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SEÇÃO IV - FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS

INFLUENCE OF TREE SPECIES ON THE HERBACEOUS UNDERSTORY AND SOIL CHEMICAL CHARACTERISTICS IN A SILVOPASTORAL SYSTEM IN SEMI-ARID NORTHEASTERN BRAZIL⁽¹⁾

R. S. C. MENEZES⁽²⁾ & I. H. SALCEDO⁽³⁾

SUMMARY

Studies from some semi-arid regions of the world have shown the beneficial effect of trees in silvopastoral systems, by promoting the formation of resource islands and increasing the sustainability of the system. No data are available in this respect for tree species of common occurrence in semi-arid Northeastern Brazil. In the present study, conducted in the summer of 1996, three tree species (*Zyziphus joazeiro*, *Spondias tuberosa* and *Prosopis juliflora*) found within *Cenchrus ciliaris* pastures were selected to evaluate differences on herbaceous understory and soil chemical characteristics between samples taken under the tree canopy and in open grass areas. Transects extending from the tree trunk to open grass areas were established, and soil (0-15 cm) and herbaceous understory (standing live biomass in 1 m² plots) samples were taken at 0, 25, 50, 100, 150 and 200% of the average canopy radius (average radius was 6.6 ± 0.5, 4.5 ± 0.5, and 5.3 ± 0.8 m for *Z. joazeiro*, *P. juliflora*, and *S. tuberosa*, respectively). Higher levels of soil C, N, P, Ca, Mg, K, and Na were found under the canopies of *Z. joazeiro* and *P. juliflora* trees, as compared to open grass areas. Only soil Mg organic P were higher under the canopies of *S. tuberosa* trees, as compared to open grass areas. Herbaceous understory biomass was significantly lower under the canopy of *S. tuberosa* and *P. juliflora* trees (107 and 96 g m⁻², respectively) relatively to open grass areas (145 and 194 g m⁻²). No herbaceous biomass differences were found between *Z. joazeiro* canopies and open grass areas (107 and 87 g m⁻², respectively). Among the three tree species studied, *Z. joazeiro* was the one that presented the greatest potential for use in a silvopastoral system at the study site, since it had a larger nutrient stock in the soil without negatively affecting herbaceous understory biomass, relatively to open grass areas.

Index terms: semi-arid region, caatinga, sustainability, fertility islands.

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RESUMO: *INFLUÊNCIA DE ESPÉCIES ARBÓREAS SOBRE O SUB-BOSQUE HERBÁCEO E CARACTERÍSTICAS QUÍMICAS DO SOLO DE UMA ÁREA SILVOPASTORIL NA REGIÃO SEMI-ÁRIDA DO NORDESTE BRASILEIRO*

Estudos de algumas regiões semi-áridas do mundo têm apontado o efeito benéfico de certas espécies arbóreas em sistemas silvopastoris, por promoverem a formação de "ilhas de fertilidade do solo" e aumentarem a sustentabilidade da produtividade agrícola. Não existem dados a esse respeito para espécies atualmente em uso no semi-árido brasileiro. Neste trabalho, realizado durante o verão de 1996, em Custódia, PE, foram selecionadas três espécies arbóreas encontradas em pastagens de capim buffel (Cenchrus ciliaris): joazeiro (Ziziphus joazeiro), umbuzeiro (Spondias tuberosa) e algaroba (Prosopis juliflora). Foram avaliadas as diferenças nas características químicas do solo e do sub-bosque herbáceo, entre áreas embaixo da copa das árvores e fora da influência da copa das árvores. Para isso, estabeleceram-se transetos partindo do caule das árvores até às áreas de pastagem sem árvores. Amostras de solo (0-15 cm) e do estrato herbáceo (biomassa viva em parcelas de 1 m²) foram coletadas a distâncias equivalentes a 0, 25, 50, 100, 150 e 200% do raio médio da copa (raio médio igual a 6,6 ± 0,5, 4,5 ± 0,5, e 5,3 ± 0,8 m, para Z. joazeiro, P. juliflora, e S. tuberosa, respectivamente). Níveis mais elevados de C, P, N, Ca, Mg, K e Na no solo foram encontrados sob a copa de Z. joazeiro e P. juliflora em relação às amostras sob pastagem. Somente o P-orgânico e o Mg no solo foram mais elevados nas áreas sob S. tuberosa. A matéria seca do estrato herbáceo foi significativamente menor sob S. tuberosa e P. juliflora (107 e 96 g m⁻², respectivamente), quando comparada com a de áreas fora da copa das árvores (145 e 194 g m⁻²). Nenhuma diferença significativa para a matéria seca foi observada sob Z. joazeiro e áreas sem árvores (107 e 87 g m⁻², respectivamente). A espécie Z. Joazeiro foi a que apresentou maior potencial de utilização em um sistema silvopastoril, com base no maior estoque de nutrientes no solo e na manutenção da produção de biomassa do sub-bosque herbáceo em relação à área sob pastagem.

