Forage production with non-conventional species in shallow, stony soils. Effect of fertilization and cutting on yield and raw protein content of three leguminous species

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ABSTRACT: Forage production by three leguminous species (*Enterolobium cyclocarpum* "guanacaste", *Leucaena esculenta* "huaje rojo" and *Tamarindus indica* "tamarindo") planted in a shálow, stony soil was evaluated.

The experiments were carried out in an experimental field located at the municipality of Xochitepec, State of Morelos, Mexico. The soil is discontinuous, with a moderate slope (up to 15°), and is underlaid by sandstones and conglomerates. The climate is warm subhumid and the vegetation is a depauperated tropical shrubland. A randomized block experimental design was used to assess the response —in terms of fresh and dry weight, raw protein content and raw protein yield— of the three species under four fertilization levels at four periodical harvests, with two replicates of each combination of species X dosage assigned to each of three blocks. Each experimental unit was constituted by a 2.5 m^2 plot containing 18 systematically arranged plants, the inner four of which were used for analysis.

The results showed that "huaje rojo" is an excellent forage producer [yield: 14.42 (fresh weight), 5.02 (dry weight) tm/ha/yr] and is resistant to manipulation. Production by "guanacaste" was fairly good [yield: 4.04 (fresh weight), 1.36 (dry weight) tm/ha/yr]."Tamarindo" showed a very poor production [yield: 1.85 (fresh weight), 0.68 (dry weight) tm/ha/yr] and does not resist manipulation. No response to fertilization was detected.

These results suggest that cultivation of indigenous species such as *L. esculenta* and *E. cyclocarpum* might constitute an advantageous land use strategy for shallow, stony soils in tropical areas which could contribute to their ecological restoration while taking advantage of the local floristic richness.

Keywords: Shallow soil productivity, leguminous yield, *Leucaena esculenta, Enterolobium cyclocarpum, Tamarindus indica.*

INTRODUCTION

The aim of this study was to evaluate the capacity for forage production of three leguminous species that had never been used for this purpose before: *Enterolobium cyclocarpum* (Jacq.) Griseb "guanacaste", *Leucaena esculenta* (M. et S. ex A. DC.) Benth. "huaje rojo" and *Tamarindus indica* L. "tamarindo". The term "forage" is used here in a rather broad sense to refer to the edible material produced by these plants.

Existent information about the cultivation of these species is quite uneven. Numerous studies dealing with species of the genus *Leucaena* have been conducted in Mexico (Sánchez and Pérez, 1977; Zárate and Sousa, 1978; Pérez, 1979; Banco de México, 1980; Zárate, 1982; Foroughbakhch and Hauad, 1989) and other parts of the world (*e.g.* Dijkman, 1950; Gray, 1968; N.A.S., 1975, 1977, 1979; Beuge, 1977; Flores and Stobbs, 1978), but most of them concern only two species: *Leucaena leucocephala* and *L. glauca*. The symbiosis between *Leucaena* and *Rhizobium* has been extensively studied (*e.g.* Aquiahuatl and Muñoz, 1983a, b; Moreno *et. al.*, 1983; De la Garza *et al.*, 1987), but in species other than *L. esculenta*. Lara and Ferrara (1986) studied the vesicular arbuscular mycorrhizal symbiosis in *L. leucocephala*. In recent years, the germoplasm of mexican species of *Leucaena* has been evaluated (*e.g.* Ramírez, 1987).

Several studies have measured forage production in *Leucaena* species but most of them have dealt with *L. leucocephala*. Reported values range from 27.5 (Relwani *et al.*, 1982) up to 52.6 (Raina *et al.*, 1984) tm of fresh weight/ha. Raina *et al.* (1984) measured fresh weight yield at seven successive cuttings in 20 cultivars and reported the following average values: 6.1, 6.7, 5.8, 7.7, 4.4, 5.8 and 5.6 tm/ha for cuts at 180, 50, 45, 60, 67, 57 and 46 days respectively. They pointed out that the marked decrease in the fifth cut coincided with the driest month of the year. Reported values of protein content in *L. leucocephala* are quite variable: 28.8% (Hutton and Bonner, 1960), 22.8% (Singh and Mudgal, 1967), 25.9% (N.A.S., 1977), 22% (Kinch and Ripperton, 1982), 18.4% and 19.3% (Krishna and Gowda, 1982), 24.7% (Relwani *et al.*, 1982) and 18.5% in the whole plant, 25% in leaves and 9% in new shoots (Pizarro and Sousa, 1983).

Information about *Enterolobium cyclocarpum* is scarse. We have found only a few references dealing with the consumption, digestibility and chemical composition of fruits and seeds and some reports on introduction trials (Massieu *et al.*, 1950; Bressani *et al.*, 1966; Vázquez-Yánez and Pérez, 1977; Janzen and Higgins, 1979; Janzen, 1981a,b; Foroughbackhch and Peñaloza, 1989). Even less information can be found about *Tamarindus indica*. N.A.S. (1979) cites only nine references worldwide concerning fruit production. Symbiosis with nitrogen-fixing microorganisms has been reported for "guanacaste" and "huaje rojo" but not for "tamarindo" (Holliday, 1984). It is very likely that the three species from symbiosis with vesicular arbuscular mycorrhizal fungi (M. Valdés, personal communication 1987).

Taking into account the envir nmental similarity of the localities where *Enterolobium* and *L. esculenta* grow naturally and of those where *Tamarindus* is cultivated, together with the known ecological requirements, morphology and growth form of these species, it was hypothesized that they could be adequately grown in the study area. The purpose of this study was to evaluate the production and raw protein content of edible material of these species under four fertilization levels and periodical cuttings. These species had never been used for forage production before and this work also represents a first attempt to test their acclimatization and management in shallow, stony soils, which have no possibility of agricultural use, in a warm subhumid climate.

