Original Research Article

How do native trees establish on degraded Caatinga sites?

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

This study evaluated tree establishment by seeding in manure-enriched substrate or by seedling planting in manure-enriched holes in two experiments carried out in Patos (PB), Brazil, in degraded Caatinga sites. Experiment one evaluated the effects of the joint seeding (absence and presence of joint seeding, but no singular seeding of any of species) of four tree species (Mimosa tenuiflora, Poincianela pyramidalis, Anadenanthera macrocarpa and Tabebuia aurea), at two levels of cattle manure (absence and presence) in a site protected from grazing. The 2x2 (absence and presence of joint seeding, and absence and presence of manure addition to the soil) factorial experiment was used with four treatments groups in two replicates to which five completely randomised blocks were assigned tentatively to control environmental heterogeneity and reduce the experimental error (e.g.: soil or fertility or erosion slope). Additional data set from six other similar adjacent blocks (size, number of treatments and plots, and level of environmental degradation), submitted to previous and current overgrazing by small ruminants (browsing goats and grazing sheep) was analysed independently. Experiment two, located in an overgrazed site currently protected from grazing, evaluated tree seedling establishment (natural and that resulting from planted Mimosa tenuiflora and Poincianella pyramidalis seedlings in manure-enriched holes according to a randomised completely blocked design with four treatments in two replicates (four controls: when no tree seedling planting occurred, and when seedling planting of one of the two tree species occurred) to which six blocks were assigned tentatively to control environmental heterogeneity and reduce the experimental error. Tree seedling establishment, natural or resulting from seeding, in plots enriched or not with manure and protected or not from grazing, was not observed during three years. Planting of M. tenuiflora accelerated the process of tree establishment, resulting in 36% survival rate and 177.5cm length growth at the end of the third year, while the other tree seeding or planting treatments resulted in no established plants. Observations should continue to determine the period suitable for making degraded Caatinga sites once again available for production.

Keywords: jurema preta, catingueira, angico, craibeira, land reclamation, tropical dry forest.

1. INTRODUCTION

Caatinga vegetation predominates in the semiarid region of northeastern Brazil, characterised by annual precipitation in the range of 500 to 700 mm, high insolation, low cloud cover, and high temperatures and evapotranspiration [1]. Firewood and charcoal from the Caatinga forest supply a third of the energy consumed in the region, mainly for cooking and burning of bricks and gypsum ore [2, 3]. The demand for energy, the expansion of agricultural and cattle raising areas, and harsh climate cause environmental impacts, such as widespread deforestation. There are reports of $11x10^3$ hectares of deforestation occurring each year in the region of Araripe-PE, where many gypsum industries have a high demand of firewood [3].

Forest recovery in these sites is slow and uncertain, and data on natural regeneration and forestry practices are lacking for most of the happenings in the Caatinga Biome. Natural regeneration is the cheapest way to recover forest cover [4], however recovery may take a long time, as it depends on seed dispersion and dispersers, seed banking, seedling establishment, trunk and root sprouting of formerly established trees [5] among other factors. There are alternatives, such as litter (100 m^3/ha) and manure (30m^3/ha) additions to improve the regenerative conditions of degraded Caatinga sites [6], a measure not practical on larger scale.

Planting, especially of native tree species, is supposed to accelerate site recovery by attracting agents of seed dispersal, such as birds and rodents, accumulating organic matter and ameliorating site conditions for seed germination and seedling establishment [7], as reported by Batista et al [8] of a site degraded by clay extraction after *Eucalyptus* spp. and *Mimosa caesalpiniaefolia* planting.

Although reports on regeneration of degraded Caatinga sites are uncommon [9], *Mimosa tenuiflora* (Willd.) Poiret), *Caesalpinia pyramidalis* Tul., *Anadenanthera macrocarpa* (Benth.) Brenan.) and *Tabebuia aurea* (Manso) Benth. & Hook. are native trees regularly seen in primary and secondary stages of revegetation of Caatinga sites [10, 11]. Reintroduction of these species may be viable by direct seeding or seedling planting, especially after the soil is physically amended and enriched with manure. The expectations are that these measures can increase the rate of seed germination and seedling establishment compared to natural tree regeneration, especially in degraded sites [12].