Termos de indexação: caatinga, região semi-árida, caatinga, sustentabilidade, ilhas férteis.

INTRODUCTION

The semi-arid region of Northeastern Brazil covers an estimated area of 6 to 9 x 10⁵ km² (Sampaio et al., 1995), which represents nearly 10% of the Brazilian territory. The main vegetation type is deciduous thorn forest or thorn bush savanna known as "caatinga". Rainfall precipitation, which ranges from 300 to 1.000 mm y⁻¹ in different areas of the region, is concentrated in tree to five months, but drought years are common and severe drought periods lasting from three to five years have occurred every three or four decades (Sampaio et al., 1995). Agricultural activities center on shifting cultivation, establishment of livestock pastures, and fuel wood harvest (Kauffman et al., 1993), but productivity is usually very low (Sampaio et al., 1995).

Low agricultural productivities are mostly a consequence of practices such as slash-and-burn of the native vegetation, applied by the majority of the farmers in the region. The use of fire to eliminate vegetation residues leads to significant decrease in soil nutrients (Salcedo et al., 1997). As a consequence of these nutrient losses, after two or three years, the depletion of yields forces the farmers to abandon the

land and clear another area to keep farming. The area left to fallow eventually recovers its natural fertility after several years (Tiessen et al., 1992). However, due to the increase in population and reduction of land availability, several farmers return to the cultivated areas before allowing enough time of bush fallow. This fact helps to increase environmental degradation, because crop development is poor and the soil gradually loses its capacity to support vegetation growth.

The preservation of trees during the slash of the native vegetation may lead to more sustainable dryland cropping systems for the semi-arid Northeastern Brazil, where "sustainability" is used to define systems capable of supporting the local population while maintaining biodiversity and soil productivity for future generations. Based on studies from other semi-arid regions of the world, it seems that agroforestry systems would have a potential to fulfill these requirements. These studies have shown the beneficial effects of trees on agropastoral systems, represented by an improvement in soil nutrient and moisture levels, which resulted in an increased herbaceous understory biomass production under trees, in comparison to open areas.

These differentiated areas are known as resource islands (Reynolds et al., 1990), isles of fertility (West, 1981), or fertile islands (Halvorson et al., 1995). Several mechanisms are involved in the formation of these differentiated zones, including increased litterfall, reduction of soil temperature, and inputs via animals (Tiedemann & Klemmedson, 1973; Weltzin & Coughenour, 1990; Farrel, 1990; Belsky et al., 1993; Rhoades, 1995). However, in some cases, trees do not have any significant effect on soil and herbs (Belsky et al., 1993), due to either the characteristics of the tree species, which is related to aspects such as the ability to associate with nitrogen fixing organisms, or the characteristics of the environment, such as amount of rainfall.

In the last few years, some studies in the semi-arid region of Brazil have been conducted in order to determine optimum tree density when thinning the "caatinga" to establish pastures for livestock (Araújo Filho, 1990; Silva et al., 1995). Higher plant biomass production was observed with a tree density corresponding to 30% of ground cover, resulting in significant increases in meat production of goats, cattle and sheep. The questions addressed in these studies brought a significant contribution to the development of alternative dryland agricultural systems in the semi-arid, particularly regarding the role of trees in these systems. However, there are no available data on the dynamics of soil characteristics after tree density reduction, which is a crucial aspect to be considered in the assessment of sustainability.

The objective of this work was to quantify the differences in soil fertility and herbaceous understory characteristics between areas under the canopy of three tree species and adjacent open grass areas, in sites where: (a) native tree species were preserved during slash of the native vegetation for the establishment of buffel grass pastures, and (b) native vegetation was completely eliminated and buffel grass pastures were established intercropped with *P. juliflora* trees.

MATERIAL AND METHODS

Three tree species were selected for this study: (a) *Spondias tuberosa* Arruda, a deciduous native species, which is always preserved during the slashing of the "caatinga"; (b) *Ziziphus joazeiro* Mart., a non-deciduous native species, also preserved during slashing; and (c) *Prosopis juliflora* (SW.) DC., an introduced leguminous species intensively cultivated in the region, whose pods are a forage source for animals during the dry season.

Description of study area

The study was conducted in 1996 in a beef cattle farm at Custódia, PE (8°13.70'S and 37°44.70'W).

