




## Article

# Tree Canopy Management Affects Dynamics of Herbaceous Vegetation and Soil Moisture in Silvopasture Systems Using Arboreal Legumes

Izabela A. Gomes da Silva <sup>1</sup>, José C. B. Dubeux, Jr. <sup>2,\*</sup> , Mércia Virginia Ferreira Santos <sup>1</sup>, Alexandre Carneiro Leão de Mello <sup>1</sup> , Márcio Vieira Cunha <sup>1</sup> , Valéria X. O. Apolinário <sup>3</sup> and Erinaldo Viana de Freitas <sup>4</sup>

<sup>1</sup> Animal Science Department, Federal Rural University of Pernambuco, Recife 52171030, Brazil; izabelagomesz@gmail.com (I.A.G.d.S.); mercia.vfsantos@ufrpe.br (M.V.F.S.); alexandre.lmello@ufrpe.br (A.C.L.d.M.); marcio.cunha@ufrpe.br (M.V.C.)

<sup>2</sup> North Florida Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, 3925 Highway 71, Marianna, FL 32446, USA

<sup>3</sup> Animal Science Department, State University of Maranhão, São Luis 65055970, Brazil; valeriaapolinario@cca.uema.br

<sup>4</sup> Agronomic Institute of Pernambuco, Recife 50761000, Brazil; erinaldo.viana@ipa.br

\* Correspondence: dubeux@ufl.edu



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**Abstract:** Understanding ecological interactions between the arboreal and the herbaceous components is key to get the full benefits from silvopastoral systems. The objective of this 2-yr research was to evaluate productivity and nutritive value of signalgrass (*Urochloa decumbens* (Stapf.) R. Webster) subjected to shading from the tree legumes *Gliricidia* (*Gliricidia sepium* (Jacq.) Steud) or *Mimosa* (*Mimosa caesalpiniiifolia* Benth.) under different tree canopy management. Trees were planted in double rows and were either unharvested or harvested only one row, leaving the other row unharvested. Response variables for the herbaceous vegetation included canopy height, herbage mass (green leaf blade, green stem, senescent leaves, and senescent stem), herbage accumulation rate, canopy bulk density, and soil moisture. Total herbage mass, green herbage mass, and green leaf mass were affected by treatment × month and harvest management × month interactions. Herbage accumulation rate in *Gliricidia* was greater (55 kg DM ha<sup>-1</sup>d<sup>-1</sup>) than *Mimosa* (32 kg DM ha<sup>-1</sup>d<sup>-1</sup>). Soil moisture was lesser at the *Mimosa* sites (16.2%) compared with the *Gliricidia* ones (17.2%), and it was greater between tree rows (21.9%) compared with full sun (11.5%), varying across the season. Harvesting management had a short-term transient effect on herbage responses. Tree canopy management can affect forage quantity and quality; however, these effects are transient and vary with tree spacing. Signalgrass grew faster and had better nutritive value when growing with *Gliricidia*.

**Keywords:** nutrient cycling; shade; tree spacing

## 1. Introduction

Shade affects the productive, nutritional, and morphological traits of tropical forages [1]. Warm-climate C4 grasses growing under shade must self-adapt through phenotypic plasticity, such as increased leaf area and shoot-to-root ratio, as well as decreased tiller population density, and canopy bulk density [2]. Moreover, shade might increase chlorophyll [3] and crude protein (CP) concentrations [4] of herbaceous vegetation in silvopastoral systems.

Silvopastoral systems with tree legumes have added benefits such as the potential biological N<sub>2</sub> fixation and nutrient cycling [5]. There have been reports that *Gliricidia* and *Mimosa* root systems are able to take advantage of the association with rhizobia symbionts, affecting soil Nitrogen (N) cycling [6].