This study evaluated the effects of manure and seed addition on natural tree seedling establishment or that resulting from joint seeding of four tree species, according to seed germination and seedling survival of *Mimosa tenuiflora* (Willd.) Poiret), *Poincianella pyramidalis* Tul., *Anadenanthera macrocarpa* (Benth.) Brenan.) and *Tabebuia aurea* (Manso) Benth. & Hook in degraded Caatinga sites protected or not from grazing. Also, it evaluated natural tree seedling establishment or that from *Mimosa tenuiflora* and *Poincianella pyramidalis* seedling planting into manure-enriched holes in a degraded overgrazed Caatinga site where no further grazing was allowed.

2. MATERIAL AND METHODS

Experiments were carried out at the NUPEARIDO Experimental Station/UFCG, in Patos-PB, Brazil, in a degraded site (07º05'10"S and 37º15'43"W) (Figure 1). Degradation resulted from grazing and browsing by sheep and goats in the last 30 years, characterized by scattered adult and no juvenile trees, and shrub stratum dominated by *Sida cordifolia* L., and incipient soil cover dominated by herbs.

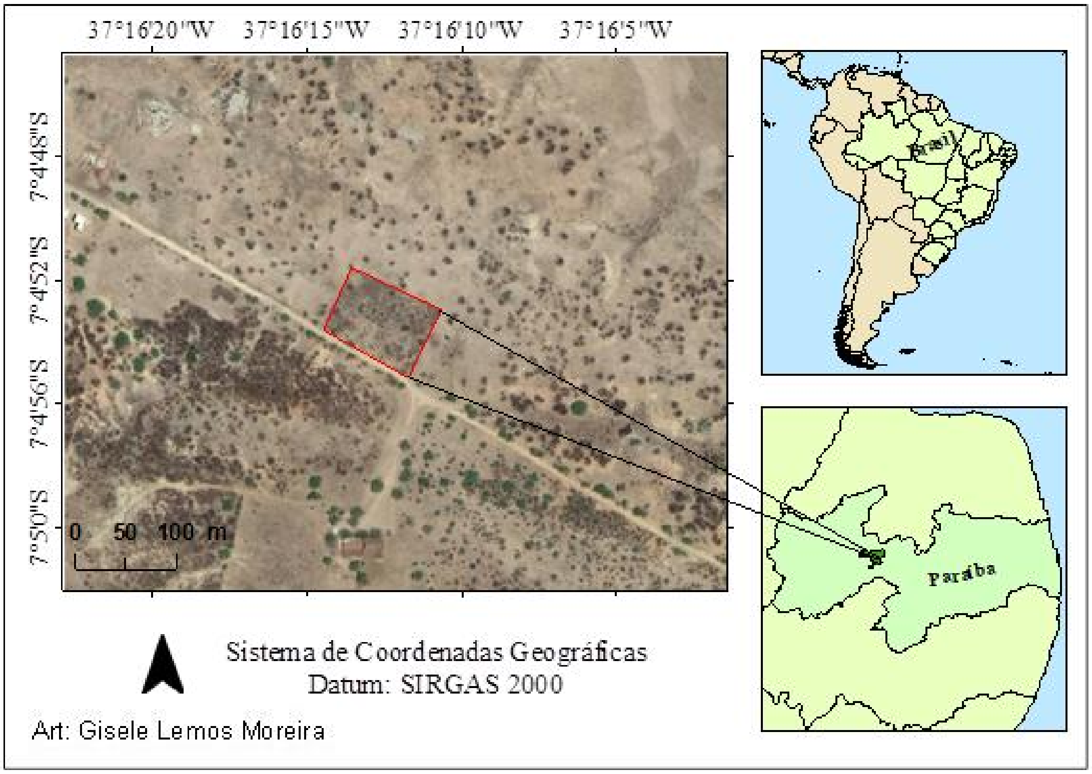

Figure 1. Google Earth picture and Map of the experimental area,

Monthly rainfall data (mm) were collected for four years (2005, 2006, 2007 and 2008) according to *Embrapa Algodão Meteorological Station — Patos – PB, Brazil* (Table 1).Observe annual precipitation observed for the period ranged from 594,2 to 1182,2mm, within the 500-to-700mm expected values for the biome (1).

TABLE 1. Monthly precipitation (mm) in four years: 2005, 2006, 2007 and 2008.

