

## ***In situ* fodder production of *Mimosa tenuiflora* under pruning in native caatinga tropical dry forest in Brazil**

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### **Abstract**

This study evaluated the effect of pruning *Mimosa tenuiflora* at the middle of the rainy season (April) or beginning of the dry season (July), during 3 consecutive years, in 2 *M. tenuiflora*-rich native stands of secondary seasonal tropical dry forest under continuous cattle browsing, in Patos-PB, Brazil. In each stand, 4 blocks with 6 homogeneous *M. tenuiflora* trees in a radius of 15 m and naturally mixed with other woody species were located 50–150 m apart. Two trees in each block were randomly assigned to the following treatments: no pruning, and pruning branches <10 mm diameter, in April or July. Annually in these months, all branches less than 10 mm diameter were pruned, leaving no photosynthetically active tissue on the plants; leaves and finer stems were removed, independent of the position in the 3-m tall trees. Basal diameter (BD) of plants, plus dry matter yield and chemical composition of the pruned material were measured. Estimated increments in BD for the 3-year period were 17.5, 7.3 and 1.1 mm for the unpruned, April-pruned and July-pruned trees, respectively. Fodder production was lower for April than July prunings, but the former had higher crude protein, P and K concentrations. However, senesced April-to-July leaf regrowth following the April pruning was not measured and represented potential lost production. Three consecutive annual prunings of fine branches produced considerable amounts of tree fodder (3–4 kg/plant DM), much of which would otherwise remain inaccessible to browsing

animals, but resulted in some degree of tree mortality (16%). Thus, although significant amounts of fodder may be collected from *M. tenuiflora* trees, pruning periodicity as well as partial pruning should be studied further.

### **Introduction**

Extensive livestock production occupies most of the 0.9 M km<sup>2</sup> of semi-arid north-eastern Brazil, with straight pasture-based systems being most common. However, foliage from the native deciduous tropical dry-forest, locally known as “caatinga”, can contribute to animal diets, especially during the long dry season (>7 months with negative water balance), when only nutrient-poor litterfall is left to be browsed on the forest floor (Sampaio 1995). Silvopastoral systems have advantages over straight pasture-based systems as both native and introduced tree species can have positive effects on soil fertility (Menezes and Salcedo 1999; Menezes *et al.* 2002; Tiessen *et al.* 2003). There is a need to develop suitable management practices to increase both fodder quality and availability.

Legume species are common in the caatinga, and contribute significantly to the diets of domestic ruminants. *Mimosa tenuiflora* is a caatinga native tree species that re-vegetates disturbed dry sites, most of them previously submitted to slash-burn-subsistence agriculture cycles, or clear cutting (Sampaio *et al.* 1993; 1998). Where it predominated, reported plant densities reached 40 000/ha (Araújo Filho and Carvalho 1996), while 58 000 seedlings/ha were observed by Bakke *et al.* (2006). During the final stages of forest succession, it averages 174 individuals/ha and represents 24% of the total number of adult woody plants (Drumond *et al.* 2002). It is a thorny species that can reach a height of 5 m, with leaves, soft twigs and small pods providing palatable fodder for cattle, sheep and goats, although the presence of tannins can adversely affect forage

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digestibility (Beelen *et al.* 2006; Pereira Filho *et al.* 2003). Its leaves and twigs can represent 22% of the diet of goats browsing in the caatinga range (Leite and Viana 1986) or 40% when animals are left in a *M. tenuiflora* protein bank area before browsing in the caatinga (Araújo Filho *et al.* 1991). While live weight of goats decreased from 30 to 22 kg over 4 months when fed exclusively on *M. tenuiflora* leaves, animals displayed no clinical symptoms (Araújo Filho *et al.* 1990). Others (Cordão *et al.* 2008) reported maintenance or slight gains in live weight of sheep, when fed with up to 33% of hay from *M. tenuiflora* stems less than 10 mm diameter.

