	619.9	28.3	11035.1	521.0	3.3	26.1	11.9
SD	0.4	3.6	15.1	29.6	145.6	11.0	4598.4	51.8	3.0	36.9	3.5

(Bautista et al., 2003a)

Weight loss data were adjusted to the negative exponential decomposition model in which the relative decomposition rate was considered as a constant (Ezcurra and Becerra, 1987).

$$y = y_0 e^{-kt}$$

where:
y = percentage of remaining mass in time t;
y_0 = amount of initial mass as a percentage when t = 0;
e = exponential constant;
k = decomposition rate coefficient expressed as daily remaining percentage; and
t = time in days

Earthworms and snails

The experimental design was a totally random arrangement of 5 x 5 m experimental units with five treatments: Leucaena, Lysiloma, Mucuna, Canavalia, and Control. Nine earthworm and snail samples per treatment were taken randomly in 0.25 m^2 quadrats to 20 cm depth (Anderson and Ingram 1993). Samples were taken manually between 0700 and 1000 h and at three times: 1) 14 das (plantlet stage); 2) 70 das (flowering stage); and 3) 84 das (harvest stage). Snails were dried at 60º C for 48 h to measure dry weight per total biomass. Earthworms were anesthetized in 10% alcohol, fixed in 4% formol, counted and weighed. Average weight per individual was calculated. The ANOVA was used with the $\log_{10} + 1$ transformed abundance and biomass data, and a Tukey test used to compare means.

Soil microclimate

Soil moisture content was measured through weight loss and soil temperature was measured with mercury thermometers permanently placed at a depth of 5 cm. A test run determined, by timing and interpretation, that the best hours to measure soil temperature were 0700, 1100 and 1500 h. A total of 84 temperature measurements were taken during the cultivation period with four replicates per treatment (Leucaena, Lysiloma and Control).The experimental design was a totally random arrangement. Results were analyzed as a time series and the tendency estimated using the third order mobile average method (Spiegel, 1997). Comparison between treatments and sample times was performed with an ANOVA using *Statistica* (StatSoft, 1995).

RESULTS AND DISCUSSION

Cover crop biomass production

At the beginning of maize planting, the average number of cover crop plants that had emerged from remnant seeds was almost twelve times greater for the cover crop of *M. deerengianum* than for that of *C. ensiformis* (Table 2). The observed low density of *C. ensiformis* may have resulted from its slow seed dispersion, since its pod is hard and does not release seeds easily. When *C. ensiformis* is broadcast-sown its germination is delayed two weeks more than normal, and for this reason it is recommended that its seeds be scarified in water during 12 h before sowing.

At 84 das (harvest stage) *M. deerengianum* had produced 2070 kg ha^{-1} dry weight of biomass with 100% ground cover, while *C. ensiformis* had produced 1087 kg ha^{-1} biomass with 40 to 60% coverage. Each legume's growth pattern influences its biomass production; in this case, *M. deerengianum* is a fast-growing vine and *C. ensiformis* is a slower-growing bush. Caamal et al. (2001) reported a first year biomass production of 6.5 t ha^{-1} for *M. deerengianum* and 3.5 t ha^{-1} for *C. ensiformis*, while in a temperate climate, Triomphe (1996) observed a biomass production of 10.7-12.4 t ha^{-1} dry weight, far more than in the present study.

Table 2. Cover crop biomass production.

	M. deerengianum		*C. ensiformis*	
	1 dbs	84 das	1 dbs	84 das
Plant density (indiv ha^{-1})	56800 a	50266 a	5067 b	42533 b
Sown plant survival (%)		84 a		71 b
Dry weight (kg ha^{-1})	112.7 a	2070 a	13 b	1087 b

†dbs= days before sowing; ‡das= days after sowing. Different letters between treatments indicate significant differences (P<0.05).

During the first days of growth, *M. deerengianum* contributed a large quantity of leaf litter and, at 84 das, a 5 cm thick layer of biomass had accumulated. Biomass of this layer was not calculated but we estimated that it would increase the recorded biomass value by approximately 30%. Triomphe (1996) reported that, in temperate conditions, *M. deerengianum* litter represented from 45-69% of the total aerial biomass. Plant development in *M. deerengianum* amounted to over 3 m of aerial growth intertwined in the lower portion of the maize plants, without covering them. Development in *C. ensiformis* was minimal, never touching the maize plants, and had less soil coverage. Overall, *M. deerengianum* is a cover crop well adapted to the study area due to plant emergence from remnant seeds, its high biomass production, survival percentage and overall development.