Average rainfall at the site is 740 mm year⁻¹ generally occurring from December to May. The farm area was originally covered with native vegetation, which was slashed with tractors pulling chains in 1984, followed by manual removal of the remaining bushes and tree stumps. The farm has a total of three thousand hectares of *P. juliflora* orchards planted with a spacing of 10 x 10 m, intercropped with buffel grass (*Cenchrus ciliaris*), which is a perennial, drought resistant forage grass. There were other large areas of established buffel grass pastures not planted with *P. juliflora*, where some native tree species, such as *Z. joazeiro* and *S. tuberosa*, had been spared during the slash of the "caatinga" and left with an average distance of around 30 to 40 m between trees. The *P. juliflora* orchards were 12 year old, and all the native tree species selected were over 50 year old, according to the locals. The orchard area and that with native tree species represent different situations in terms of potential differences in soil and herbaceous characteristics within each system, since *P. juliflora* trees were planted at the same time of the pastures while the native trees were already present when the pasture was established.

The pastures do not receive chemical fertilization and are mowed with tractors every two years at the end of the dry season for controlling invasion by woody species. No fire is used in the management of the pastures. Animal density in the farm fluctuates around 0.17 animal ha⁻¹, which is a relatively low density for buffel grass pastures in the region. Low animal density associated with high tree density in the pastures helped to reduce potential animal effects on the formation of fertility islands under the trees. The dominant soil type in the area is Noncalcic Brown (Ustalf), with extensive patches of Regosol (Orthent) in the lower parts of the landscape. Both soil types have a sandy loam texture in the top layer. The sampling areas are predominantly flat, with slopes ranging from 0 to 3%.

Soil and herbaceous understory sampling

Seven trees of each species were selected, giving preference to isolated mature trees. The selected individuals of *P. juliflora* were all located in areas of Noncalcic Brown, while those of *Z. joazeiro* were in Regosol areas. Individuals of *S. tuberosa* were found in areas with both soil types, so four trees were selected in Regosol areas and three in Noncalcic Brown areas. In each tree, canopy radius was determined by averaging the distance measured from the trunk to the canopy edge in four different directions. Soil samples were collected with a pickaxe and a shovel to a depth of 15 cm, and herbaceous understory samples were collected by clipping all standing live biomass in 1 m² plots. Both soil and plant samples were collected in a transect oriented to the north at distances which corresponded to 0, 25, 50, 100, 150 and 200% of the canopy radius,

starting from the trunk. Mean canopy radius was 6.6 ± 0.5 , 4.5 ± 0.5 , and 5.3 ± 0.8 m for *Z. joazeiro*, *P. juliflora*, and *S. tuberosa* trees, respectively.

Herbaceous understory samples were taken at each sampling position of the transects in 1 m² (1.4 x 0.7 m) plots positioned transversely in relation to the transect. All standing live biomass was clipped to ground level and placed in paper bags. Following an oven-dry period of 48 h at 60°C, forbs and grasses were sorted out and their individual dry matter weights recorded.

Soil and plant tissue analysis

The soil samples were air-dried and passed through a 2 mm sieve. Organic P was estimated from the 0.5 mol L⁻¹ H₂SO₄ extractable P in a soil sample ignited at 550°C and an unignited sample (Olsen & Sommers, 1982). Inorganic P was extracted using resin bags (Sibbesen, 1977) and determined colorimetrically (Murphy & Riley, 1962). Exchangeable bases were extracted with 1 mol L⁻¹ NH₄Cl. Calcium, Mg, and K in the filtered extracts were determined by atomic absorption and Na by flame emission spectrophotometry. Soil pH was measured in a 2.5:1 (water:soil) suspension. The sand content was determined by passing a dispersed sample through a 0.053 mm sieve, after a pretreatment with sodium hexametaphosphate solution. In a subsample ground to pass through a 0.25 mm sieve, total C was determined by wet oxidation-diffusion (Snyder & Trofymow, 1984) and total N by Kjeldahl digestion (Bremner & Mulvaney, 1982). In four trees of each species, soil bulk density was measured by taking two additional soil cores from both under canopy and open grass areas. The cores were 7.5 cm in diameter and 10 cm in height, and were taken from the 2 to 12 cm soil layer. Bulk densities of total soil and of soil fines (< 2 mm) were calculated for each soil type and sampling position in relation to the tree.

Plant samples were ground and subsamples digested with a sulfuric acid-hydrogen peroxide mixture (Thomas et al., 1967). The digests were analyzed for N and P by autoanalysis (Thomas et al., 1967), and for Ca, Mg, and K by atomic absorption spectrophotometry.

Statistical analysis

The data were initially analyzed for each species separately through regression analysis, using distance from the tree trunk as the independent variable. Variability among replicates yielded non-significant results on the effect of distance upon the soil or herbaceous understory characteristics. Thus, results obtained at 0, 25 and 50% sampling positions were considered as "under canopy", while those at 100, 150 and 200% were defined as "open grass", and compared through orthogonal contrasts, separately for each species.