Fodder yields of *M. tenuiflora* are normally reported in the literature as the amount of dry matter (DM) from coppice regrowth after clear-cutting for firewood production (*e.g.* Pereira Filho *et al.* 2000a), since top branches are usually inaccessible for browsing and only litterfall and accessible branches can be consumed by the animals. Owing to the ubiquitous nature of this species, pruning of *M. tenuiflora* can be a source of abundant fodder in a region where, during the dry season, domestic ruminants frequently perish or lose most of the weight gained during the previous rainy season. The use of this natural resource can be optimised with no extra cost, except for the labour of the stakeholder family. However, while pruning of fine branches inaccessible to browsing could increase the quantity of available fodder, the timing and frequency of prunings to optimise productivity of *M. tenuiflora* are not defined in the literature.

Fodder production of *M. tenuiflora* was maximised when harvesting all leaves from re-growth at the end of the rainy season (680 kg/ha DM) and again at the end of the dry season (902 kg/ha DM), or when, after an initial clear cut at 80 cm-height, re-growth from 7-year-old trees was harvested 2 or 4 times in a 1-year experiment (Vasconcelos and Araújo Filho 1985). Pereira Filho *et al.* (1999) obtained maximum fodder production from re-growth when cutting *M. tenuiflora* at 75–100 cm above the soil. Under these regimes, *M. tenuiflora* retained its leaves longer during the dry season, as opposed to its deciduous nature when not managed. However, after clear-cutting woody species at 30 cm-height in mixed 40 to 60-year-old mature caatinga stands, with approximately 23 000 stems/ha, Hardesty *et al.* (1988) obtained greater fodder yields from *M. tenuiflora* using a single annual pruning early in

the dry season (5.8 kg/plant), than with prunings early in the rainy season (4.0 kg/plant) or in the middle of the dry season (2.3 kg/plant).

The ability of *M. tenuiflora* plants to tolerate pruning is not clear in the literature. While mature *M. tenuiflora* plants survived annual pruning during 2 consecutive years, after clear-cutting at 30 cm above the soil (Hardesty *et al.* 1988), 3 consecutive prunings (March, August and August of the following year) of all re-growth in young trees, after clear-cutting at 25, 50, 75 or 100 cm, caused high mortality (Pereira Filho *et al.* 2000a).

In the present study, we initially pruned all fine branches ( $\leq 10$  mm diameter) of *M. tenuiflora* trees in native caatinga coppices, and then measured basal diameter growth and tree fodder production and composition at 2 annual pruning dates, either the middle of the rainy season (April) or the beginning of the dry season (July), during a 3-year period.

## Materials and methods

### Site description and tree selection

The experiment was carried out at 2 *M. tenuiflora*-dominated caatinga sites. Site 1, located at the NUPEARIDO experimental station, 6 km SE of Patos-PB (07°05'S, 37°16'W; ~280 m asl), has an area of 80 ha that is periodically logged for firewood and fence post production, while producing forage for 80 cattle of different ages, which continuously browse. Site 2, located at Várzea de Jurema ranch, 17 km W of Patos-PB (07°03'S, 37°20'W; ~260 m asl), is an abandoned cotton field of 120 ha, unattended since 1990 and still showing remnants of scattered cotton plants. Secondary vegetation is continuously browsed by 50 cattle of different ages. Cattle browsing continued during the experimental period, uniformly across blocks at both sites.

Both sites had a *M. tenuiflora* tree density of approximately 1000 trees/ha, up to 3-m tall, with basal diameters of 50 to 80 mm. The number of developing individuals of other woody species was close to 250 plants/ha in Site 1, mainly *Jatropha mollissima* (~100 plants/ha) and *Aspidosperma pyrifolium* (~150/ha) and 90 plants/ha in Site 2, mainly *Jatropha mollissima* (~30 plants/ha) and *Caesalpinia pyramidalis* (~60 plants/ha). *M. tenuiflora* trees were selected

**Table 1.** Selected properties of soil samples (0-20 cm) from the experimental sites at NUPEARIDO (S1) and Várzea de Jurema (S2).

Site	Sand	Silt	Clay	Soil density	SOC <sup>1</sup>	pH	P	H+Al	Ca	Mg	K	Na
		(%)		(kg/dm <sup>3</sup> )	(g/kg)		(mg/kg)	-----	-(cmol <sub>c</sub> /kg)	-----		
S1	79.5	9.6	10.8	1.4	6.7	6.0	3.8	1.8	1.2	1.1	0.51	0.03
S2	75.5	14.0	10.5	1.4	5.3	5.4	3.1	1.6	2.7	1.0	0.21	0.09

<sup>1</sup> Soil organic carbon.