CHARACTERISTICS OF THE STUDY AREA

The experiments were carried out in a experimental field near the Atlacholoaya town, municipality of Xochitepec, in the Mexican State of Morelos (coordinates: 18° 44' 50''N, 99° 13' 41''W), at an altitude of 1,100 m a.s.l. (Fig. 1). The field is located on a slope (up to 15°) at the left side of a ravine formed by the Apatlaco river. The underlying materials are Miocene-Pliocene sandstones and conglomerates (SPP, 1981). The soil is discontinuous, shallow (depth $\leq$ 20 cm) and corresponds to a Lithosol with residues of Haplic Pheozem with lithic phase (SPP, 1981). The climate is warm, subhumid, with a mean annual temperature of 24°C and a mean total annual rainfall of 850 mm, almost all of which falls between June and September. The original vegetation of the zone was a low-stature, deciduous tropical forest which, upon disturbance, has been replaced by a tropical shrubland. There exists an upper shrub stratum dominated by *Ipomoea* and *Carica*, with a few scattered emergent threes of *Bursera* and *Thevetia*. Plants of *Gliricidia*, *Sesbania*, *Mimosa* and *Dalea* form a low shrub stratum. The herbaceous layer is mainly constituted by *Opizia*, *Bouteloua* and *Crotalaria*. All the zone has been badly overgrazed and erosion has led to the formation of extensive areas where soil has been completely lost and the bedrock is exposed.

MATERIAL AND METHODS

Seed collection and germination

Seeds of *Enterolobium cyclocarpum* and *Tamarindus* indica were collected from trees growing in the Nieves town in the Mexican State of Veracruz, in May, 1986. Seeds of *Leucaena esculenta* were collected in January, 1987 from one tree growing near the study area. Samples of these seeds were tested for viability and germination. It was found that the seeds of *Leucaena esculenta* germinated readily but those of *Enterolobium* and *Tamarindus* did not due to their hard seed coats. The seeds of these species were therefore treated with concentrated sulfuric acid for 15 min and thoroughly washed with tap water afterwards.

Black plastic bags containing 2 kg of previously sterilized silt from irrigation channels were used as germination pots. On February 28, 1987, three seeds of the corresponding

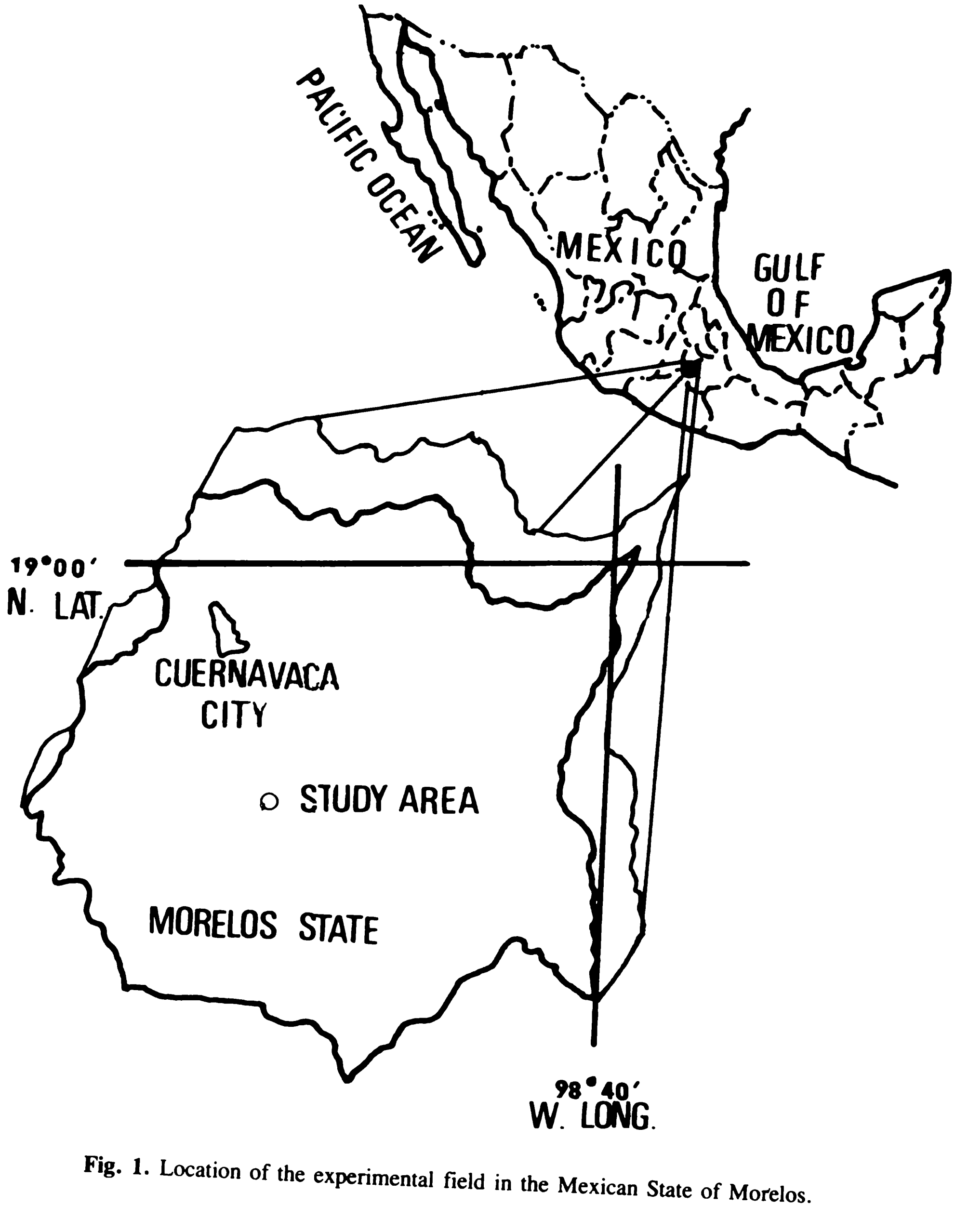

Fig. 1. Location of the experimental field in the Mexican State of Morelos.

species were sown on each pot. The pots were kept at a nearby plant nursery belonging to the Comisión Nacional de Fruticultura, where they were watered daily for the first 15 days and then every other day until transplantation.