Selecting the appropriate arboreal species for a silvopastoral system is key to enhance sustainability. Multi-purpose tree species with economic potential that also provides shading, soil protection, fire resistance, without toxic effect to animals, and forage potential must be selected [7]. Tree spacing and canopy management affect the dynamics of the herbaceous vegetation, and it varies with species, environment, and management practices. Tree density affects the conditions of the light environment under the canopy, altering the growth of forages. The greater the spacing between the rows of trees, the greater the light penetration reaching the understory, favoring herbage accumulation [8]. Most of the studies with tropical grasses have shown a reduction in forage production when shade levels exceed 50% of the incident radiation due to the acute decrease in photosynthetic rates of C<sub>4</sub> grasses [9].

The potential for commercial use of timber and firewood in these tree legume species, especially Mimosa, contributes significantly to generate revenue for the producer with the sale of wood and other products extracted from trees [10]. Moreover, the changing perception of the consumer about food production practices in various parts of the world is very present and noticeable [11,12], which justifies the development of technologies or new alternatives to provide more comfort and welfare to production animals. We hypothesized that contrasting management of the tree canopy would affect the responses of the herbaceous vegetation and soil moisture; however, these responses would vary with tree species. The objectives were to assess herbage and soil moisture responses under two different silvopasture systems using contrasting harvesting strategies for the arboreal component. The hypothesis behind these management strategies was that harvesting one of the rows would enhance the light environment in the understory while providing cash flow for the producer by selling the harvested wood.