**Table 2.** Monthly rainfall during the experimental period, Patos-PB.

Month	Year			
	2002	2003	2004	2005
Jan	307	103	342	23
Feb	81	38	179	75
Mar	144	206	22	385
Apr	89	105	77	62
May	69	16	14	23
Jun	47	15	52	47
Jul	1	4	29	0
Aug	0	0	4	3
Sep	0	1	1	0
Oct	0	0	0	0
Nov	8	0	0	0
Dec	25	26	83	179
Total	770	514	803	797

Source: EMBRAPA/CNPA Experimental Station, Patos-PB.

according to height ( $\approx 3$  m), proximity to each other, and trunk bifurcation (above 50 cm high), seeking homogeneity and ease of basal diameter measurement.

#### Soil characteristics

Soils were classified according to the Brazilian soil classification system as Orthic Hypochromic Luvisol (Site 1) and Orthic Chromic Luvisol (Site 2) (EMBRAPA 1999) (Haplustalfs in the USA classification system). Following air drying and sieving ( $<2$  mm), composite soil samples (0–20 cm) from each site were analysed for physical and chemical properties. Both soils are sandy, low in organic matter and deficient in extractable P (Table 1).

#### Climate

According to the Köppen classification, the regional climate is classified as Aw' (Bezerra *et al.* 2004), with a rainy season extending from late December to early June. During the experimental period, total annual rainfall ranged from 514 to

803 mm (Table 2), with a potential evapotranspiration close to 2000 mm/yr (Sampaio 1995). This means that only 3 or 4 months of each year showed a positive water balance. Temperatures in March – July are not expected to fall below 20°C, while temperatures can exceed 35°C during the dry and hot period (August – February).

#### Experimental design

The experimental field layout at both sites was the same and consisted of 4 blocks, 50–150 m apart from each other. Each block showed different sizes and contained 6 homogeneous *M. tenuiflora* trees naturally distributed and mixed with other caatinga trees and bushes. However, the distance between trees within blocks did not exceed 15 m. Two of the 6 *M. tenuiflora* trees in each block were randomly assigned to each of the 3 experimental treatments: a control (no pruning); annual pruning in April (middle of rainy season, fully vegetative stage); and annual pruning in July (beginning of dry season, just before leaf senescence), totalling 16 trees per treatment. Annual prunings consisted in cutting all branches less than 10 mm diameter, leaving no photosynthetically active tissue on the plants; leaves and finer stems were removed, independent of their position in the 3-m tall trees. No flowers or pods were observed on the annual re-growth branches of the pruned plants during the experimental period. Data collection on control plants consisted of height and basal diameter measurements only.

#### Data collection

Height and basal diameter (BD) were measured in April and July from 2002 to 2005, using a graduated rod and digital calipers, respectively. Diameter was estimated by averaging 2 perpendicular diameter measurements at paint-marked points on the trunk, 10 cm above the soil surface. Diameters of the unpruned control trees were measured

twice each year (April and July) to allow the estimation of the April to April and the July to July increments in BD, while diameters of the April or July-pruned trees were measured once each year in April or July, respectively.

Following the April or July pruning, the collected fodder was weighed, and cut mechanically into 1–2 cm pieces. Fresh sub-samples were weighed, dried in a forced air circulation oven at 65°C for 72 h, and reweighed for dry matter (DM) determination. The dried material was ground (<1 mm) and analysed for neutral (NDF) and acid (ADF) detergent fibre (van Soest 1967), crude protein (CP) after Kjeldahl digestion and distillation of total N (Bremner and Mulvaney 1982) and ash content (550°C for 4 h). NDF and ADF were assayed without a heat-stable amylase and expressed inclusive of residual ash. Sub-samples of the fodder collected in 2002, 2003 and 2004 were ground to pass a 100-mesh sieve and analysed for total P and K after digestion with sulphuric acid-hydrogen peroxide mixture (Thomas *et al.* 1967); P in the digests was analysed by colorimetry and K by flame photometer.