The dry matter and nutrient stock of the herbaceous understory had a log-normal distribution and, for this reason, statistical analyses were performed on the log-normally transformed data. Forbs were found mostly under the canopies, being almost absent in the open grass areas around the three tree species. For this reason, there were many missing points for forbs in the open grass areas, and the statistical analysis for nutrient content was done only for the grass samples.

RESULTS AND DISCUSSION

Soil characteristics

For the three species, there were no differences in soil bulk density and sand content between canopy and open grass areas. Average bulk densities for total soil (including gravel) were 1.12, 1.1, and 1.07 g cm⁻³ in the areas of *Z. joazeiro*, *S. tuberosa*, and *P. juliflora*, while bulk densities for fines only (< 2 mm) were 1.08, 0.85, 0.93 g cm⁻³, respectively. Sand content averaged 709, 753 and 597 g kg⁻¹ soil in areas of *Z. joazeiro*, *S. tuberosa*, and *P. juliflora* trees, respectively. This lack of differences allowed for the comparison of soil nutrient levels between canopy and open grass areas without the need for soil texture and bulk density adjustments.

The concentration of all soil nutrients was higher under the canopies of *Z. joazeiro* and *P. juliflora* trees in comparison to open grass areas surrounding these trees (Table 1). Only the levels of soil organic P and of exchangeable Mg were significantly higher under the canopies of *S. tuberosa* than in the correspondent open grass areas (Table 1). Higher soil nutrient content is commonly observed under trees within tree-grass systems (Rhoades, 1997). This pattern likely originates from increased nutrient uptake by tree roots at both greater depths under the tree and in the surrounding soil, followed by the recycling of these nutrients to the area beneath the tree through litterfall and root turnover (Rhoades, 1997).

Concentrations of soil organic P and total C and N were very low in the Regosol soil type, which corresponds to the areas where *Z. joazeiro* trees were located, regardless of the sampling position (Table 1). Noncalcic Brown (NCB) soil type, which corresponds to the areas of *P. juliflora* trees, has higher values of organic matter and exchangeable bases than the Regosol, but has very low concentrations of extractable Pi. The values for the *S. tuberosa* area are intermediate, since these trees were found in areas of both Regosol and NCB. The low values of total N and organic P agree with reviews about the fertility status of soils in the semi-arid region of Northeastern Brazil, that have indicated generalized deficiencies in N (Sampaio & Salcedo, 1997), as well as in P and K (Sampaio et al., 1995).

Table 1. Mean values (n = 21) of various soil characteristics (0-15 cm) under and outside the canopy (open grass) of *Z. joazeiro*, *P. juliflora*, and *S. tuberosa* trees and net effect of sample position on soil characteristics

Position	C	N	Po ⁽¹⁾	Pi ⁽²⁾	Ca	Mg	K	Na	pH _w
	g kg ⁻¹	mg kg ⁻¹				mmol _c kg ⁻¹			(1:2.5 w:s)
<i>Z. joazeiro</i>									
Under canopy	8.3	917	81	26	45	14	10.5	1.5	6.8
In open grass	6.1	673	56	14	31	10	6.6	1.0	6.2
p-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Difference ⁽³⁾ (kg ha ⁻¹)	2138	237	24	12	272	47	148	11	-
<i>P. juliflora</i>									
Under canopy	16.8	1552	146	6	83	22	8.7	1.6	6.8
In open grass	12.1	1206	123	3	66	17	5.3	1.1	6.7
p-value	< 0.01	< 0.01	< 0.01	0.02	0.03	0.01	< 0.01	< 0.01	ns ⁽⁴⁾
Difference ⁽³⁾ (kg ha ⁻¹)	3934	290	19	3	285	50	111	10	-
<i>S. tuberosa</i>									
Under canopy	11.4	1118	109	10	53	18	7.62	1.1	6.1
In open grass	11.8	1117	86	6	56	15	7.68	1.1	6.5
p-value	ns	ns	0.01	ns	ns	0.02	ns	ns	0.04
Difference ⁽³⁾ (kg ha ⁻¹)	-	-	18	-	-	28	-	-	-

⁽¹⁾ Organic P. ⁽²⁾ Inorganic P. ⁽³⁾ Difference in soil nutrient concentrations between under the canopy and open grass positions, expressed in an area basis (bulk densities for < 2 mm soil = 1.08, 0.93 and 0.85 g cm⁻³ for *Z. joazeiro*, *P. juliflora* and *S. tuberosa* areas, respectively) and with a 60% ground cover by tree canopies. ⁽⁴⁾ Non-significant at p < 0.10.

The differences in soil nutrient content under and outside the canopies were converted to a hectare basis according to the soil bulk density of each area. These values were adjusted to a 60% ground cover by the canopies, which was the average value observed in the *P. juliflora* orchards. Under the assumption of similar tree densities for the three species, the differences in soil nutrient concentrations led to a relatively high net nutrient accretion under the canopies of *Z. joazeiro* and *P. juliflora* trees, in comparison to buffel grass areas without trees (Table 1).