Experimental design

In the experimental field an area of 42 × 12 m was delimited and subdivided into three contiguous blocks of 14 × 12 m each. Twenty four 2.5 × 1 m plots (experimental units) were established in each block in a regular pattern with a distance of 1 m between adjacent plots. Two plots of each block were then randomly assigned to each of the twelve treatments resulting of the combinations of three species and four fertilization levels, in a factorial randomized block design. Mixtures of Ammonium Sulfate (containing 20.5% of N) and Calcium Superphosphate (containing 19% of P_2O_5) were used for fertilization. The four fertilization levels chosen were as follows:

a) Control: No fertilizer.
b) Low dose: equivalent to 80 kg/ha of N plus 20 kg/ha of P_2O_5.
c) Medium dose: 100 kg/ha of N plus 40 kg/ha of P_2O_5.
d) High dose: 120 kg/ha of N plus 60 kg/ha of P_2O_5.

Transplantation

Seedlings were transplanted to the experimental field when they had reached ≈15 cm height and had at least five leaves. In each plot, 18 pits of ≈15 cm diameter and ≈25 cm depth were dug in a systematic arrangement with a spacing of 0.5 m between pits. Each pit was filled with the content of a germination pot containing seedlings of the proper species and watered to saturation immediately after. The plants were then watered every 4-6 days until the onset of the rainy season. To prevent the plants from being damaged by livestock or other large animals, the whole experimental area was fenced with wire-mesh and barbed wire.

Two weeks after transplantation, when it was considered that the plants had survived and become properly established, the plots were thinned manually leaving only one plant per pit to provide a density of 18 plants per plot.

Fertilization and cutting

The total amount of fertilizer to be applied to each plant was divided in four equal portions; the first portion was applied one week after transplantation and the other three immediately after the first, second and third cuts, respectively. On each occasion, a 3-5 cm deep sickle-shaped groove was excavated around the plant, the proper amount of fertilizer deposited along it, and the groove covered again with soil.

Cuts were taken when most of the plants had reached 40 cm height at least. The first cut was taken 84 days after transplantation and the other three at the following intervals: 63, 63 and 84 days, respectively. In all cases only the four central plants of each plot were cut, the outer 14 being used as guard plants to avoid edge effects. Each plant was cut with shears ±10 cm above the soil surface, put into a paper bag, weighed, taken to the laboratory, oven dried at 100°C until constant weight, and weighed again.

Chemical analysis of plant material and soil

Samples of the dried plant material were ground in a blender, sifted through a 0.5 mm-mesh sieve and thoroughly mixed in preparation for chemical analysis. Total nitrogen content was determined by the micro-Kjeldah method with an autoanalyzer (Technicon Industrial Systems, 1977). Raw protein content was calculated by multiplying total nitrogen content by a factor of 6.25. Raw protein yield per plot was then calculated by multiplying raw protein content by the dry weight yield of the corresponding plot.

Five composite soil samples were taken from points considered to be representative of the variation range of the field. Dry and moist color, texture, pH, electric conductivity, cation exchange capacity, base saturation and available Phosphorus content were determined using the methods described in Soil Survey Staff (1984).

Data analysis

The data of dry and fresh weight yield, raw protein content percentage and raw protein yield were separately subjected to profile analyses of repeated measurements in order to compare the responses of the three species under the four fertilization doses over the four successive cuts. In those cases where the null hypothesis of parallel profiles was rejected, univariate analyses of variance were performed to test for differences between treatments at each particular harvest; differences between harvests within each treatment were then tested by means of the Hotelling T^2 statistic. Raw protein content data were arcsin transformed prior to analysis. Computational details of the statistical tests can be found in Morrison (1976).

RESULTS AND DISCUSSION

Soil characteristics

The main properties of the soil are as follows: dry color 10YR 5/2 grayish brown; moist color 10YR 2/1 black; texture sandy clay loam; pH = 7.8; electric conductivity 0.46 mmhos/cm; cation exchange capacity 26 meq/100 g of dry soil; base saturation 100%; organic matter content 2.3%; available phosphorus 0.6 kg/ha.

Fresh weight yield

The mean fresh-weight-yield profiles corresponding to the 12 experimental treatments (3 species × 4 fertilization doses) are shown in Fig. 2. Profile analysis showed that the profiles are not all parallel; they differ significantly among species ($P < 0.001$; see Table 1) but neither the fertilization nor the interaction (species X fertilization) effects were significant. This means that the three species responded differently to cutting but their responses were not influenced by the fertilization treatments employed. The yield of *E. cyclocarpum* did not change in the first two harvests, decreased significantly ($P < 0.05$; see Table 1) in the third and more drastically so in the last cut. In contrast, *Leucaena* responded positively to the first cut reaching a much higher yield in the second harvest but then its production diminished markedly and progressively in the last two cuts. The