Mulch and cover crop foliage quality

The foliage of *L. leucocephala* had more N percentage than that of *L. latisiliquum*, while the latter generally had larger amounts of recalcitrant and polyphenolic compounds (Table 3). The N percentage in *L. leucocephala* (3.49%) was similar to the 3.55% reported by Tian et al. (1993), its total polyphenol content was close to that reported by Kachaka et al. (1993) and its lignin content was close to that observed by Vanlauwe et al. (1997). The foliage of *L. latisiliquum* contained 55% more lignin and 40% less polyphenols, compared to levels reported by Hernández (2000); a result of tissue maturity. The lignin/N ratio was lower in *L. leucocephala* than in *L. latisiliquum*, and the polyphenols + lignin/N ratio further highlighted this difference. The *L. latisiliquum* mulch decomposed to give more N, lignin and polyphenols than the *L. leucocephala* mulch. Foliage quality expressed as the (lignin + cellulose)/N ratio was better in *L. leucocephala* (7.63) than in *L. latisiliquum* (11.22).

The two cover crops had similar N percentages in their foliage but *M. deerengianum* had almost 50% more hemicellulose, a recalcitrant compound. Foliage quality, expressed as the (lignin + cellulose)/N ratio was better in *C. ensiformis* (5.54) than in *M. deerengianum*, although the former had more lignified stems and pods.

Mulch Decomposition

Decomposition of the *L. leucocephala* mulch occurred in two phases, one of rapid weight loss (60 to 80%) during the first 20 days, and a later period of slower decomposition (Fig. 2). The first phase had a k = -22.8, and a half-life of t_{50}= 10.5 days. The equation derived for this relationship was: $y = 0.86\ e^{-22.8\ t}$ (r^2= 0.87); whereas the second phase derived equation was: $y = 0.28\ e^{-1.17\ t}$ (r^2= 0.91). The *L. latisiliquum* mulch decomposed more slowly, with a k = -1.7 (r^2= 0.99) and a half-life of t_{50}= 171 days.

Table 3. Chemical composition of legume mulches and cover crops.

Parameters	Mulches		Cover crops	
	L. leucocephala kg ha^{-1} (%)	*L. latisiliquum* kg ha^{-1} (%)	*M. deerengianum* kg ha^{-1} (%)	*C. ensiformis* kg ha^{-1} (%)
Nitrogen	126.0 (3.49)	166.0 (2.86)	78.4 (3.78)	41.7 (3.84)
Lignin	287 (7.97)	895 (15.42)	117 (5.67)	66 (6.06)
Cellulose	674 (18.72)	967 (16.64)	391 (18.90)	165 (15.22)
Hemicellulose	376 (10.45)	601 (10.37)	544 (26.27)	144 (13.29)
Polyphenols	(3.95)	(8.61)	(2.07)	nm
Water	(64)	(56)	(74)	(71)