#### Statistical analyses

Preliminary data analyses showed that differences in soil fertility between Sites 1 and 2 (Table 1) had no significant effect on the response variables, so treatment effects were analysed using a mixed statistical model for repeated measures (Schabenberger and Pierce 2002), in randomised blocks with 8 replicates. Basal diameters (BD) of trees pruned in April or July were compared with BDs of intact control trees measured at the same time (fixed effects), while annual repeated measures (2002–2005) were considered as random effects. Similarly, comparative fodder production and composition between April and July (fixed effects) were mixed with annual repeated measures (2003–2005) (random effects). Fodder production and dry matter composition data for 2002 were not included in the mixed model because they did not represent a full-year production; 2002 data were analysed separately, using a Student's t-test comparison of pruning dates. Height data were not included in the statistical analyses because the 'between' and 'within' variabilities were similar. Firewood volume estimates were computed from  $V = 4.472602 \cdot \text{DBH}^3 - 20.077291$  ( $P < 0.01$ ,  $r^2 = 0.80$ ), where V is firewood volume

( $\text{dm}^3/\text{plant}$ ) and DBH is the diameter (cm) at breast height (Leite 2002). We substituted basal diameter (BD) at 10 cm height for the DBH value in the equation.

## Results

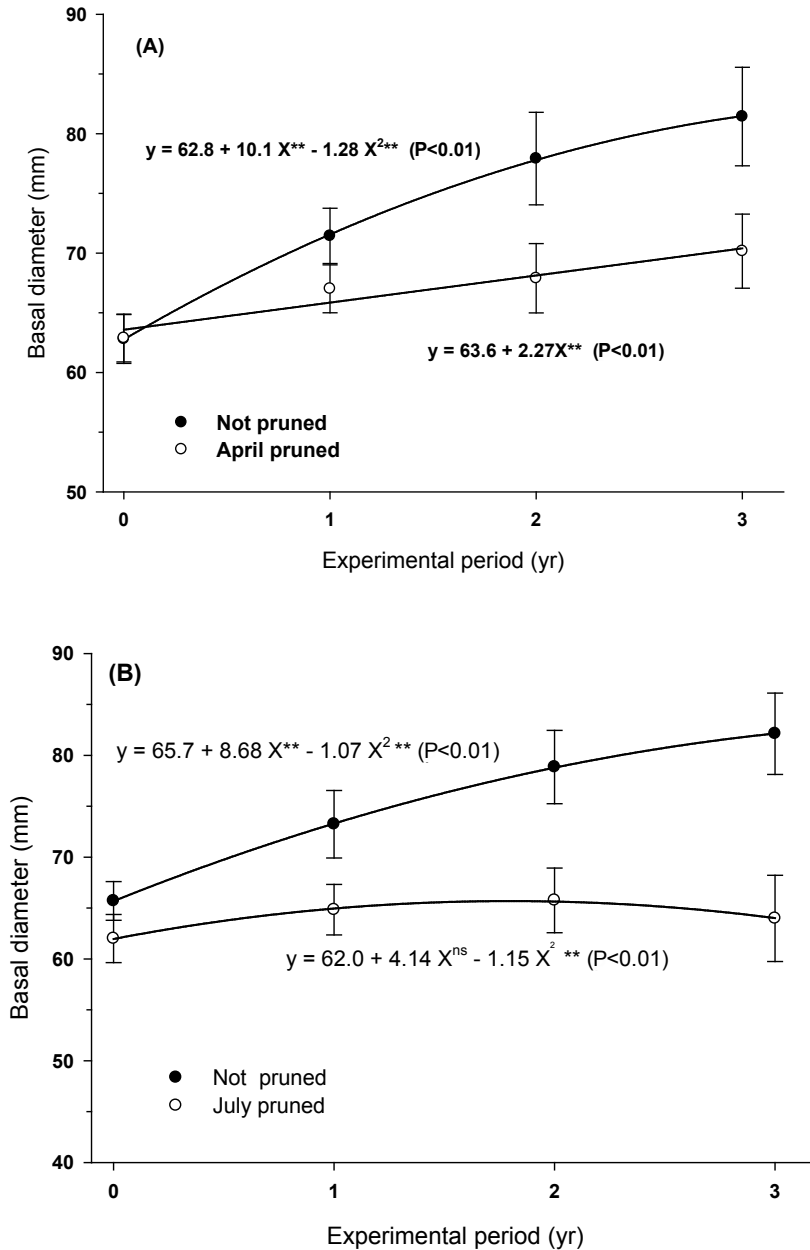
### Basal diameter

Basal diameters (BD) of control *M. tenuiflora* trees were quite homogeneous, measuring  $62.8 \pm 2$  mm (mean  $\pm$  s.e.) (Figure 1A) at the beginning of the experimental period (April 2002), and  $65.7 \pm 2.0$  mm (Figure 1B) at the beginning of the dry season (July 2002). Pruned trees in April 2002 had initial mean BD of  $63.6 \pm 1.9$  mm, while those pruned in July 2002 averaged  $62.0 \pm 2.4$  mm (Figures 1A and 1B, respectively). During the experimental period, BD of unpruned controls increased by 18.8 (from April 2002 to April 2005) or 16.4 (from July 2002 to April 2005) mm, while increases for pruned trees were 6.8 (from April 2002 to April 2005) and 2.1 (from July 2002 to July 2005) mm. During the 3-year period, the height of unpruned control trees increased from approximately 3 m to 3.9 m (data not shown).

Pruning time affected the rate of increase in BD. Pruning at the middle of the rainy season (April) allowed a steady increase in BD (2.27 mm/yr) during the whole experimental period (Figure 1A). Conversely, pruning at the beginning of the dry season yielded a final BD, in July 2005, similar to that at the beginning of the experiment (Figure 1B), with only the quadratic relationship between basal diameter and year being significant ( $P < 0.01$ ).