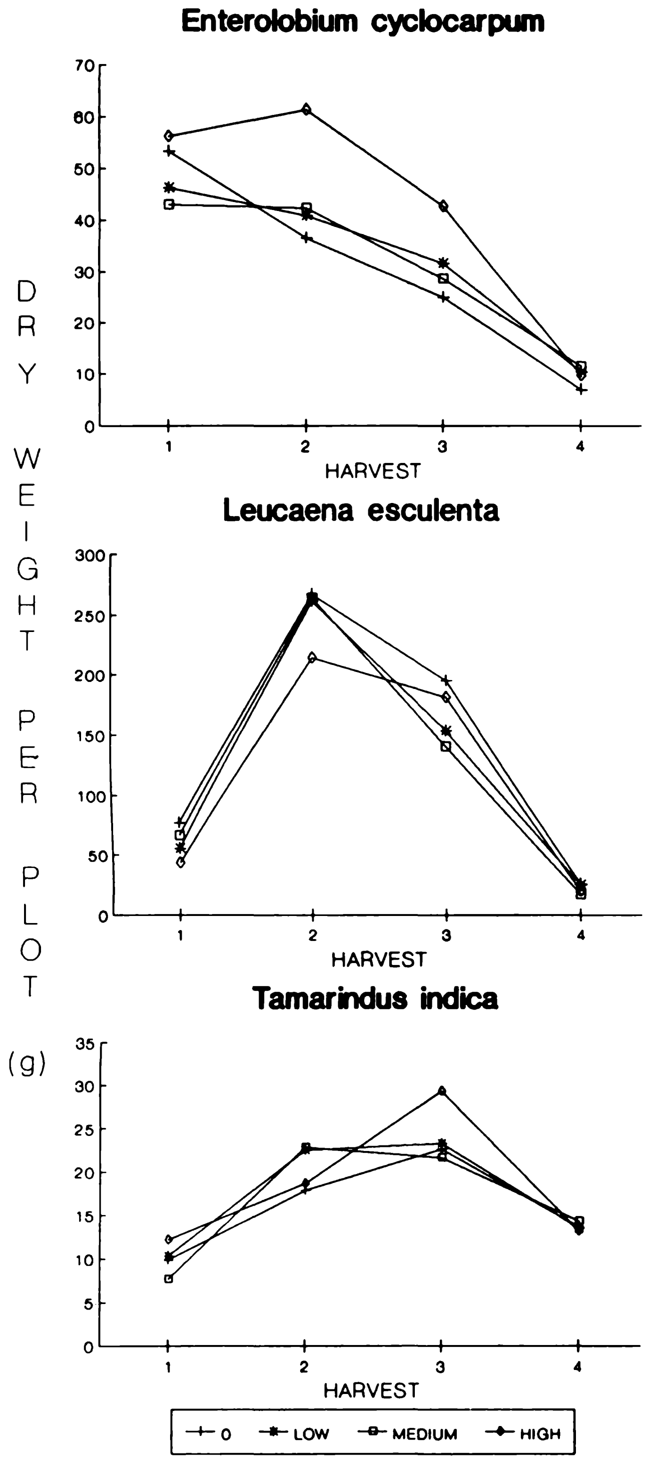

Fig. 2. Mean fresh-weight-yield profiles of the three species under the four fertilization doses. Each point is the average of six replicates. Note the different scale on the vertical axis of each graph.

TABLE 1. Profile analysis of fresh weight yield data. Values followed by the same letter are not significantly different at $\alpha = 0.05$ based on Scheffe's simultaneous multiple comparisons test.

Test of parallelism

Source of variation	Wilks'Λ	d.f.	P
Species	0.068	6,112	0.000 ***
Dose	0.886	9,136	0.645 ns
Species × Dose	0.774	18,158	0.494 ns

Multiple comparisons among treatments at each harvest

	Mean fresch weight yield (g/plot)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	153.25 a	149.83 a	83.29 a	17.46 a
Leucaena	188.58 a	788.00 b	425.48 b	39.75 b
Tamarindus	31.58 b	69.88 a	59.71 a	23.92 a

Multiple comparisons among cuts within each treatment

	Mean fresh weight yield (g/plot)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	153.25 a	149.83 a	83.29 b	17.46 c
Leucaena	188.58 a	788.00 b	425.48 c	39.75 d
Tamarindus	31.58 a	69.88 b	59.71 b	23.92 c

yield of *T. indica* was always very low, increased slightly and significantly in the second cut and also showed a significant reduction in the final harvest.

The marked reduction in yield experienced by the three species in the final cut might have been caused by a severe disequilibrium in their water balance (as no rainfall occurred during the period between the third and fourth cuttings), rather than by a negative effect of the cuttings on their growth.

Overall, *Leucaena* was always the best producer and *Tamarindus* the worst. In the first cut, the mean yields of *E. cyclocarpum* and *L. esculenta* were similar to each other (153.25 vs, 188.58 g per plot, respectively) and much higher than that of *T. indica* (31.58 g per plot, $P < 0.05$; see Table 1). In the second harvest, *L. esculenta* reached a peak yield (788.00 g per plot) far above those of the other species (149.88 g per plot for *Enterolobium*, 69.88 g per plot for *Tamarindus*), which did not differ significantly between them. Although the yields of the three species decreased significantly in the third and fourth cuts, the values for *L. esculenta* (425.58 and 39.75 g per plot, respectively) were always significantly higher than those for *Enterolobium* (83.29 and 17.46 g per plot) and *Tamarindus* (59.71 and 23.92 g per plot).

The average annualized fresh weight yields for the three species were: 4.04 *(Enterolobium)*, 14.42 *(Leucaena)* and 1.85 *(Tamarindus)* tm/ha/year at a density of 40,000 plants/ha. These values are quite low compared to those previously reported for *Leucaena leucocephala* which range from 27.5 (Relwani *et al.*,.1982) to 52.6 (Raina *et al.*, 1984) tm/ha/yr at densities of about 67,000 and 133,300 plants/ha respectively, but suggest that a higher production might be possibly obtained in cultures with a higher density. This possibility is the subject of current research.

The average water content percentages for the three species were: *Enterolobium* 68.63%, *Leucaena* 67.80% and *Tamarindus* 62.47%.

Dry weight yield

Figure 3 shows the mean dry-weight-yield profiles of the 12 experimental treatments. As can be seen, these profiles show a pattern very similar to that of the fresh weight data: they are not all parallel, there are significant differences among species ($P < 0.001$; see Table 2) and neither the fertilization nor the interaction (species X fertilization) effects were significant. *Tamarindus indica* had very low yields (about 17 g per plot in average) which did not vary significantly among cuts (Table 2). The yield of *Enterolobium* remained constant in the first two cuts and decreased significantly in the third and fourth harvests. In contrast, the yield of *Leucaena* greatly increased in the second cut but then also decreased markedly in the last two harvests.