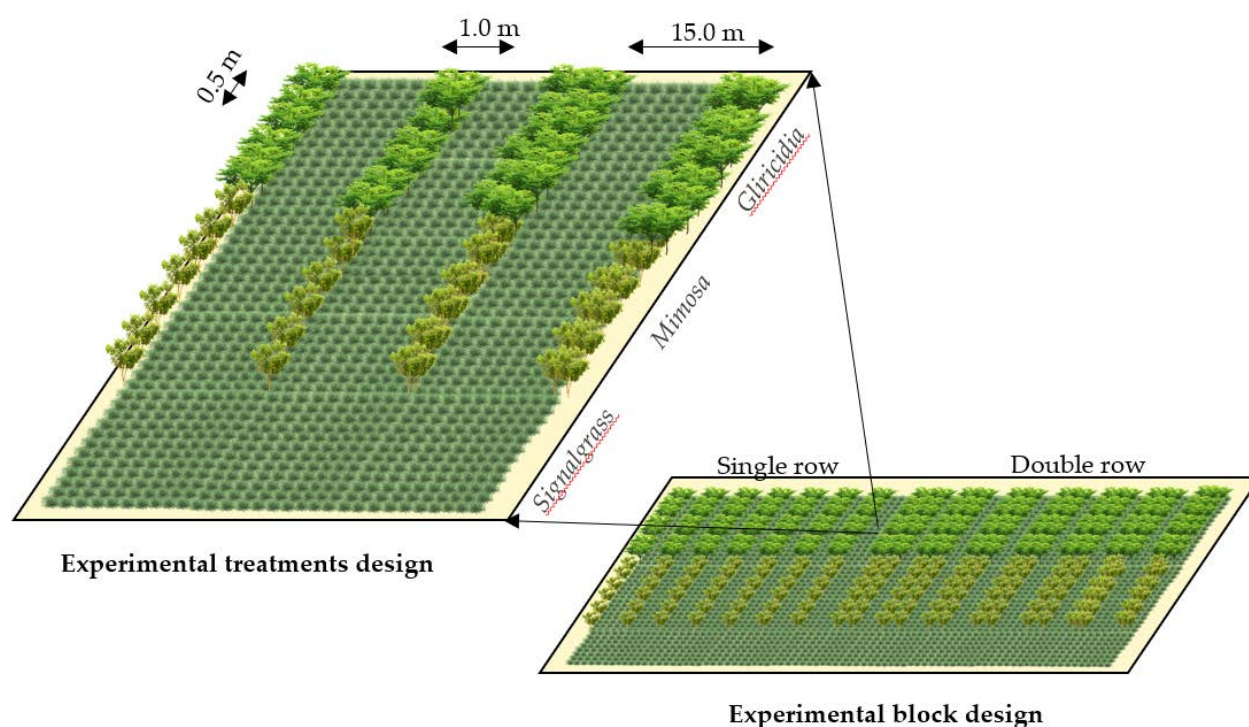
## 2. Materials and Methods

### 2.1. Site Description and Establishment

The study was carried out at the Experimental Station of Itambé (7°23' S and 35°10' W and 190 m above sea level), Agronomic Institute of Pernambuco-IPA. The soil in the experimental area is classified as a Ultisol [13]. Average annual rainfall is 1200 mm, and annual average temperature is 25 °C. The relative annual air humidity is 80%, and the local climate is defined as As' warm-humid rainy tropical with dry summer. Soil chemical characteristics in 2017 were:  $\text{pH}_{(\text{water}, 1:2.5)} = 5.2$ , Mehlich-I P = 7.2 mg dm<sup>-3</sup>; Ca<sup>2+</sup> = 3.0 cmol<sub>c</sub> dm<sup>-3</sup>; Mg<sup>2+</sup> = 1.1 cmol<sub>c</sub> dm<sup>-3</sup>; K<sup>+</sup> = 0.17 cmol<sub>c</sub> dm<sup>-3</sup>; Al<sup>3+</sup> = 0.17 cmol<sub>c</sub> dm<sup>-3</sup> [14].

### 2.2. Treatments and Experimental Design

In 2011, tree legumes were established in double rows in 1-ha paddocks. Each paddock had 14 double rows, resulting in 2500 trees ha<sup>-1</sup>. Legume seeds were planted in a greenhouse and inoculated with specific Bradyrhizobium strains, obtained from the soil microbiology laboratory at Federal Rural University of Pernambuco (UFRPE). All paddocks were fertilized in July 2011 with 44 kg P ha<sup>-1</sup> (as ordinary superphosphate) and 100 kg K ha<sup>-1</sup> (as potassium chloride) on the entire area. Legume seedlings were transplanted to the field in June 2011 with approximately 30-cm height and planted in 20-cm deep furrows. In September 2016, in order to allow more light to reach the herbaceous layer, one of the tree rows was harvested in half of the plots, reducing the tree population to 1250 trees ha<sup>-1</sup> (Figure 1). The harvested side was randomized in each experimental unit. All plots were managed under continuous stocking, and specific details about livestock management are described by [15].



**Figure 1.** Experimental design of one block with three experimental units.

Signalgrass was planted between tree rows. Signalgrass had previously been established in one of the blocks since 1969 [16]. In the other two blocks, signalgrass was established along with the tree legumes, between the double rows. Briefly, the establishment of signalgrass occurred in open pits (about 5-cm deep), spaced  $1.0 \times 0.5$  m; seeds were placed manually (10 kg of commercial seed  $\text{ha}^{-1}$  with 40% of pure viable seeds). Pastures were fully established by the end of the rainy season in 2011.

A 2-yr experimental period was adopted from January 2017 to December 2018. Treatments consisted of two silvopasture systems with two harvest regimes for the tree components. In one harvesting regime, the trees in the double-rows were not harvested, whereas in the other harvesting regime, the trees from one-row were harvested while keeping the trees from the other row. The hypothesis behind these management strategies was that harvesting one of the rows would enhance the light environment in the understory while providing cash flow for the producer by selling the harvested wood. The treatments were: (1) *Urochloa decumbens* Stapf. (signalgrass) + *Mimosa caesalpinifolia* Benth (Mimosa) → Mimosa; (2) signalgrass + *Gliricidia sepium* (Jacq.) Steud (Gliricidia) → Gliricidia. Treatments were allocated in split-plot in a randomized complete block design. The main plot was the tree species, and the split-plot was the harvest management. Therefore, half of the entire paddock was under a given harvest regime. Split plots were randomized across experimental units.