### Firewood production

Pruning affected BD growth and firewood production estimates (Table 3). Estimated absolute increments in unpruned controls (April and July) averaged 7.8  $\text{dm}^3/\text{tree}$  during the 3-year experimental period, while increments for pruned trees were reduced to 39% (April pruning) and 12% (July pruning) of that value. Since data in Table 3 were obtained by substituting the BD data (Figures 1A and 1B) in the regression equa-



**Figure 1.** Effect of annual pruning at the middle of the rainy season (A) and beginning of the dry season (B) on the basal diameter of *M. tenuiflora* trees (means  $\pm$  s.e.), relative to unpruned control trees during 3 years (0=2002; 3=2005).

**Table 3.** Effects of pruning treatments upon volume estimates<sup>1</sup> of *M. tenuiflora* firewood in April 2002 and July 2005, and volume increments during that period, using the regression model proposed by Leite (2002).

Treatments	Month	Volume (dm <sup>3</sup> )		Increment		
		2002 Initial	2005 Final	Relative (Final/Initial)	Absolute (dm <sup>3</sup> ) (Init-Final = I)	Relative to T1 (I/I <sub>T1</sub> )
No pruning (T1)	Apr	8.01	16.3	2.04	8.29	1.00
April pruning	Apr	8.06	11.31	1.40	3.25	0.39
No pruning (T1)	Jul	9.30	16.65	1.79	7.35	1.00
July pruning	Jul	7.65	8.54	1.12	0.89	0.12

<sup>1</sup> Volume values tend to be overestimated as basal diameters were used instead of DBH.

tion proposed by Leite (2002) (see Materials and methods), no statistical analysis was performed on firewood estimates. However, linear and quadratic equations fitted to the BD data of trees pruned in April and July (Figures 1A and 1B, respectively) suggested that firewood obtained in April of the 3<sup>rd</sup> year was significantly larger than in July of the same year.

#### Fodder production

The effect of pruning date on fodder production was the opposite of that for BD growth. While both pruning times reduced forage production, pruning in April caused a marked linear decrease in fodder production, with the decrease in July much less pronounced and with a quadratic component (Table 4). Accumulated fodder production during the 3-year experimental period amounted to 3 and 4 kg/plant DM for the April and July prunings, respectively, with half of these amounts produced during the first year, following the initial pruning (Table 4).