Analyses of variance of the mean dry weight yields at each harvest led to the same conclusions as the fresh weight data (see Table 2): *Leucaena* had always the highest yields and *Tamarindus* the lowest. *Enterolobium* had a yield as high as *Leucaena's* in the first cut and as low as *Tamarindus's* in the following cuts.

The mean annualized dry weight yields of the three species were: 1.36 *(Enterolobium)*, 5.02 *(Leucaena)* and 0.68 *(Tamarindus)* tm/ha/yr. By comparison, N.A.S. (1977) reports values ranging from 12 to 20 tm of edible (leaves and young shoots) dry matter/ha/yr for the best forage-producing varieties of *Leucaena leucocephala* cultivated in good soils and under favorable climate or with irrigation. However, if we take into account the climatic conditions in our study area together with the poor quality of these soils and their consequently low or even null agricultural productivity, then the forage production here obtained with *L. esculenta* can be regarded as considerably good. In addition, as was stated above, the possibility exists for even better yields to be achieved by using cultures with densities higher than those employed in this study.

Raw protein content

The mean raw-protein-content profiles corresponding to the 12 experimental treatments are shown in figure 4. In this case, the first null hypothesis of profile analysis (*i.e.* treatment mean profiles all parallel) was not rejected ($P >> 0.05$; see Table 3), thus indicating that the protein content of the plants varied, over the four cuttings, in the same fashion in all the 12 treatments.

The test of identical profile heights (*i.e.* identical mean protein contents in all the

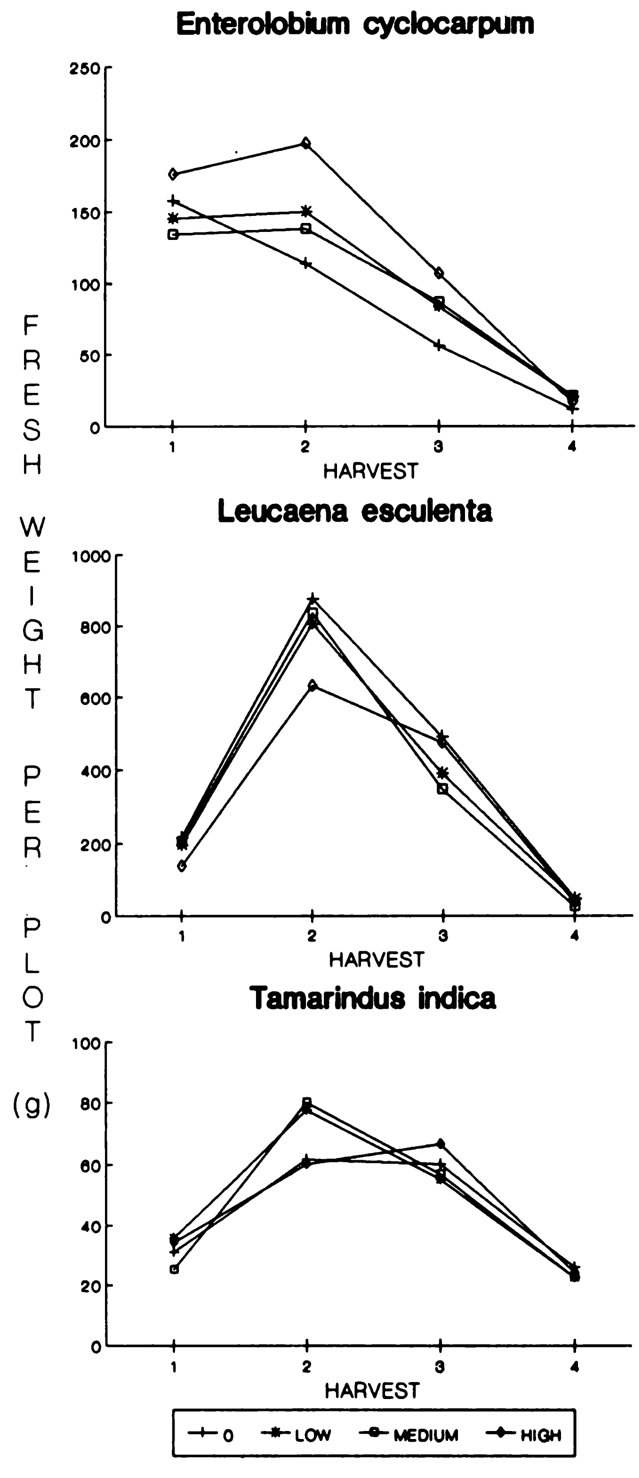

Fig. 3. Mean dry-weight-yield profiles of the three species under the four fertilization doses. Each point is the average of six replicates. Note the different scale on the vertical axis of each graph.

TABLE 2. Profile analysis of dry weight yield data. Values followed by the same letter are not significantly different at $\alpha = 0.05$ based on Scheffe's simultaneous multiple comparisons test.

Test of parallelism

Source of variation	Wilks'Λ	d.f.	P
Species	0.067	6,112	0.000 ***
Dose	0.830	9,136	0.296 ns
Species × Dose	0.748	18,158	0.516 ns

Multiple comparisons among treatments at each harvest

	Mean dry weight yield (g/plot)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	49.67 a	45.25 a	32.00 a	9.60 a
Leucaena	60.50 a	251.83 b	167.50 b	22.04 b
Tamarindus	10.00 b	20.46 a	24.25 a	13.67 a

Multiple comparisons among cuts within each treatment

	Mean dry weight yield (g/plot)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	49.67 a	45.25 a	32.00 b	9.60 c
Leucaena	60.50 a	251.83 b	167.50 c	22.04 d
Tamarindus	10.00 a	20.46 a	24.25 a	13.67 a

treatments at a given harvest, assuming parallel profiles) showed highly significant ($P < 0.001$; see Table 3) differences among species but no fertilization or interaction effects. This means that species differ in their mean protein levels but these were not influenced by the fertilization treatments. Scheffé's simultaneous multiple comparisons (Table 3) showed that, in each harvest, *Leucaena* and *Enterolobium* had similar ($P > 0.05$) protein contents which were significantly ($P < 0.05$) higher than that of *Tamarindus*. It can be concluded, therefore, that not only was *Tamarindus* the poorest fodder-producer of the three, but it also produced foliage of a significantly lower nutritional quality (in terms of its protein content).