### 2.3. Herbage Responses

The average canopy height (CH) of signalgrass was measured using a sward stick [17] at 60 random points, and the average of these 60 scores was used in the regression equation to estimate herbage mass. Signalgrass herbage mass was determined using the double-sampling technique [18]. Briefly, every 28 days, direct measurements were obtained by harvesting six  $0.25\text{-m}^2$  quadrats per paddock at ground level. After harvesting the forage, botanical and morphological separations were performed.

Grass samples were separated into stem (green and dead) and leaf blade (green and dead). Forage samples were oven-dried at  $55\text{ }^\circ\text{C}$  for 72 h to a constant weight. Herbage mass was calculated without considering the dead material. Laboratory analyzes (CP and

DM concentrations) were performed only in the green forage fractions (leaf and stem). Dead material was used to calculate the proportion of leaf and stem and DM concentration.

Herbage accumulation rate (HAR) was determined by placing four exclusion cages within each paddock. The cage location was defined by assessing 60-point measurements with the sward stick. Cages were placed on an average location and relocated every 14 d to a new location within the paddock. This procedure was done in order to minimize the effect of structural differences in the canopy. Differences between mean values at the beginning and at the end of 14 days, divided by the growth period, resulted in the herbage accumulation rate [19].

Canopy bulk density of signalgrass was expressed in  $\text{kg DM ha}^{-1} \text{cm}^{-1}$ , and it was obtained by dividing the green herbage mass by the average canopy height, which was determined by using 60-point measurements with measuring sward stick. Sward stick was preferred over disk height to measure canopy height because the compressed disk height might overrate canopy bulk density [20]. The measurement was taken at the extended height of individual profiles, according to the recommendation of Frame [21].

#### 2.4. Soil Moisture

Soil moisture was calculated by the difference between wet ( $m_1$ ) and dry ( $m_2$ ) masses, divided by dry mass and multiplied by 100 [22]. Soil samples were collected from 0 to 20-cm soil layers, at two sites, i.e., between tree legume rows and at full sun (i.e., the middle of the grass strip), every 56 days. Samples were weighed and placed in a greenhouse at 105 °C for 24 h.