† nm= not measured

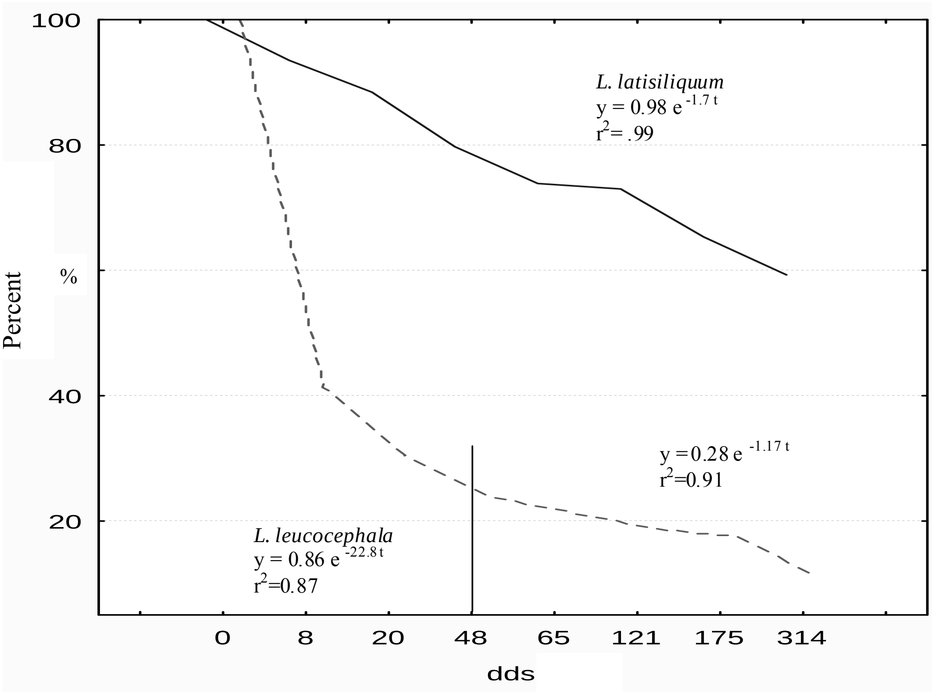

Figure 2. Weigth loss of legume mulches.

Lignin content defines mulch quality and, in the present study, the lignin/N, polyphenols/N and polyphenols + lignin/N ratios were all lower in the *L. leucocephala* mulch. This difference between species coincides with the higher decomposition constants observed for *L. leucocephala* in comparison to *L. latisiliquum*. Palm and Rowland (1997) observed a similar trend in ligneous forests, reporting a positive correlation between lignin/N ratio values and litter decomposition constants. Kachaka et al. (1993) used the lignin + polyphenols/N ratio to show the decomposition/mineralization rates of different legume materials.

Eight days after mulch application, the N content in the remaining material had dropped considerably. In this period, *L. leucocephala* released 53% of its N content and *L. latisiliquum* released 43% (Fig 3), while N content changed only slightly over time in the remaining material. Both mulches released 75 kg ha^{-1} of N in the first eight days after application. During the entire maize cultivation cycle, *L. leucocephala* mineralized more than 100 kg ha^{-1} of N (80% of the initial deposit) and *L. latisiliquum* released 80 kg ha^{-1} of N (50% of the initial deposit). This lower deposition of N by the *L. latisiliquum* mulch likely occurs because N is fixed to lignin. Both mulches can be used as organic fertilizers due to the N they release, although the lower decomposition and N release rates of the *L. latisiliquum* mulch may result in more and better edaphic organic matter with continual use.

Earthworms

At 14 das, earthworm density and biomass were highest in the Mucuna and Leucaena treatments (Table 4) and, at 70 das, the Leucaena and Lysiloma treatments had the lowest densities. Earthworm density was negatively associated with mulch nutrient input in all four legume-treatments, with better mulch quality (reduced [lignin + cellulose] /N ratio) yielding higher earthworm density (Fig. 4). At 84 das, earthworms were absent from soil samples in all of the treatments. The two possible explanations for this are: that soil disturbance during harvest drove the earthworms away; and/or, that in response to an approximately 15% drop in soil moisture at this time, earthworms took refuge in the C horizon below 20 cm depth, which is difficult to sample given its high content of rock fragments.

Between 14 and 70 das, earthworm biomass dropped by 69% in the Lysiloma treatment, by 84% in the Mucuna treatment and by 87% in the

Leucaena treatment. Earthworm biomass remained unchanged in the Control and Canavalia treatments, though there was an increase in earthworm density (Table 4). The earthworms collected at 14 das were larger in size than those collected at 70 das (Fig 5), suggesting that different species may have dominated at different times during the study. García (2005), in the same zone, found four earthworm species: *Dichogaster afinis*; *Pontoscolex corethrurus*; *Balanteodrilus pearsei*; and sp. nova. The dominant species at 14 das was *B. pearsei*, one of the larger species, whereas the dominant earthworms collected at 70 das were the smallest of these four species, namely, *D. afinis*.