The test of horizontal profiles was also rejected ($P < 0.001$; Table 3), thus indicating that the average protein content of the plants varied among cuts within each treatment. Scheffé's simultaneous multiple comparisons showed that, in all the treatments, protein content decreased significantly ($P < 0.05$; see Table 3) from the first to the second

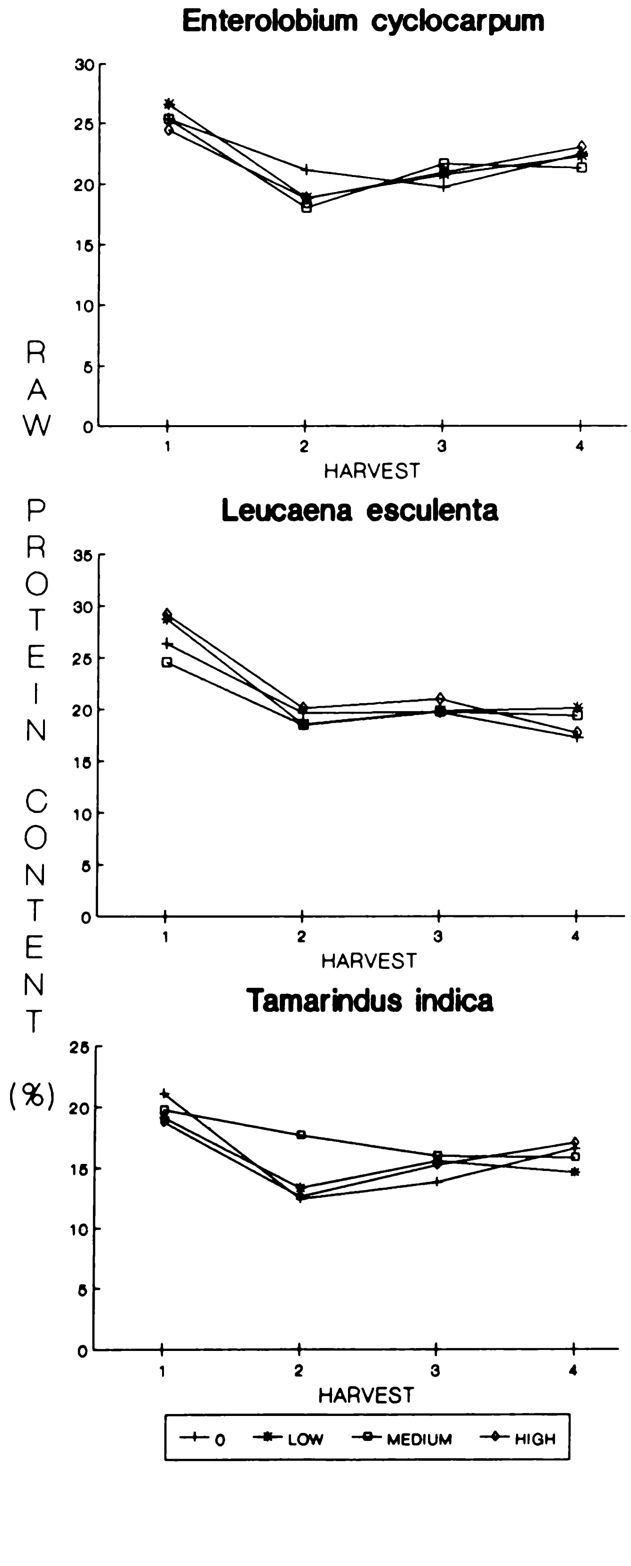

Fig. 4. Mean raw-protein-content profiles of the three species under the four fertilization doses. Each point is the average of six replicates. Note the different scale on the vertical axis of each graph.

TABLE 3. Profile analysis of raw protein content (%) data. Values followed by the same letter are not significantly different at $\alpha = 0.05$ based on Scheffe's simultaneous multiple comparisons test.

Test of parallelism

Source of variation	Wilks'Λ	d.f.	P
Species	0.857	6,112	0.184 ns
Dose	0.934	9,136	0.916 ns
Species × Dose	0.783	18,158	0.699 ns

Test of identical profile heights

Source of variation	Wilks'Λ	d.f.	P
Species	0.375	8,110	0.000 ***
Dose	0.930	12,145	0.981 ns
Species × Dose	0.756	24,193	0.874 ns

Multiple comparisons among species

Species	Overall mean protein content (%)
Enterolobium	21.92 a
Leucaena	21.78 a
Tamarindus	16.21 b

Test of horizontal profiles

Hotelling $T^2 = 89.39$ F = 28.80 with 3,58 d.f. P < 0.001***

Multiple comparisons among cuts over all the treatments

Cut	Overall mean protein content (%)
First	24.09 a
Second	17.48 b
Third	18.67 b
Fourth	18.98 b

cutting but remained constant afterwards. This reduction might have been due to the greater proportion of woody material developed by the plants as they grew older.

The final mean protein contents (average of the three last cuts over all the fertilization treatments) were: 20.76% *(Enterolobium cyclocarpum)*, 19.31% *(Leucaena esculenta)* and 15.05% *(Tamarindus indica)*. These values are rather low compared to those previously reported for *Leucaena leucocephala* which range from 18.5 to 28.8% (Hutton and Bonner, 1960; Singh and Mudgal, 1967; N.A.S., 1977; Kinch and Ripperton, 1982; Relwani *et. al.*, 1982; Pizarro and Sousa, 1983; Saunders *et. al.*, 1987). However, taking into account that those values have been obtained in plants grown under much more favorable climatic and soil conditions than those used in the present study, the nutritional quality of the foliage of *Leucaena esculenta* and *Enterolobium* can then be considered as quite acceptable. It must be pointed out, to this respect, that none of the plants showed any signs of inoculation by *Rhizobium*.