#### 2.5. Data Analyzes

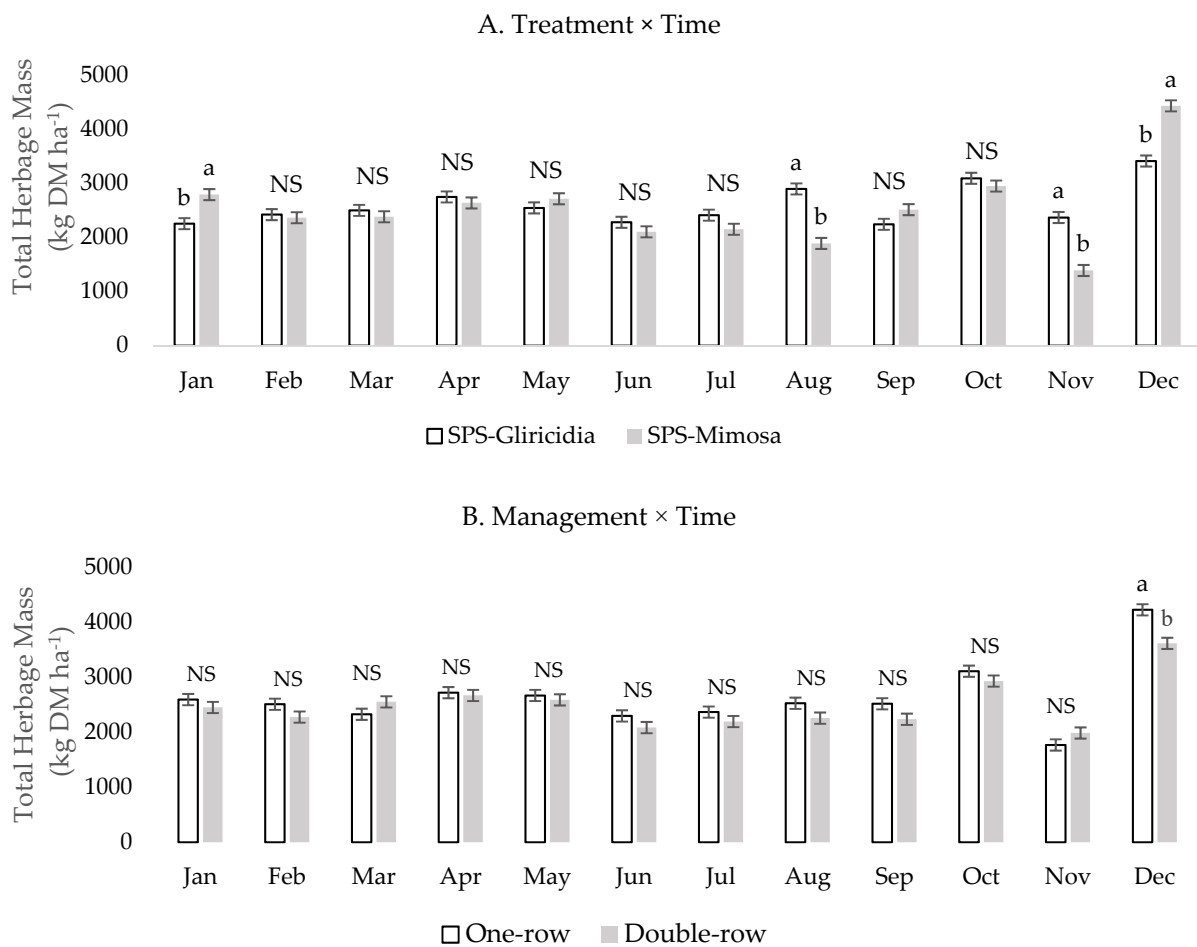
The data were submitted to statistical analysis using the mixed procedure of the statistical package SAS (Cary, NC, USA) 9.4. Fixed effects included tree species and harvest management and the interaction between them. Months were considered repeated measures. Year and block were considered random effects. Averages were compared using PDIFF of the SAS adjusted by Tukey, and statistical differences were considered significant when  $p \leq 0.05$ .

### 3. Results

#### 3.1. Total Herbage Mass and Total Green Herbage Mass

There was a significant treatment  $\times$  time interaction for total herbage mass ( $p < 0.05$ ). In eight out of twelve months of the year, herbage mass was similar between the two legume systems, with Mimosa presenting greater herbage mass in January and December, and Gliricidia with greater herbage mass in August and November (Figure 2A). Interaction also occurred between harvest management  $\times$  month, and one-row area had greater total herbage mass only in December (Figure 2B).

There was a treatment  $\times$  month interaction ( $p < 0.05$ ) for total green herbage mass, and there was no significant difference between harvesting management for this response ( $p \geq 0.05$ ). Gliricidia always had greater green herbage mass for the herbaceous vegetation than Mimosa, but the difference varied along the season. May to July were the months with greater proportions of green material to both systems, corresponding to the rainiest months (Table 1).



**Figure 2.** Total herbage mass of legume trees under different tree canopy management during the experimental period. Subfigure (A) denotes Treatment × Time interaction and subfigure (B) denotes Management × Time interaction. Different letters between treatments within each month indicate significant difference using the PDIFF procedure adjusted to Tukey ( $p < 0.05$ ). NS = non-significant. Data averaged across two experimental years and three blocks. SPS = silvopasture system.