Characteristics such as tree species, age, gender (Rhoades et al., 1994; Rhoades, 1995; Rhoades, 1997), or soil type (Campbell et al., 1994) may lead to a lack of tree effect on soil properties. In the present study, differences in average soil properties between samples under the canopy of *S. tuberosa* trees and open grass areas were very small (Table 1). One of the reasons for this lack of differences is the fact that *S. tuberosa* trees were located both in NCB and Regosol soil types. The collection of samples from the two soil types led to a significant increase in the variability within each sampling position, and resulted in no significant differences between canopy and open grass areas. After analyzing the results of the trees located in the patches of NCB and Regosol separately, there was indication of the influence of soil type on the effect of *S. tuberosa* trees on soil nutrients. Under the canopy of the four *S. tuberosa*

trees growing in the Regosol, there was significantly more soil total N and organic P than in the open grass areas, but no such differences were observed with the three trees located in the patches of NCB (Figure 1). The lack of differences in areas of NCB may be a result of the finer texture of this soil type, which did not allow for the detection of any eventual tree influence, as opposed to the areas of Regosol. Sand content in the top soil layer (0-15 cm) in areas of Regosol was 25% higher than in the areas of NCB, and this proportion may be even higher at greater soil depths due to the presence of the argillic horizon in NCB soils. Campbell et al. (1994) found that, in sandier soils, even a moderate increase in soil organic matter beneath the tree crowns greatly increased the soil exchange complex and led to a significant tree effect on soil nutrients. The authors also found that, in finer-textured soils, where the exchange complex is dominated by the mineral component rather than by organic matter, trees had a minor effect on soil nutrients (Rhoades, 1997).

The differences in soil nutrient concentrations found between the areas under the canopies of *P. juliflora* trees and open grass developed in a relatively short period of time (12 years) after tree planting. Since the trees and grasses were planted immediately after the removal of the native vegetation, it is possible that the observed patterns resulted from both an increase in soil nutrient concentration under the canopy and a simultaneous

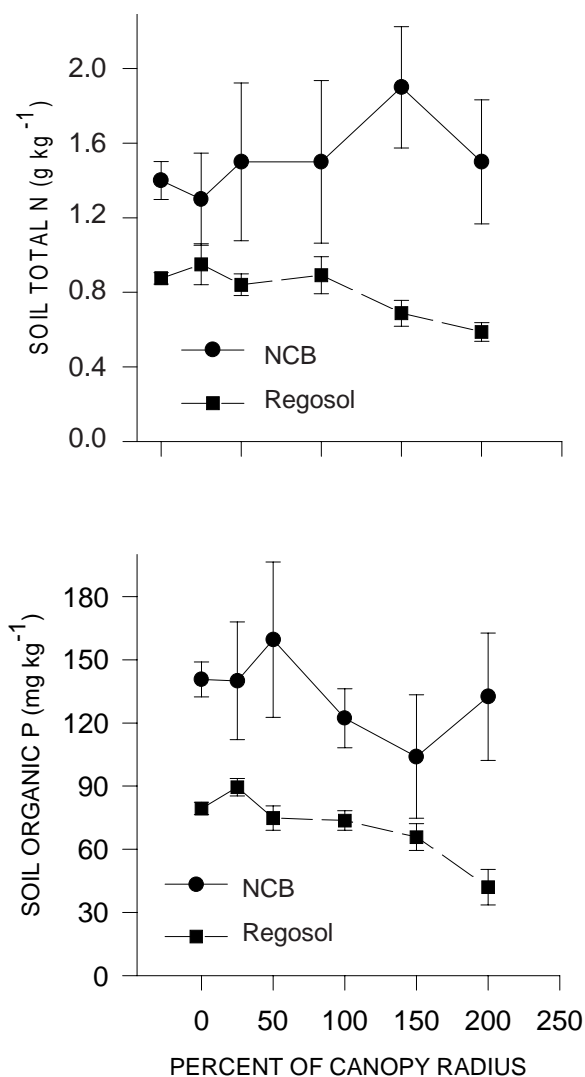


Figure 1. Soil total N and organic P under and next to the canopy of *S. tuberosa* trees located in areas of Noncalcic Brown (NCB) and Regosol in Custódia, PE. Error bars represent the standard error of the mean for NCB (n = 3) and Regosol (n = 4) areas.

decrease in soil nutrient concentration in the grass areas during that period. This could also have been the case in the areas of *Z. joazeiro* and *S. tuberosa*, with the difference that the individuals of these two native species were much older (> 50 years) and were preserved during the slash of the native vegetation and the implementation of *C. ciliaries*. However, due to the absence of a control area, no inferences regarding the dynamics of the system can be made.