#### Fodder quality

Average concentrations of NDF, ADF and hemicellulose (HC) in harvested sprouts of *M. tenuiflora* between 2003 and 2005, were 56.5, 41.8 and 14.6%, respectively (Table 4). Crude protein concentrations were higher in material harvested in April than in that harvested in July (13.0 vs 10.7%), while P concentrations were about 0.095%. Concentrations of fibre, HC and ash in fine branches were not affected ( $P > 0.05$ ) by pruning dates. Crude protein, P and K concentrations, on the other hand, were greater ( $P < 0.10$ ) in April than in July pruning.

Fodder composition changed with time, in some cases with significant linear or quadratic effects (2002 data for fine branches not included in the analysis) (Table 4). Likely interactions between pruning dates and variations in total rainfall and distribution among years make interpretation of these effects difficult.

#### Discussion

This study has shown that *M. tenuiflora* trees can produce significant amounts of fodder for use by livestock. However, it has not shown a clear pruning strategy for this species. The trend of higher forage production showed by trees pruned in July than in April supported the findings of Hardesty *et al.* (1988) that pruning *M. tenuiflora* early in the dry season resulted in higher fodder production than pruning early in the rainy season. It also confirmed different plant responses to pruning date: April pruning allowed sustained BD growth but decreased resprouting, while July pruning showed an opposite trend. However, as no measurement was made on regrowth by the April-pruned trees following pruning, differences in fodder production between April- and July-pruned trees might actually be less pronounced than reported.

The quantity of fodder produced by *M. tenuiflora* plants was significant, especially considering the scarcity of fodder during most of the year in the semi-arid region of north-eastern Brazil. Based on the average plant density of 1000 trees/ha at both experimental sites, about 3–4 t/ha DM of fodder was produced over 3 years by the 7-year-old *M. tenuiflora* native stands, in addition to the 4.0 t/ha DM of fine branches from the initial pruning in 2002 (Table 4). Even higher production might be possible, since Bakke *et al.* (2007) obtained higher annual yields (3.3

kg/plant) in 2-year-old *M. tenuiflora*, when all plants in a dense stand were pruned annually during three consecutive years. Means for sprout production were lower than the 4.0 to 5.8 kg/tree obtained in two consecutive years under clear-cutting management of mature (40 to 60-year-old stand) *M. tenuiflora* (Hardesty *et al.* 1988), but higher than the 1.6 kg/plant DM obtained in one year (Vasconcelos and Araújo Filho 1985) from 7-year-old *M. tenuiflora*. These differences in fodder production would result from a variety of factors such as tree age, pruning regimen and soil characteristics. Regardless of this differential response between pruning dates, the decline in fodder production with time for both pruning dates indicated that *M. tenuiflora* trees were not adapted to annual pruning of all sprouts (*i.e.*, one annual event of total defoliation with pruning of all fine branches). These trees would be expected

to perish in a few years under a regimen of annual pruning (Pereira Filho *et al.* 2000a). Five trees (or 16%) from the pruning treatments perished in the present experiment. Longer regrowth intervals or partial defoliation of *M. tenuiflora* trees could possibly maximise production and minimise plant mortality. Studies with *G. sepium* and *E. poeppigiana* indicated that partial rather than total defoliation resulted in sustainable growth and production (Chesney and Vasquez 2007).

Another possible reason for decreasing fodder production with time is that only a few of the many trees present in each site were pruned. Thus, in addition to coping with the stress caused by pruning, these trees had to compete for light, water and nutrients with surrounding intact plants. In contrast to these results, Bakke *et al.* (2007) reported relatively stable annual fodder production over a 3-year period, when all indi-

**Table 4.** Dry matter and composition of fine branches (<10 mm diameter, initial pruning) and sprouts (annual prunings) of *M. tenuiflora* trees as a function of pruning date.