Month	**Year**			
	2005	**2006**	**2007**	**2008**
January	43.6	0.0	16.6	27.4
February	79.8	168.8	264.7	227.1
March	237.9	244.1	50.1	491.6
April	103.9	202.4	112.5	216.9
May	58.8	128.8	43.1	187.4
June	31.8	23.4	8.3	14.0

July	0.0	0.2	2.9	15.6
August	0.0	0.0	1.2	2.2
September	0.0	0.0	0.0	*-
October	0.0	15.3	0.0	-
November	0.0	1.3	0.0	-
December	78.0	83.2	94.8	-
TOTAL	**633.8**	**867.5**	**594.2**	**1182.2**

**Data on monthly precipitation were not necessary after the end of the experimental period*
Source: Embrapa Algodão Meteorological Station — Patos – PB, Brazil.

Tree seeds were collected in late 2004 and 2005, and remained stored (5ºC) until they were sown in the field in March 2006 [Experiment one: joint seeding of *Mimosa tenuiflora* (Willd.) Poiret), *Poincianella pyramidalis* Tul., *Anadenanthera macrocarpa* (Benth.) Brenan.) and *Tabebuia aurea* (Manso) Benth. & Hook], or used, in December 2004, one to three months after collection, to produce seedlings in the UFCG nursery facilities. These seedlings were planted in the field in March 2005 (Experiment two: planting of *M. tenuiflora* and *Poincianella pyramidalis* seedlings).

Experiment one evaluated the effects of two levels (absence and presence) of cattle manure and two levels (absence and presence) of joint seeding of four native trees (*Mimosa tenuiflora*, *Poincianela pyramidalis*, *Anadenanthera macrocarpa* and *Tabebuia aurea*) on tree seedling establishment (natural or that resulting from joint seeding of the four native trees), based on percentage of seed germination and seedling survival with two replicates, according to a randomised completely blocked design in 2x2 factorial and in five blocks (10 treatment groups) in an area protected from grazing. The 0.5m^2 square plots were subdivided in time (May 6, July 15 and, November 18 2006, March 18 2007 and March 22 2008) and data were collected in the 0.25 m^2 inner area of each plot. There were six other blocks (i.e.: treatment groups) located in an adjacent grazed area, in which the 2x2 factorial design is also employed with the date introduced as a sub-plot similarly randomised respectively. Data sets from the grazed and non-grazed plots were analysed independently, and no formal comparisons were made, but their differences stricken.

Although zero averages for some factor levels were cited, such levels were not formally included in the statistical analysis, and the number of the degrees of freedom for plot factors was reduced to one, and only the ANOVA's F test (P<0.05) was employed in drawing conclusions. For the sub-plot date factor, no further test or statistical procedure other than the ANOVA's F test (P<0.05) was carried out. Values of the number of seedlings were transformed (square root) prior to ANOVA.

Just prior to seed deposition, top soil (top 10 cm) was mixed with the equivalent of 120m^3 of cattle manure (6L of cattle manure/plot) and applied according to experimental setup. Seeding occurred between March 18 and 28, 2006 in the plots where seed addition treatment was assigned. In these plots, *M. tenuiflora* (400seed/plot), *P. pyramidalis* (100seed/plot), *A. macrocarpa* (100seed/plot) and *T. aurea* (100seed/plot) seeds were jointly placed and slightly pressed on the soil surface, half of them in the 0.25m^2 outer area and half in the 0.25 m^2 inner area of each plot. Data on the number of seedling in the inner square of each plot were collected in May 6, July 15 and November 18, 2006, March 18, 2007 and March 22, 2008.

Experiment two considered the effects of *M. tenuiflora* and *P. pyramidalis* seedling planting into manure-enriched holes on tree revegetation of degraded Caatinga sites. Tree seedlings were grown at the UFCG Seedling Nursery facilities in Patos-PB, Brazil, from mid-December 2004 to mid-March 2005. Seedling planting in the field occurred in March 19 and 20, 2005. At this moment, mean height and basal diameter (mean±SE) of the 108 *M. tenuiflora* seedlings were (72.70+0.97) cm and (6.90+0.08) mm, respectively. For the *P. pyramidalis* seedlings the respective values were (24.40+0.62) cm and (4.08+0.05) mm. In April 16 and June 12, 2005, seedlings that remained developing in nursery replaced the dead seedlings.