Soil nutrient concentrations in dry tropical forests are characterized by strong seasonal patterns

(Roy & Singh, 1995) due to the fluctuations in soil moisture associated with the rainfall pattern. A strong pulse of available nutrients, such as available P or mineral N, may occur early in the rainy season due to mineralization after the rain or the release of nutrients mineralized during the dry season (Campo et al., 1998). In the present study, because the soil samples were taken in one single occasion, it could be possible that soil sampling at different times of the year could have yielded different results in the concentrations of mineral N, inorganic P, or exchangeable cations, such as K, Ca, Mg, and Na. However, the pools of organic C, N, and P make up the bulk of the amount of the three elements in those soils and, under conventional management practices, usually do not vary significantly within a year. The patterns observed for exchangeable cations were fairly consistent with the patterns of the nutrients in the organic forms. Therefore, it is likely that the observed differences in concentration of exchangeable cations between under-canopy and open-grass positions would still be present in samples taken at different times of the year.

The two soil types and the tree species selected for this study are representative of large areas in the Northeastern semi-arid region. Since the area selected for the study was not experimentally manipulated and is under commercial management, it seems reasonable to expect that the observed trends will also be present in similar soil-tree species combinations. It remains to be determined if the fertility islands observed around these trees could potentially benefit the crop or pasture intercropped with them, assuming an adequate tree density is established.

Herbaceous understory characteristics

There were no significant differences in herbaceous aboveground biomass (AGB) between under canopy and open grass areas for *Z. joazeiro* trees, but for *S. tuberosa* and *P. juliflora* trees there was significantly less herbaceous AGB under the canopy (Table 2). No animals were allowed in the pastures during the period between the first rains of the season and the sampling date at the beginning of grass seed production. Therefore, herbaceous AGB results should express the values for potential peak standing AGB in the open grass areas and under the canopies of the three tree species.

Herbaceous species composition was not specifically determined, but it was visually evident that there was more diversity of species under the canopies of the trees than in the *C. ciliaries* dominated open grass areas. AGB of *C. ciliaries* corresponded to 58 to 75% of total herbaceous AGB under the canopies, and 94 to 99% in the open areas (Table 2). Significantly lower levels of *C. ciliaries* AGB under the canopy of *S. tuberosa* and *P. juliflora* were responsible for the significant differences in total

herbaceous AGB between canopy and open areas for these species, since AGB of forbs was significantly higher under the canopies of all three species (Table 2). It is hypothesized that understory microclimatic conditions or competition between the trees and the herbaceous understory for resources such as soil moisture and/or light may have led to the lower levels of *C. ciliaries* AGB under the canopies. The absence of significant differences between grass AGB levels under the canopy of *Z. joazeiro* and open areas suggest that competition for those resources may be less intense under the canopies of *Z. joazeiro*, when compared to the other two tree species.

Forbs were almost absent in the open grass areas, when compared to the areas under tree canopies, especially in the case of *Z. joazeiro* and *S. tuberosa* (Table 2). These results indicate that these trees provided an understory environment favorable for the forb growth. Therefore, even without increasing soil nutrients or herbaceous AGB, which was the case of *S. tuberosa*, trees promoted the establishment of areas with increased biodiversity, relatively to the low diversity stands of *C. ciliaries* surrounding each tree.

Significantly higher concentrations of *C. ciliaries* tissue N were observed under the canopy of *Z. joazeiro* trees in comparison to open grass areas (Table 3). Similarly, higher *C. ciliaries* tissue Ca was found under *Z. joazeiro* and *S. tuberosa* trees. Levels of Ca in *C. ciliaries* tissue were slightly lower under the canopies of *P. juliflora*, but no differences were observed for the other nutrients analyzed. The range

of values for *C. ciliaries* tissue nutrient concentration observed in this study is consistent with values from previous studies with this (Havard-Duclos, 1967; Esechie, 1992; Pandeya & Lieth, 1993) and other tropical grass species (Malavolta et al., 1986).