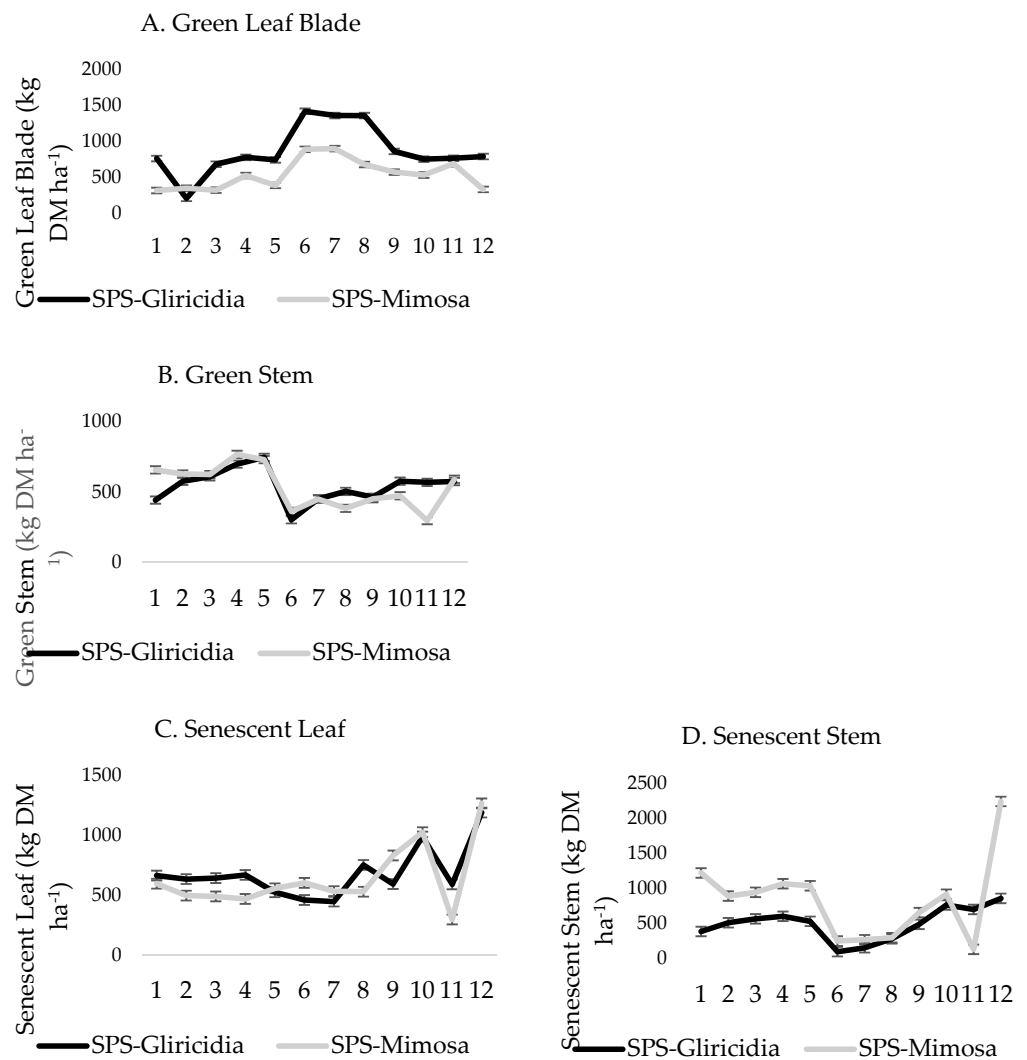
**Table 1.** Total green herbage mass (kg DM ha<sup>-1</sup>) for both systems during the experimental period.

	Gliricidia <sup>†</sup>	Mimosa	<i>p</i> Value
	kg DM ha <sup>-1</sup>		
January	1207 c	977 c	<0.001
February	1287 c	979 c	<0.001
March	1293 bc	949 c	<0.001
April	1479 c	1103 bc	<0.001
May	1491 b	1120 bc	<0.001
June	1724 a	1254 ab	<0.001
July	1814 a	1351 a	<0.001
August	1864 a	1066 bc	<0.001
September	1327 bc	1028 c	<0.001
October	1332 bc	1008 c	<0.001
November	1337 bc	988 c	<0.001
December	1366 bc	925 c	<0.001
SEM <sup>†</sup>	54		

<sup>†</sup> Means followed by equal lowercase letters in the column do not differ by the PDIFF procedure adjusted by Tukey ( $p < 0.05$ ). SEM = standard error of mean.