This experiment consisted of four treatments (T0=control 1, T1=control 2=opening of 30cm x 30cm x 30cm planting holes enriched with 5L of manure but no tree seedling planting, T2= the same as T1 and planting of *M. tenuiflora* seedlings in mid March 2005, one month after hole preparation, and T3=the same as T1 and planting of *P. pyramidalis* seedlings in mid March 2005, one month after hole preparation) and six blocks with two treatment replications. Experimental plots measured 9m x 9m, with three lines of three plants. Plots were subdivided in time (April 1, July 12, and November 25, 2005), and sub-plot consisted of one three-plant line randomly chosen for each date. Blocks were located in a fenced area not grazed by domestic ruminants.

Once a year, weeding was performed in a 50cm radius area around each planted seedling to reduce herb competition. Herbs growing in T0 and T1 and between plants in T2 and T3 plots remained intact to ensure soil protection and organic matter accumulation.

The statistical procedures (ANOVA), tests (ANOVA's F test) and significance level (5%) used in the first experiment were similar in this experiment. Collected data considered seedling survival, length (cm) taken with a graduated rod, and basal diameter (mm) measured with a digital calliper 5 cm above soil surface.

3. RESULTS AND DISCUSSION

Herbs were present in all plots, but no established tree seedling was observed in 2006, 2007 and 2008 in plots that received no seeds of tree species. Lack of natural tree regeneration may indicate poor or no existent tree seed bank or deteriorated environmental conditions, such as soil compaction and erosion.

No effect of manure addition was detected on tree seedling emergence or persistence in seeded plots, whether grazing was allowed or not. Under both grazing conditions, seedlings of the four native trees germinated in all plots in which seeds were sown, but the mean number of tree seedling decreased for all species from May to December 2006 (Table 2). *Tabebuia aurea* was characterised by its relatively high initial number of germinated seeds (half or more of the observed tree seedlings per plot), although the number of its seeds sown per plot was a quarter of *M. tenuiflora's*. *Mimosa tenuiflora* strategy was unique because some of its seeds were left to germinate in the moist season of the following year, while no seed of the other three tree species remained in the soil or showed to be able to germinate after the first few months they were sown. This all-in-one-event strategy was already reported for *T. aurea* by [13]. The soft tegument of the seeds of this species certainly explains this all-in-one-event strategy, as well as that observed for *P. pyramidalis* and *A. macrocarpa*, while that of parceling germination in two or more years, now observed for *Mimosa tenuiflora,* characterises legume species with seeds with hard tegument, and results in longer persistence of propagules in seed bank [14].

The number of observed seedlings of the four tree species tended to be higher in non-grazed than in grazed plots. No seedling that germinated during the first moist season (2006) after seeding survived to the following year, and all observed seedlings in the following year (March 2007) were only new *M. tenuiflora*, but none survived to the third year (2008). This indicates the high level of difficulty for the establishment of tree seedlings in degraded Caatinga sites, even for ones receiving the equivalent of 14 million tree seeds/ha and 120m^3 of manure/ha in years when annual rainfall showed to be close or superior to the expected average (500 to 700mm)(1)

Estimated average number of *M. tenuiflora* seedling per plot corresponded to 3% or less of the seeds of this species deposited on the soil surface of each plot, 20% or less for *P. pyramidalis*, 22% or less for *A. macrocarpa*, and 59% or less for *T. aurea* (Table 2). *Poincianela pyramidalis* and *A. macrocarpa* seeds germinated less than reported elsewhere [11, 14, 15], probably a result of the poor site conditions.

TABLE 2: Mean number of seedlings (total and on a species basis) in 0.25 m^2 plots sown with four tree species*, according to the level of manure addition to the soil (absence and the equivalent to 120m^3/ha) and sheep and goat grazing (absence and presence) between two months and 2 years after sowing.