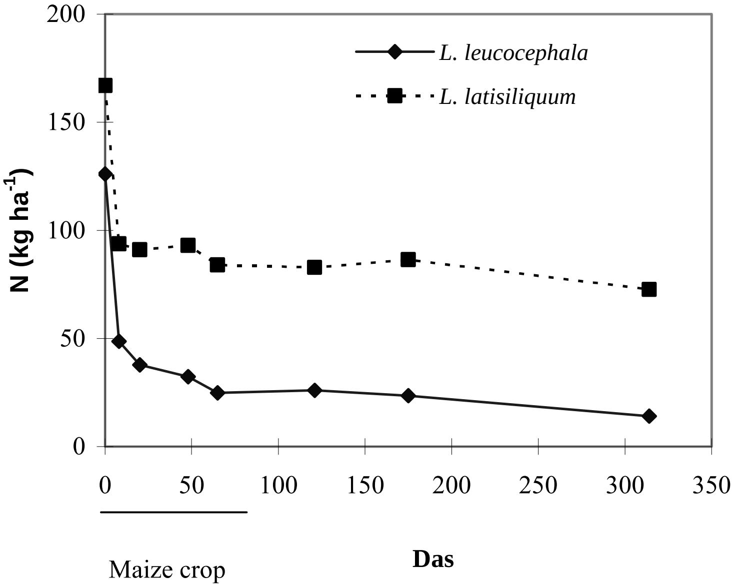

Figure 3. Nitrogen content in mulch residues.

Table 4. Earthworm and snail populations in maize cultivation with legume mulches or cover crops.

Treatment	Earthworm Density (individuals m^{-2})			Earthworm Biomass ($g\ m^{-2}$)		
	14 das	70 das	84 das	14 das	70 das	84 das
Control	$17^{a□}$	$263^{b\beta}$	0	$3.64^{a\alpha}$	$3.62^{a\alpha}$	0
Canavalia	$53^{ab\alpha}$	$223^{b\beta}$	0	$7.15^{ab\alpha}$	$9.25^{a\alpha}$	0
Mucuna	$189^{b\alpha}$	$168^{b\alpha}$	0	$29.39^{b\alpha}$	$4.80^{a\beta}$	0
Leucaena	$145^{b\alpha}$	$125^{ab\alpha}$	0	$36.85^{b\alpha}$	$4.76^{a\beta}$	0
Lysiloma	$100^{ab\alpha}$	$48^{a\alpha}$	0	$12.94^{b\alpha}$	$3.98^{a\beta}$	0
	Snail Density (individuals m^{-2})			Snail Biomass ($g\ m^{-2}$)		
Control	$142^{a\alpha}$	$72^{a\alpha}$	$57^{ab\alpha}$	$11^{a\alpha}$	$3^{a\alpha\beta}$	$2^{ab\beta}$
Canavalia	$137^{a\alpha}$	$222^{a\alpha}$	$133^{b\alpha}$	$5^{a\alpha}$	$8^{a\alpha}$	$5^{b\alpha}$
Mucuna	$58^{a\alpha}$	$184^{a\alpha}$	$181^{b\alpha}$	$13^{a\alpha}$	$9^{a\alpha}$	$5^{b\alpha}$
Leucaena	$154^{a\alpha}$	$100^{a\alpha}$	$5^{a\beta}$	$5^{a\alpha}$	$4^{a\alpha}$	$2^{a\beta}$
Lysiloma	$194^{a\alpha}$	$101^{a\alpha}$	$4^{a\beta}$	$9^{a\alpha}$	$5^{a\alpha}$	$2^{a\beta}$

† Different letters (a and b) between treatments indicate significant difference (P<0.05). ‡Different Greek symbols (α and β) between sampling times indicate significant differences (P< 0.05), n= 9