Month of pruning	Fine branches <sup>1</sup>		Sprouts		Year effects	
	2002	2003	2004	2005	p Lin.	p Quad.
	Dry matter (kg/plant)					
Apr	4.0a	1.7	0.9	0.4	<0.001	NS
Jul	4.1a	2.0	1.1	0.9	<0.001	0.007
	Neutral detergent fibre (%)					
Apr	58.7a	55.4	57.0	50.8	0.004	0.042
Jul	59.7a	59.9	58.9	57.0	0.094	NS
	Acid detergent fibre (%)					
Apr	43.9a	41.1	43.5	37.1	0.003	0.023
Jul	45.3a	43.3	44.3	41.3	NS	NS
	Hemicellulose (%)					
Apr	14.8a	14.3	13.5	13.0	0.089	NS
Jul	14.5a	16.6	14.6	15.7	NS	NS
	Ash (%)					
Apr	2.6a	2.8	3.1	4.1	<0.001	0.032
Jul	2.1a	2.1	3.2	3.8	<0.001	NS
	Crude protein (%)					
Apr	9.4a	13.0	13.0	13.1	NS	NS
Jul	7.5b	10.1	11.1	10.8	NS	NS
	Phosphorus (mg/g DM)					
Apr	0.74a	0.95	0.95	n.d. <sup>2</sup>	NS	-
Jul	0.62b	0.71	1.1	n.d.	<0.001	-
	Potassium (mg/g DM)					
Apr	6.2a	8.5	6.8	n.d.	<0.001	-
Jul	4.8b	6.9	6.8	n.d.	NS	-

<sup>1</sup> Fine branches in 2002 were not considered in the statistical analyses of year effects. Treatment means in this column followed by the same letter do not differ ( $P>0.01$ ) by the Student's *t*-test. <sup>2</sup> Not determined.

viduals of a dense *M. tenuiflora* plantation were pruned annually.

In addition to the plant stress caused by pruning, the nutrient supply by the soil could have influenced the results. Under natural conditions, most of the annual nutrient uptake by the plant returns to the soil through litterfall (Fraga and Salcedo 2004), but this recycling process was interrupted under the conditions tested in the present experiment. Low phosphorus concentrations in *M. tenuiflora* fodder were a reflection of their low values in the soils (Table 1); on the other hand, low concentrations of K were found in the dry matter of *M. tenuiflora* (Table 4) in spite of an adequate soil supply (Table 1). Previous field (Bakke *et al.* 2007) and greenhouse (Dantas *et al.* 2006) studies also classified *M. tenuiflora* as a low-demanding species for K, in comparison, for example, with *G. sepium* (Valadares Filho *et al.* 2001; Dantas *et al.* 2006). Bakke *et al.* (2007) estimated that P and K exports through fodder represented about 21% and 7% of available stocks in the 0–20 cm layer of the soil, respectively, which would also apply to the present study. Even considering a thicker soil layer, continuous soil exploitation should restrict fodder production, particularly owing to P limitations (Fraga and Salcedo 2004).

In spite of these limitations, the advantage of *M. tenuiflora* resides in its natural colonisation of dry upland sites with shallow soils, high drought resistance and strong re-growth after cutting or browsing. Other leguminous introduced fodder trees, such as *Leucaena leucocephala* (Roothaert and Paterson 1997), are well adapted in the more humid areas of the Brazilian savannah (locally known as “cerrado”) or specific caatinga moist sites, but are unable to establish and thrive in caatinga dry sites. In addition, introduced species might suffer attack by local pests, as was the case with the severe psyllid attack on *L. leucocephala* in East Africa reported by Roothaert and Paterson (1997). However, tests have shown that *M. tenuiflora* and *L. leucocephala* can be cultivated in fodder banks in lowland sites in the caatinga to produce protein-rich food and liveweight gains of 36 and 15 g/d, respectively, in goats browsing in the caatinga range and given access to the fodder banks for 2 hours each morning (Araújo Filho *et al.* 1991). While the alternative tree species *Prosopis juliflora* shows drought tolerance comparable with that of *M. tenuiflora*, its leaves and twigs are unpalatable. Its cultivation should focus

on fruit collection rather than forage production (Carvalho *et al.* 1992).