Raw protein yield

Profile analysis of the protein yields per plot (Fig. 5) showed that the profiles were not all parallel; they differed significantly ($P < 0.001$; Table 4) among species but neither the fertilization nor the interaction effects were significant ($P >> 0.05$). In *Enterolobium cyclocarpum*, significant ($P < 0.05$; see Table 4) reductions in protein yield occurred in the second and fourth cuts; the former having been mainly caused by the decrease in protein content and the latter by the low dry matter production reached in the preceding period. In contrast, the high dry matter yield of *Leucaena esculenta* at the second cut compensated for the decrease in protein content so that its protein yield also reached a peak in the second cut, but decreased markedly and progressively in the following harvests due to the decreasing production made in those periods. Finally, the very low dry weight yields of *Tamarindus indica*, combined with its inherently lower protein content, resulted in very low protein yields which diminished slightly but significantly in the last harvest.

As can be expected from the dry weight yields and protein contents, *Leucaena* always had the highest protein yields and *Tamarindus* the lowest. In the first harvest, the mean protein yields of *Leucaena* and *Enterolobium* were similar to each other (12.40 and 15.87 g/plot, respectively; $P > 0.05$; see Table 4) and far higher ($P < 0.05$) than that of *Tamarindus* (2.03 g/plot). In the following cuts, however, both *Enterolobium* and *Tamarindus* had similarly low protein yields which were well below those of *Leucaena*.

The mean annualized protein yields of the three species were: 295 *(Enterolobium)*, 1031 *(Leucaena)* and 108 *(Tamarindus)* kg/ha/yr, with a density equivalent to 40,000 plants/ha. The protein yield of *Leucaena esculenta* falls well within the range of values reported for *Leucaena esculenta* (800 to 4300 kg/ha/yr; N.A.S., 1977) but those of *Enterolobium* and *Tamarindus* are comparatively low.

Conclusions

The yield, raw protein content and response to cutting of the three species examined were not significantly affected by the fertilization treatments employed. This might have been due either to the amount of nutrients added not having been high enough to promote

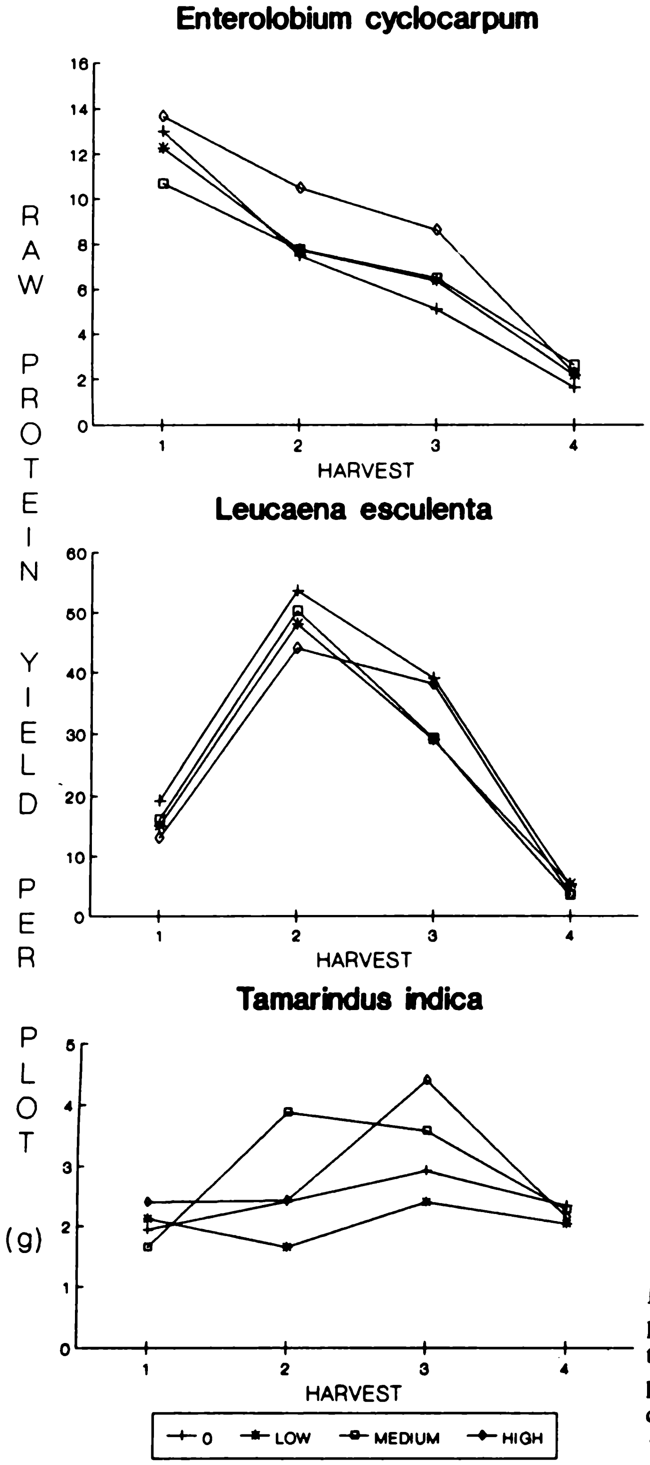

Fig. 5. Mean raw-protein-yield profiles of the three species under the four fertilization doses. Each point is the average of six replicates. Note the different scale on the vertical axis of each graph.

Table 4. Profile analysis of raw protein yield data. Values followed by the same letter are not significantly different at $\alpha = 0.05$ based on Scheffe's simultaneous multiple comparisons test.