Overall, *C. ciliaries* tissue nutrient concentrations were higher in areas of *Z. joazeiro* (Regosol soil type) when compared to areas of *P. juliflora* (NCB soil type) (Table 3), even though the areas of Regosol had lower soil N, Ca, and Mg levels (Table 1). Individuals of *S. tuberosa* were selected from both areas (Regosol and NCB) and the tissue nutrient concentration values of *C. ciliaries* found under and around these trees are consistently in between those for *C. ciliaries* found in areas of *Z. joazeiro* and *P. juliflora* (Table 3). In the semi-arid region of Northeastern Brazil, the farmers generally prefer to establish agricultural fields in areas of Regosol, even though these soils are usually sandy and low in nutrients. This preference is usually a result of the higher soil moisture availability for the crops found in these sandy soils, due to higher water infiltration and lower evaporation rates as compared to finer textured soils (Oliveira et al., 1992). According to the inverse texture hypothesis (Noy-Meir, 1973), in arid and semi-arid regions, sandy soils usually store higher amounts of plant available water and, for this reason, are considered more fertile than fine textured, nutrient richer soils. As a consequence, the higher availability of soil water in sandier soils may also lead to higher nutrient availability due to increased soil organic matter mineralization. Salcedo & Menezes (1999) conducted a soil N mineralization field study at the same site of the present work. The authors found higher amounts of N mineralized in field incubation cores in areas of Regosol than in areas of NCB, even though total soil N was 55 to 246% higher in NCB areas. These results may explain the higher tissue nutrient concentration in *C. ciliaries* from Regosol areas in comparison to NCB areas (Table 3).

Outside the canopies, either forbs were absent or the AGB was in most cases too low to allow the analysis of tissue nutrient concentration. For this reason, no statistical comparisons between canopy and open grass areas were performed (Table 4). Median rather than mean values are shown to avoid the influence of extreme values observed in some samples. The overall trend in tissue nutrient concentration of forbs is very similar to the trend observed for grasses. With no exceptions, tissue nutrient concentration of forbs under the canopies of *Z. joazeiro* was higher than under the canopies of *P. juliflora*, while those under the canopies of *S. tuberosa* were intermediate.

There were no differences in the amount of nutrients immobilized in the herbaceous AGB under the canopies and open grass areas in the case of *Z. joazeiro* trees, with the exception of significantly higher levels of Ca under the trees (Table 5). A lower

Table 2. Mean values and standard errors (n = 21) of dry matter under and outside (open grass) the canopy of *Z. joazeiro*, *P. juliflora* and *S. tuberosa* trees

Position	Understory vegetation		
	Forbs	Grasses	Total herbs
	g m ⁻²		
	<i>Z. joazeiro</i>		
Under canopy	27.5 (6.7)	79.7 (18.9)	107.2 (19.2)
In open grass	0.99 (0.52)	86.2 (7.3)	87.2 (7.4)
p-value	< 0.01	ns	ns
	<i>P. juliflora</i>		
Under canopy	24.3 (7.2)	71.6 (19.2)	95.9 (17.5)
In open grass	0.38 (0.24)	193.2 (28.9)	193.6 (29.1)
p-value	< 0.01	< 0.01	0.011
	<i>S. tuberosa</i>		
Under canopy	44.6 (9.3)	61.9 (28.0)	106.5 (26.3)
In open grass	9.2 (5.0)	136.1 (23.1)	145.3 (22.0)
p-value	< 0.01	< 0.01	0.09

ns Non-significant at p < 0.10.

Table 3. Mean values⁽¹⁾ of grass (*C. ciliares*) tissue nutrient concentration under and outside (open grass) the canopy area of *Z. joazeiro*, *P. juliflora*, and *S. tuberosa* trees

Position	N	P	Ca	Mg	K
g kg ⁻¹					
<i>Z. joazeiro</i>					
Under canopy (n = 19)	15.1	1.73	7.77	2.46	39.2
In open grass (n = 21)	12.5	1.99	6.18	2.19	35.7
p-value	0.023	ns	0.094	ns	ns
<i>P. juliflora</i>					
Under canopy (n = 17)	10.7	0.90	4.22	1.76	21.8
In open grass (n = 21)	9.0	1.16	4.59	1.91	23.6
p-value	ns	ns	0.080	ns	ns
<i>S. tuberosa</i>					
Under canopy (n = 15)	12.3	1.18	6.99	2.45	32.7
In open grass (n = 21)	11.3	1.17	5.62	2.75	29.1
p-value	ns	ns	0.039	ns	ns

⁽¹⁾ Means were calculated based on number of samples (n) indicated in each line, where grasses were found. Total number of sampling sites was 21. ns Non-significant at $p < 0.10$.

Table 4. Sample medians and ranges of forb tissue nutrient concentration under and outside (open grass) the canopy of *Z. joazeiro*, *P. juliflora*, and *S. tuberosa* trees⁽¹⁾