		No sheep and goat grazing				
		day/month/year				
Manure		6/5/2006	15/7/2006	18/11/2006	18/3/2007	22/3/2008
	Total	53.1a**	37.07a	16.02a	2.5a	0.0
	M. tenuilfora	6.1	4.1	1.0	2.5	0.0
Absence	*P. pyramidalis*	10.0	5.2	1.9	0.0	0.0
	A. macrocarpa	10.9	6.8	0.7	0.0	0.0
	T. aurea	26.1	21.6	12.6	0.0	0.0
	Total	47.6a	39.3a	21.8^a	4.7a	0.0
	M. tenuilfora	5.5	4.2	1.1	4.7	0.0
Presence	*P. pyramidalis*	6.8	4.3	1.4	0.0	0.0
	A. macrocarpa	5.6	4.6	1.0	0.0	0.0
	T. aurea	29.7	26.2	18.3	0.0	0.0
		Area under sheep and goat grazing				
		day/month/year				
		6/5/2006	15/7/2006	18/11/2006	18/3/2007	22/3/2008
	Total	34.8a	10.3a	3.6a	1.5a	0.0
	M. tenuilfora	5.0	0.8	0.2	1.5	0.0
Absence	*P. pyramidalis*	5.3	0.3	0.2	0.0	0.0
	A. macrocarpa	5.6	0.4	0.0	0.0	0.0
	T. aurea	18.9	8.8	3.2	0.0	0.0
	Total	33.1a	9.8a	1.4a	1.3a	0.0
	M. tenuilfora	4.4	0.9	0.0	1.3	0.0
Presence	*P. pyramidalis*	5.1	0.0	0.0	0.0	0.0
	A. macrocarpa	4.8	0.8	0.2	0.0	0.0
	T. aurea	18.8	8.1	1.2	0.0	0.0

**Mimosa tenuiflora, Poincianela pyramidalis, Anadenanthera macrocarpa and Tabebuia aurea.*
***Means in the columns corresponding to the manure levels in the "No sheep and goat grazing" level, followed by the same letter, do not differ by the ANOVA F test (P>5%). The same is true for the other grazing level.*

The lowest average value for the number of *M. tenuiflora* seedlings in May 2006 (4.4 seedlings/0.25m^2) (Table 2) corresponds to 176 x 10^3 seedlings/ha. Bakke et al [9] reported a minimum and a maximum of 3.7 x 10^3 and 58 x 10^3 seedlings of this species per hectare during the dry and the raining seasons, respectively in *M. tenuiflora*-rich Caatinga sites. The high seedling number reported in the present study may result from the high number of *M. tenuiflora* seeds present in the soil after the addition of the equivalent to 8 x 10^6 seeds of *M. tenuiflora*/ha. However, this high initial number of seedlings did not assure seedling establishment, certainly due to the poor conditions of the degraded experimental site despite the addition of the equivalent of 120m^3 of cattle manure to the top soil. It should be tested if too many tree seeds were added to each plot, and thus, resulted in high levels of competition and total failure in seedling establishment, or if an even higher number of seeds has to be added to assure survival of tree seedlings in degraded Caatinga sites.

Data collected in Experiment one and two showed that natural regeneration of native trees in degraded Caatinga sites does not begin at least during the first three years after site protection from grazing. However, 93.9, 40.0 and 36.2% of the planted *M. tenuiflora* seedlings survived, respectively to November 2006, March 2007 and June 2008 (8, 12 and 27 months after planting, respectively). For *P. pyramidalis* this number was 75.2% in November 2008 and close to zero in the last two dates.

The growth of *M. tenuiflora* planted seedlings was significantly faster than that observed for planted *P. pyramidalis* in the formally analysed dates (April 01, July 12 and November 25, 2005). *Mimosa tenuiflora* was longer than 100cm/plant and *P. pyramidalis* reached a third of this value in November 2005 (Table 3). For basal diameter, the respective values were 11.1 and 5.0 mm/plant. Sampaio et al [16] consider that the low initial growth profile adopted by *P. pyramidalis* as a strategy to increase survival in dry sites. Although this strategy may be advantageous in some Caatinga sites, it did not show success in the experimental degraded site considering the very low seedling survival rate.

TABLE 3: Mean length and basal diameter of the surviving *Mimosa tenuiflora* and *Poincianela pyramidalis* planted seedlings in five dates between April 2005 and June 2008.

day/month/year	Length (cm/plant)		Basal diameter (mm/plant)	
	M. tenuiflora	***P. pyramidalis***	***M. tenuiflora***	***P. pyramidalis***
01/04/2005	71.1 a*	25.0 b	6.8 a	4.2 b
12/07/2005	109.3 a	31.7 b	11.6 a	5.0 b
25/11/2005	104.6 a	35.7 b	11.1 a	5.0 b
03/03/2007	69.3	**-	10.3	-
30/06/2008	177.5	-	24.8	-

**Mean values in the same line and for the same variable followed by different letters differ by the ANOVA F test (P<5%).*
***No surviving seedling*

Almost every *P. pyramidalis* seedling showed dried stems or were dead in March 2007 and June 2008, and no ANOVA could be run on the date subplot data. However, average mean values of *M. tenuiflora* length and basal diameter for these dates were included in Table 3. Its average length and basal diameter increased from 104cm and 35.7mm, in November 2005, to 177.5cm and 24.8mm in June 2008, showing the growth potential of this species in degraded Caatinga sites. The decrease in averages values observed in March 2007 resulted from the accidental grazing event that occurred in August 2006. This showed that *M. tenuiflora* tolerates heavy grazing 17 months after planting in degraded Caatinga sites and resumes growth even though an average of 35 cm was removed from its longest branch (and all the branches in general). The lower average basal diameter results from the nutrient reserve depletion and the high stress level that certainly occurred to the plants due to sprouting in the dry season after the grazing event in August 2006.