With regard to fodder quality, the estimated NDF and ADF values found in this study confirm the findings of other authors (Vasconcelos and Araújo Filho 1985; Pereira Filho *et al.* 2000b) that *M. tenuiflora* forage was quite fibrous. The higher crude protein, P and K concentrations observed in forage from April pruning than from July pruning probably reflected nutrient resorption in the July material, as nutrients in mature leaves just prior to senescence are translocated to other plant parts prior to abscission (Renteria *et al.* 2005). CP concentration in forage cut in April (13%) was close to the maximum values reported for *M. tenuiflora* fodder in the literature (Pereira Filho *et al.* 2000b), owing to the presence of many young leaves and succulent stems. However, material from July prunings contained ~10% CP, reflecting the presence of thicker stems and mature leaves. Although these CP concentrations are considered sufficient for animal maintenance, high concentrations of tannins in these forages can hinder digestion of CP and nutrient absorption (Pereira Filho *et al.* 2003; Beelen *et al.* 2006), which warrants further study. Phosphorus and K showed a resorption trend similar to that of N in 2003 but not in 2004. Phosphorus concentrations in the sprouts (Table 4) were in the range found by Bakke *et al.* (2007) in dense stands of *M. tenuiflora* planted in a similar soil, but lower than values reported for other legume species (Barnes 1995).

Differences in BD growth between pruned and intact plants suggest a marked reduction of plant reserves (Figures 1A and 1B). There are no specific studies on pruning of *M. tenuiflora* and dynamics of non-structural carbohydrate reserves, but such data are available for other tropical legume trees such as *Gliricidia sepium* and *Erythrina poeppigiana* (Nygren *et al.* 2000; Garcia *et al.* 2001; Chesney and Nygren 2002; Chesney and Vasquez 2007) and non-legume tree species (*Croton sonderianus*) (Carvalho *et al.* 1998).

Several weeks were needed by *G. sepium* and *E. poeppigiana* to recover carbohydrate reserve levels following pruning (Chesney and Vasquez 2007), so it seems reasonable to assume that this also applies to *M. tenuiflora*. In addition, Erdmann *et al.* (1993) showed that deciduous trees in the seasonally dry tropics accumulated reserve carbohydrates early in the dry season. Thus, it is



possible that pruning in July, before the senescence of leaves, reduced translocation of reserves from sprouts to stem and roots, leaving plants with partially depleted reserves for full sprouting and replenishment of non-structural carbohydrates. Conversely, trees pruned in April had approximately 12 weeks under favourable climatic conditions to sprout and rebuild reserves before the onset of the dry season. This would explain the stronger deleterious effect on BD resulting from pruning in July relative to April. However, extrapolation of results should be done cautiously owing to variability among species in their capacity to build up non-structural carbohydrate reserves.

The quadratic response observed in BD on July-pruned trees implied actual reductions in BD between two consecutive measurements in some trees, possibly related to the sharp decrease in rainfall that occurs in July, at the onset of the dry period (Table 2). Changes in wood volume triggered by modifications in the water potential status of trees are expected to be small, but bark can show considerable variations in volume (Tyree and Ewers 1991). Bark dehydration and consequent shrinking as a result of water deficits probably caused the reductions in BD. Worbes (1999) reported reductions in diameter of various tree species and attributed shrinking of the stem to water loss.

The phenological cycle of *M. tenuiflora* was also affected by the annual pruning regimens, since flowering and pod filling were observed only in the unpruned controls. This is in contrast with the behaviour of *Gliricidia sepium* that showed a normal phenological cycle under a similar pruning regimen in subhumid conditions (Nygren *et al.* 2000). The difference in phenological response between the 2 species could be indicative of a greater stress level in *M. tenuiflora* trees, probably owing to more severe climatic conditions than in the *G. sepium* study.

## Conclusions

The results of this study indicate that *M. tenuiflora* trees seem unable to sustain production of shoots under the harvesting strategy used, regardless of the differential response between pruning dates that favoured the early season pruning. However, the results could be confounded as only some trees in the stands were defoliated,

while surrounding trees were left intact. Further studies are warranted to determine whether the trees perform better when all plants in a stand receive comparable treatment. Some refinement of the pruning strategy might be necessary to optimise yields of high quality material, *e.g.* partial defoliation.

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