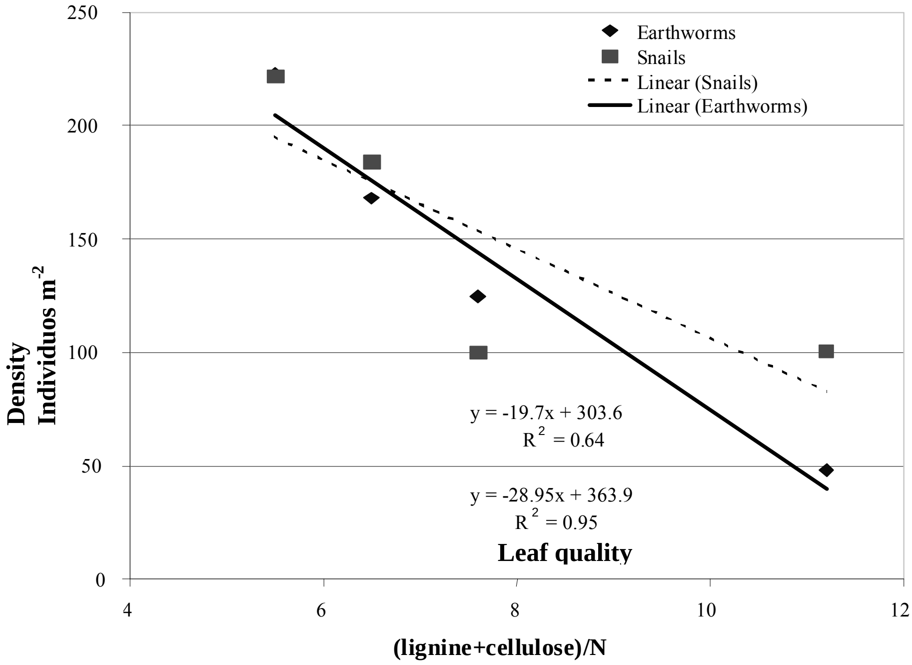

Figure 4. Relationships between leaf quality of legumes used as mulch with cover crops and earthworm density .

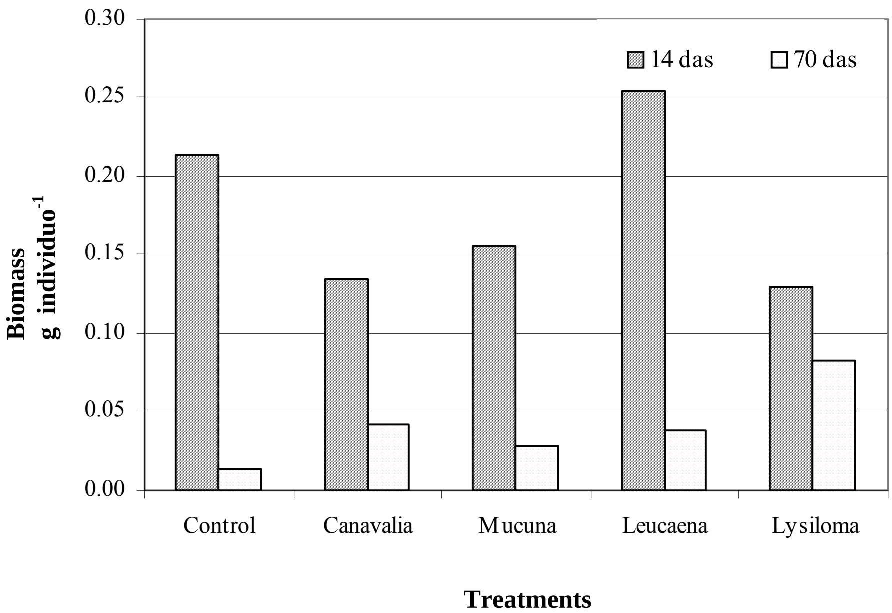

Figure 5. Total biomass of earthworms with maize, mulch and cover crops.

Earthworm samples are best taken before 1000 h as no individuals were found in samples taken after this time. This may have resulted from their movement into the C horizon, or closer to the bedrock, in search of better moisture and temperature conditions. References to the time in which the samples were taken are rarely found in the literature, making the present data significant for future research on edaphic macro-invertebrates, particularly in Leptosols and subhumid warm areas (Anderson and Ingram, 1993; Fragoso, 2001).

So far, this is the only study that has reported on earthworm density and biomass for karstic origin Leptosols in Latin America (Fragoso, 2001; Brown et al., 2001). Earthworm density for the four legume treatments was higher than the 51 individuals m^{-2} reported by Brown et al. (2001) in other soils and environments. Fragoso (2001) reported a mean of 200 individuals m^{-2} in dry subhumid forests, which is similar to densities recorded in the Control and Canavalia treatments at 70 das. Earthworm biomass values, however, are more appropriate for agronomic evaluation. For example, Fragoso (2001) observed a mean biomass value of 26 g m^{-2}, higher than in the Control, Canavalia and Lysiloma treatments. Positive effects on soil quality and agricultural production are reported to occur at earthworm biomasses greater than 30 g m^{-2}. Such high earthworm biomasses were only observed in the Mucuna and Leucaena treatments up to 14 das, because the Leptosol group typically has very little fine soil; even though the low numbers of earthworms recorded here are beneficial for soils and crops.