Three years after planting, height and diameter showed to be below the values reported by APNE [17] for *M. tenuiflora* of similar age and planted in similar spacing, in a non-degraded Caatinga site in Limoeiro do Norte (CE): 350 cm high/plant and 38mm of basal diameter/plant (see data from plots CMP01 and CMP06 of that study).

Although not formally considered in statistically analyses, canopy of *M. tenuiflora* was more developed than that of *P. pyramidalis* . This is important for soil protection (erosion and solar radiation) and for foraging and firewood production. Altogether, seedling survival, growth and canopy development support the use of *M. tenuiflora* in the recovery of degraded Caatinga sites.

No naturally regenerating tree seedling was observed in any plot of Experiment one and Experiment two. It was reasonable to expect a few of them because no animals were allowed to graze in the area and the seed bank certainly had some *M. tenuiflora* seeds from the two adult trees of this species in the area that produced fruits and seeds during the experimental period. However, 10 naturally regenerating *M. tenuiflora* plants developed in the fenced area outside the plots of Experiment one and Experiment two. Certainly, these plants are as old as or younger than the planted seedlings because the site had no regenerating *M. tenuiflora* in the beginning of the experiments.

In June 2008, the height and diameter of these plants averaged (151±20) cm and (15±2) mm, respectively. These are similar to the June 2008 values observed on planted *M. tenuiflora* of Experiment two (Table 3). This is unexpected, due to the presumably better conditions (e.g.: seedling x seed, manure-enriched holes x degraded soil, weeding x high competition) available to the planted than to the naturally regenerating *M. tenuiflora* individuals. This is supportive to the natural regeneration as a forest management tool and deserves further studies to detect the microsite characteristics that allowed plants to freely develop in degraded sites as much as the plants originated from two-month old seedlings planted in holes enriched with manure. Replication of these microsite characteristic in planting holes certainly has the potential to further improve the performance of planted *M. tenuiflora* seedlings.

Considering the 60 m x 70 m protected area in which experiments were carried out, the 10 naturally regenerating *M. tenuiflora* are equivalent to less than 24 plant/ha, while the 64 *M. tenuiflora* surviving planted seedlings in the twelve 9 m x 9 m experimental plots are equivalent to 658 plants/ha. However, these values are well below those reported by Bakke et al [9] and Araújo & Carvalho [18], and show how difficult seedling establishment is in degraded Caatinga sites.

The initial herb soil cover of the experimental area by Sida species (*Sida cordifolia* and *Sida sp.*) was almost non-existent. The predominance of these species would suggest that the plant succession process was regressive [18] (i.e.: probably, the climax would be different from that observed before the area was degraded by deforestation and overgrazing), had the pressure on the area remained unchanged. During the experimental period, when grazing was not allowed, other species of herbs, such as Lavandula sp. And Senna obtusifolia enriched the herb community dominated by the two *Sida* species. Certainly, the relative value of the two *Sida* species regarding soil cover diminished and tends to further do so in the future. This suggests that factors, such as time, animal deferment and planting of *M. tenuiflora* seedlings, are appropriate to reestablish plant cover and diversity of degrade Caatinga sites.

4. CONCLUSION

Natural regeneration of native trees in degraded Caatinga sites does not occur or seems to happen slowly whether or not the soil is ameliorated physically or enriched with manure, and grazing is controlled.

Tree revegetation of degraded Caatinga site is unsuccessful after sowing *Mimosa tenuiflora*, *Poincianella pyramidalis*, *Anadenanthera macrocarpa* and *Tabebuia aurea* whether or not the seedbed is ameliorated physically or by manure addition, and grazing is controlled.

The prospects of tree revegetation of degraded Caatinga sites are enhanced by planting *Mimosa tenuiflora* seedlings into manure-enriched holes.

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