Position ⁽¹⁾	N	P	Ca	Mg	K
g kg ⁻¹					
<i>Z. joazeiro</i>					
Under canopy (n = 16) ⁽²⁾	23 (13-33)	2.3 (1.2-3.5)	29 (12-43)	5.7 (3-14)	36 (14-59)
In open grass (n = 4)	18 (17-20)	1.8 (1.1-1.9)	26 (16-29)	7.7 (4.8-7.7)	26 (11-30)
<i>P. juliflora</i>					
Under canopy (n = 14)	13 (10-19)	0.95 (0.6-1.9)	18 (9-37)	3.5 (1-17)	17 (8-35)
In open grass (n = 3)	18 (16-19)	1.1 (1.06-1.12)	21 (15-26)	5.8 (3.2-8.5)	25 (11-38)
<i>S. tuberosa</i>					
Under canopy (n = 19)	19 (13-25)	1.7 (1.3-2.5)	20 (11-33)	3.9 (2-12)	29 (13-54)
In open grass (n = 7)	29 (21-35)	2.2 (1.7-2.5)	25 (19-30)	7.9 (6-10)	37 (19-65)

⁽¹⁾ Statistical comparisons between positions were not performed due to the small sample sizes for open-grass areas. ⁽²⁾ The letter n indicates the number of sampling sites where forbs were found, of a total of 21 sites.

amount of nutrients was immobilized in the herbaceous AGB under *P. juliflora* canopies, with the exception of Ca, when compared to open grass areas. This was primarily a consequence of the lower levels of herbaceous AGB under the canopies, since there were no differences in *C. ciliares* tissue nutrient concentration for this species (Table 3). In the case of *S. tuberosa* trees, even though significantly lower levels of herbaceous AGB were found under the canopy in comparison to open areas (Table 2), there were no significant differences in the amount of nutrients immobilized in herbaceous AGB between the two areas. This pattern was a result of the higher tissue nutrient concentration of forbs in comparison to *C. ciliares* (Tables 3 and 4), since forbs made up a higher proportion of the herbaceous AGB under the canopy (42%) as compared to open areas (6%) (Table 2).

Soil moisture seems to be the most limiting resource for plant growth in the study site. For this reason, it is hypothesized that the significantly lower levels of peak standing herbaceous AGB under the canopy of *P. juliflora* and *S. tuberosa* trees were a result of competition between the tree and the herbaceous plants for soil moisture. Recent studies have suggested that this competitive interaction varies according to the level of rainfall precipitation, and competition is stronger at low rainfall sites (Belsky, 1994). There is no available information in the literature about *S. tuberosa* competitive interactions with the herbaceous understory, but Parker & Martin (1952) identified a significant

decrease in soil moisture under the canopies of *P. juliflora* trees. This could be the case of the present study, where these two tree species may be decreasing the availability of soil moisture under the canopy. If soil moisture levels are lower under

Table 5. Mean values (n = 21) of nutrient stock in the herbaceous layer under the canopy and in open-grass areas of *Z. joazeiro*, *P. juliflora*, and *S. tuberosa* trees

Position	N	P	K	Ca	Mg
mg m ⁻²					
<i>Z. joazeiro</i>					
Under canopy	1287	146	2751	884	246
In open grass	991	155	2821	484	175
p-value	ns	ns	ns	0.01	ns
<i>P. juliflora</i>					
Under canopy	689	61	1250	454	157
In open grass	1287	161	3507	669	280
p-value	0.04	< 0.01	< 0.01	ns	0.04
<i>S. tuberosa</i>					
Under canopy	1053	101	1913	866	249
In open grass	1365	137	3040	726	318
p-value	ns	ns	ns	ns	ns

ns Non-significant at $p < 0.10$.

the canopies, the positive effects of soil nutrient enrichment may be canceled out, especially in environments where soil water is a highly limiting factor, such as in the semi-arid region of Northeastern Brazil. Further work in our study site is necessary for testing this hypothesis.

CONCLUSIONS

1. The soil under the canopies of *Z. joazeiro* and *P. juliflora* trees had a significant higher nutrient content than that within *C. ciliates* pastures, but little differences in soil nutrient content were observed in the case of *S. tuberosa* trees.

2. The herbaceous aboveground biomass found under the canopies of *P. juliflora* and *S. tuberosa* was lower in comparison to open grass areas, but biomass levels were similar in the case of *Z. joazeiro* trees and surrounding areas.

3. Within the herbaceous layer under the canopies of the three tree species, aboveground biomass of *C. ciliates* was lower than in the open areas, but aboveground biomass of forbs was significantly higher.

4. Significantly higher concentrations of *C. ciliates* tissue N were found under the canopy of *Z. joazeiro* trees in comparison to open grass areas, and of Ca under both *Z. joazeiro* and *S. tuberosa* trees. Concentration of nutrients in *C. ciliates* tissue was higher in areas of Regosol, in comparison to areas of NCB, although soil N, Ca, and Mg was lower in the Regosol.

5. These results indicate the potential of certain tree species, such as *Z. joazeiro*, for maintaining soil fertility without negatively affecting herbaceous productivity. However, there is a need for further understanding of the tree-herb-soil interactions in semi-arid Northeastern Brazil, which could serve as basis for the establishment of sustainable silvopastoral systems in the region.

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