Other soils in Latin America have higher earthworm abundance values (120 to 300 individuals m^{-2}) (Brown, 2001), but also have soil volumes that range from four to six times more than Leptosol (Tian et al., 1993). Another contrast is that Ferralsol is found in rainy tropical climates whereas the Leptosol in the present study occurs in a subhumid tropical (AWo) climate.

Mulch quality is known to influence earthworm populations (Tian et al., 1993; Fragoso et al. 1995), which is in agreement with the data presented here. The *L. leucocephala* mulch quality, as determined by the (lignin + cellulose)/N ratio, was higher than that of the *L. latisiliquum* mulch (Fig 2). Of the two tested cover crops, *C. ensiformis* had better quality mulch than *M. deerengianum*, though the latter produced more litter biomass as a result of its better development and adaptation to the maize cultivation conditions and soils.

Finally, application of mulch and cover crops provided a more favorable soil environment for earthworms, mainly by preserving soil moisture and contributing nutrients. Soil temperature had no apparent negative influence on earthworm density; in fact, higher temperatures led to greater abundance, with soil moisture most affecting earthworm abundance.

Snails

Nine morphospecies of snails were identified during the study, of which *Praticolela graseola* was dominant. The snails were observed on the soil surface or on the plants.

Snail density and biomass at 14 and 70 das exhibited no significant differences between treatments due to wide variability in the data, although differences were observed at 84 das. At this time, the mulches (*L. leucocephala*, *L. latisiliquum*) had the lowest values and the cover crops (*M. deerengianum*, *C. ensiformis*) the highest values (Table 4). These differences probably resulted from: the lack of available food in the mulches, which lose their labile compounds in the first few days after application; the more propitious microclimate; and the greater availability of food in the cover crops. The latter treatments provided more cover than the mulches (100% with *M. deerengianum* and 60% with *C. ensiformis*), leading to a better microclimate environment and a greater amount of available food, both in the quantity of mulch and in the amount of living plant tissue. This suggests that the presence of terrestrial snails was favored by the improved microclimate in the cover crops, and by the quantity and quality of the food these provided.

Results of snail density in the treatments with *C. ensiformis* and *M. deerengianum* were higher than the 130 individuals m^{-2} reported for a dry forest in Cuba (Mijail et al., 1996). Very little comparable research has been done in Mexico, and Brown et al. (2001) did not include snail biomass or density data, because they considered these to be relatively insignificant. This does not agree with the present results because snails had a higher density than earthworms, perhaps because of the high calcium levels (required by snails for proper growth) in the region's Leptosols (Stork and Eggleton, 1992; Alvarez and Willig, 1993; Hermida and Ondina, 1995; Naranjo and Palacio, 1997).

Soil microclimate

The legume mulches and cover crops maintained soil moisture content and reduced average soil temperature. Moisture content was over 90% lower in the Control treatment than in the other four treatments, indicating that both, legume mulches and cover crops, aided in conserving soil moisture content. Soil temperature was most influenced by the mulches at 1500 h. The Control, in many cases, had the highest soil temperatures throughout the study and no differences were noted between the lower soil temperatures in the mulch and cover crop treatments (Fig. 6). Snails were less susceptible to rainfall than earthworms, as they were found throughout the growth period, even when soil moisture content had decreased.

Agronomic implications

Both legume mulches maintained higher soil moisture levels, an important benefit in subhumid tropical climates, and improved soil N content by releasing it during the first eight days after application. The amount of N released by both mulches is adequate for maize production, but applications need to be synchronized with maize growth (Table 5). Maize yield in the experimental plot in the fourth year of seasonal cultivation was 1.78 t ha^{-1} with *L. latisiliquum* and 1.75 t/ha with *L. leucocephala* mulches (Caamal et al., 2001); much higher than the 0.7 t ha^{-1} average yield in the second year. For optimal use of these legume mulches we recommend that: a) the *L. leucocephala* mulch be applied 10 to 15 das to better utilize released N, or b) that the same amount be applied between 10 and 25 das to improve synchronicity and thus maximize growth, and c) plant *L. leucocephala* and *L. latisiliquum* as living , and to trim less-lignified, younger branches to facilitate mulching.