### 3.2. Green and Dry Plant Fraction (Leaf Blade and Stem) Biomass

There was a treatment  $\times$  evaluation interaction for green leaf blade mass and for green stem mass. Green leaf blade biomass was greater for Gliricidia in most of the months, but the difference between systems varied along the year (Figure 3A; SE = 39 kg DM ha<sup>-1</sup>). Green stem biomass varied between systems along the year, with Mimosa showing greater green stem biomass in the first evaluation but declining along the year (Figure 3B; 28 kg DM ha<sup>-1</sup>).



**Figure 3.** Green leaf blade (A), green stem (B), senescent leaf blade (C) and senescent stem (D) during the experimental period. SPS = silvopasture system.

There was treatment  $\times$  evaluation interaction for senescent leaf (Figure 3C; SE = 41 kg DM ha<sup>-1</sup>) and senescent stem (Figure 3D; SE = 68 kg DM ha<sup>-1</sup>), which varied in both cases along the season. Mimosa had greater senescent stem biomass starting for the first five months of the year and in the last month. The rainy season (June–September) had greater green forage biomass for both treatments compared with the dry season.

There was a management  $\times$  month interaction for green leaf mass (Table 2). Green leaf mass did not differ among management systems (i.e., tree species and harvest management) in any of the months, but they did vary along the months. Interaction occurred because the variation along the months was not similar for both systems, as indicated by the *p* values comparing management systems within each month.

**Table 2.** Green leaf blade in one-row and in double-row during the experimental period.

Evaluation	Green Leaf Mass		p Value
	One Row *	Double Row	
	kg DM ha <sup>-1</sup>		
January	534 ef <sup>†</sup>	550 de	1.000
February	536 ef	527 e	1.000
March	474 f	538 de	0.9714
April	529 ef	589 cde	0.9875
May	557 def	580 cde	1.000
June	1192 a	1122 a	0.9341
July	1140 ab	1125 a	1.000
August	1049 b	994 a	0.9966
September	733 c	707 bc	1.000
October	627 cde	665 bcd	1.000
November	690 cd	771 b	0.7781
December	530 ef	598 cde	0.9545
SEM	54		

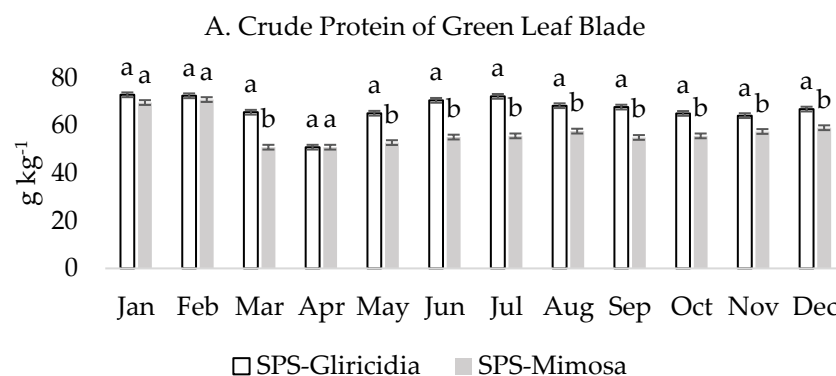
<sup>†</sup> Means followed by equal lowercase letters within the same column do not differ by Tukey test ( $p \leq 0.05$ ).  $p$  value compares within row. \* One row = double-row planting with one row harvested; double-row = double-row planting with no rows harvested; SEM = standard error of mean.