Test of parallelism

Source of varation	Wilks'Λ	d.f.	P
Species	0.090	6,112	0.000 ***
Dose	0.902	9,136	0.747 ns
Species × Dose	0.832	18,158	0.902 ns

Multiple comparisons among treatments at each harvest

	Mean raw protein yield (%)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	12.40 a	8.385 a	6.66 a	2.16 a
Leucaena	15.87 a	49.00 b	33.87 b	4.42 b
Tamarindus	2.03 b	2.95 a	3.66 a	2.20 a

Multiple comparisons among cuts within each treatment

	Mean raw protein yield (%)			
	First cut	Second cut	Third cut	Fourth cut
Enterolobium	12.40 a	8.385 b	6.66 b	2.16 c
Leucaena	15.87 a	49.00 b	33.87 c	4.42 d
Tamarindus	2.03 a	2.95 a	3.66 a	2.20 b

a significant response in the growth and productivity of the plants, or to the fact that productivity was being limited by some environmental factor (*e.g.* moisture availability) other than the availability of nitrogen and/or phosphorus. None of the plants developed association with *Rhizobium*.

The capacity for forage production of the three species tested was significantly different. The mean annualized fresh (dry) weight yields of edible material were as follows: *Enterolobium cyclocarpum* 4.04 (1.36), *Leucaena esculenta* 14.42 (5.02) and *Tamarindus indica* 1.85 (0.68) tm/ha/yr with a planting density equivalent to 40,000 plants/ha. Taking into account the soil and climatic conditions of the site where these experiments were carried out, *Leucaena esculenta* can be regarded as a good forage producer. Moreover, it is likely that higher productivities might be reached with cultures of a higher planting density.

The protein content percentages indicate that the nutritional quality of the edible material produced by *Leucaena esculenta* (average final protein content = 19.31%) and

Enterolobium cyclocarpum (20.76%) is similar to that of other species regardes as good forage-plants (25-34%). However, the nutritional value of the foliage produced by *Tamarindus indica* was considerably low (protein content = 15.05%).

The protein content of the foliage of *Leucaena esculenta,* together with its high productivity, resulted in protein yields (average = 1031 kg/ha/yr) which fall well within the range of values reported for plants considered as good forage-producers (800-4300 kg/ha/yr in *Leucaena esculenta*). In contrast, the protein yields of *Enterolobium* and *Tamarindus* were rather poor, due to their low productivities and/or their low protein content.

Leucaena esculenta and *Enterolobium cyclocarpum* resisted manipulation very well. In fact, the plants of *Leucaena esculenta* resprouted vigorously after cutting and its production greatly increased after the first cut. In contrast, the plants of *Tamarindus indica* were negatively affected by cutting, they resprouted only slowly and feebly and made a very low production overall.

These results suggest that *Leucaena esculenta* might constitute a very valuable plant resource for tropical areas. On the one hand, plants of this species can grow very well in shallow, stony soils (which have little or null possibility of traditional agricultural use) and their cultivation could help to fix the soil, reduce erosion and improve some soil characteristics (*e.g.* organic matter content, structure, water holding capacity, etc.). On the other hand, the high productivity and the nutritional quality of the edible material produced by *Leucaena esculenta* make it a good forage-producing plant. Thus, cultivation of this species would be profitable and, at the same time, could contribute to the ecological restoration of degraded soils.

Enterolobium cyclocarpum might also be useful for these purpose, but further experimental work is needed in order to determine the most adequate planting conditions. On the contrary, the low productivity of *Tamarindus indica,* together with the low nutritional quality of its foliage and its being adversely affected by cutting, make it scarcely useful in this regard.

RESUMEN

Se evaluó la producción de forraje de tres especies de leguminosas cultivadas en un terreno con suelo somero y pedregoso: *Enterolobium cyclocarpum* (''guanacaste''), *Leucaena esculenta* (''huaje rojo'') y *Tamarindus indica* (''tamarindo'').

Los experimentos se efectuaron en un campo experimental localizado en el municipio de Xochitepec, estado de Morelos, México. El suelo es discontinuo y de pendiente moderada (hasta 15°). El material geológico subyacente está constituido por areniscas y conglomerados. El clima es cálido subhúmedo y la vegetación es un matorral tropical depauperado. Se utilizó un diseño experimental en bloques aleatorios para evaluar la respuesta —en términos de peso seco, peso fresco, contenido de proteína cruda y rendimiento de proteína cruda— de las tres especies bajo cuatro diferentes dosis de fertilización en cuatro cortes periódicos, asignando dos réplicas de cada combinación de especies X dosis a cada uno de tres bloques. Las unidades experimentales estuvieron constituidas por parcelas rectangulares de 2.5 m^2, cada una de las cuales contenía 18 plantas dispuestas sistemáticamente. Sólo las cuatro plantas centrales de cada parcela se utilizaron para los análisis.

Los resultados obtenidos muestran que el "huaje rojo" es un excelente productor de forraje [rendimiento: 14.42 (peso fresco), 5.02 (peso seco) tm/ha/año] y es resistente al manejo. La producción del "guanacaste" fue media [rendimiento: 4.04 (peso fresco), 1.36 (peso seco) tm/ha/año]. El "tamarindo" tuvo una muy pobre producción de forraje [rendimiento: 1.85 (peso fresco), 0.68 (peso seco) tm/ha/año] y no resiste el manejo. No se observó respuesta alguna a la fertilización.

Estos resultados sugieren que el cultivo de especies nativas tales como *L. esculenta* y *E. cyclocarpum* puede representar una alternativa ventajosa para el uso de terrenos erosionados en áreas tropicales, la cual podría contribuir a su recuperación ecológica aprovechando, al mismo tiempo, la riqueza florística local.

Palabras clave: Productividad en suelos someros, rendimiento de leguminosas, *Leucaena esculenta, Enterolobium cyclocarpum, Tamarindus indica.*

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