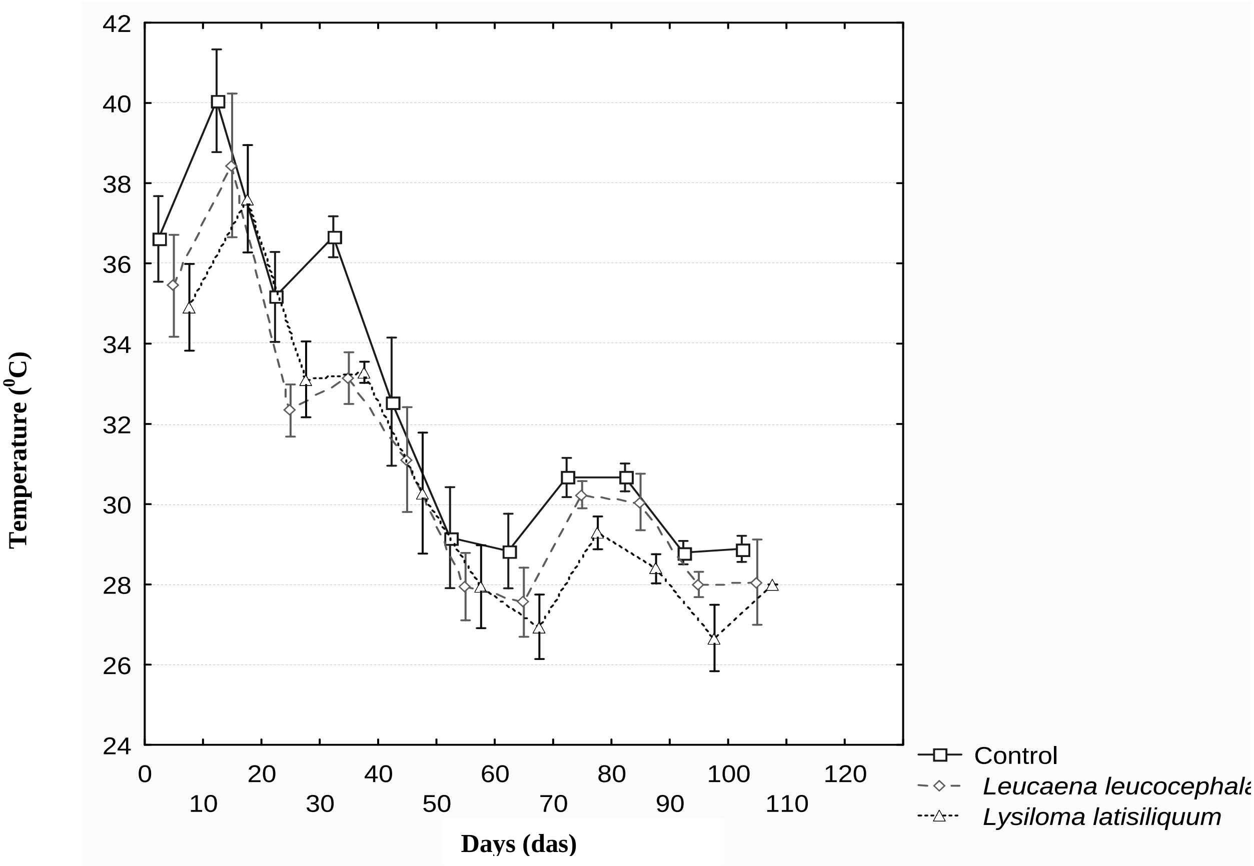

Figure 6. Soil temperature in treatments with mulch.

Table 5. Agronomic characteristics of the studied legume mulches and cover crops.

Property/Process	*M. deerengianum*	*C. ensiformis*	*L. latisiliquum*	*L. leucocephala*	Reference
Synchronicity with maize	deficient	Deficient	deficient	deficient	Present study
Earthworm populations	average	Low	low	adequate	Present study
Microclimate improvement	adequate	deficient	adequate	minimal	Present study Caamal et al., 2001
N release	not measured	not measured	deficient	adequate	Present study
MOS contribution	low	very low	adequate	deficient	Present study
Regeneration	good	deficient	not applicable	not applicable	Present study
Soil protection	very acceptable	minimal	acceptable	minimal	Caamal et al., 2001
Weed control	average	very low	low	very low	Caamal, 1995 Caamal et al., 2001
Labor	high	average	high	high	Caamal et al., 2001
Maize production	average	low	average	high	Caamal et al., 2001;
Displacement of other crops	yes	yes	no	no	Castillo, 2005
Legume seed production	high	low	possible	possible	Caamal et al., 2001; Castillo, 2005

Of the two studied cover crops, *M. deerengianum* exhibited the best adaptation to maize cultivation under the study zone's climatic and soil conditions, due to its percent coverage, biomass and regeneration from unharvested remnant seeds. As a cover crop, this legume is reported to reduce weed presence and biomass (Caamal et al., 2001) and should be planted 40 days after maize planting; which has no effect on maize production and also produces 2.7 t ha^{-1} of legume seed. In contrast, *C. ensiformis* did not meet the minimum requirements for a cover crop due to its low coverage and biomass. In addition, its regeneration from remnant seeds is minimal, and it does not form nodules and, thus, does not fix molecular N. These cover crops, particularly *M. deerengianum*, require of a further study of their agronomical advantages (e.g., N fixation, increased organic P, production of human and/or animal food), and better synchronization between N release (through mineralization of remnant cover crop biomass) and N requirements of the main crop.

Based on the present results and on recent data from the same experimental field (A. Caamal, personal communication), application of *L. leucocephala* (as a mulch) or *M. deerengianum* (as a cover crop) produces positive results in maize cultivation, while use of *L. latisiliquum* (as a mulch) or *C. ensiformis* (as a cover crop) provides no substantial benefits. Currently, the latter two legumes are no longer used because they have not been found to benefit maize production or aid in weed control.

Use of the proper mulches and cover crops clearly benefits crop production, although, even with their application agricultural use of soils can lead to long term losses of organic matter, P and K (Castillo, 2005). Although mineralization rates in the study zone are high, the degradation process is not yet fully understood (Amaya et al., 2005). Further research is needed to mitigate decreases in assimilable P by using cover crops that form mycorrhizal associations, thus converting mineral P into organic P for later release. Another option for raising organic P levels would be to manipulate earthworm intestinal microorganisms, which can solubilize phosphoric rock, converting mineral P into assimilable P (Banik and Dey, 1982; Mba, 1993; Mba, 1997).

The present results also indicate that even though some mulches and/or cover crops are beneficial, there is no single ideal mulch or cover crop that provides all needed characteristics (weed control, complete nutrient contribution, soil moisture conservation, increased biodiversity, edibility, use as a forage crop, etc.). What is needed is to diagnose the main agronomic problems being addressed and then select the best cover crop or mulch for each situation. In this case, in low karstic plains (< 10 masl) in the Yucatán state, the primary agronomic problems of farmers are: soil moisture (seasonal and irregular rain), weed control, soil fertility and limited external inputs (such as fertilizers and pesticides) (Bautista et al., 2005). Cover crops and mulches can be used as a solution of these mentioned problems but it is necessary to choose the cover crop and/or mulch to solve each problem. Many farmers do not have money to buy fertilizers and pesticides, so the mulch of *L. leucocephala* is an adequate option to solve the low soil fertility problem. Also, many farmers do not use irrigation water so that the use of *M. deerengianum* as a cover crop and of *L. latisiliquum* as mulch can solve the low moisture soil problem. If the principal agricultural problem is weed control, a cover crop of *M. deerengianum* can be used. The problems with nematodes appear in the 3rd year of cropping and can be attended with *Mucuna deerengianum* as cover crop

The use of plant mulch can be high labor demanding, however, the bushy habit of *L. leucocephala* and its invasive character in the zone makes it easy to manage requiring a low labor input. On the contrary, *L. latisiliquum* is a tree and its use as mulch requires of higher labor input; yet, *L. latisiliquum* can be used as a live fence to be defoliated for mulch production.

In general, a diagnosis of the major agronomic problems should be made first, and the selection of plants to be used as cover crops and/or mulches should be decided afterwards, in agreement with their potential and properties.

CONCLUSION

The *L. leucocephala* mulch and, *M. deerengianum* and *C. ensiformis* cover crops appeared to produce a temporary increase in earthworm population density, while the *L. latisiliquum* mulch had no effect on this variable. Earthworms are more dependent on moisture and resource quality than snails. The mulches and cover crops examined also appear to have produced a drop in snail density and biomass; although as soil moisture decreased, use of *M. deerengianum* as a cover crop promoted increased snail density and biomass. The studied mulches and cover crops aided in preserving soil moisture and reducing soil temperature.

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