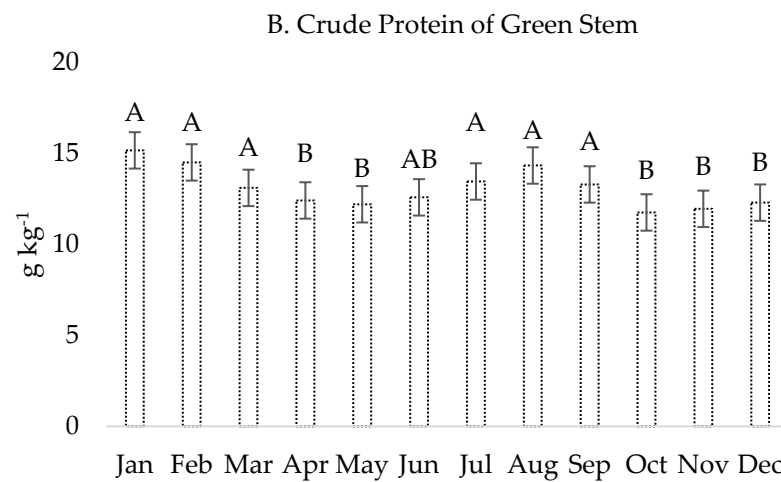
### 3.3. Crude Protein of Green Leaf Blade and Green Stem

There was a treatment  $\times$  evaluation interaction for crude protein of green leaf blade (Figure 3A). Signalgrass in Gliricidia had greater CP in the green leaf blade in nine out of twelve evaluations, compared with the signalgrass growing in the Mimosa (Figure 4A). Crude protein of green stem varied along the evaluations; however, the results were not as affected by rainfall (Figure 4B).

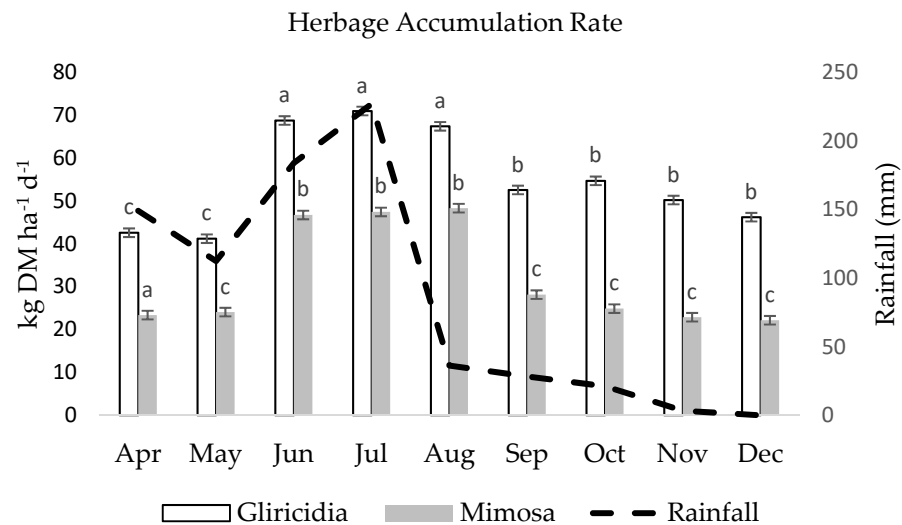
### 3.4. Herbage Accumulation Rate

There was a treatment  $\times$  evaluation interaction for herbage accumulation rate (HAR) (Figure 5). Herbage accumulation rate was always greater for signalgrass growing in the Gliricidia compared with Mimosa. The HAR peaked in July (71 kg DM ha<sup>-1</sup> d<sup>-1</sup> for Gliricidia and 48 kg DM ha<sup>-1</sup> d<sup>-1</sup> for Mimosa) and had its least growth rate in December (22 kg DM ha<sup>-1</sup> d<sup>-1</sup>), coinciding with greater and lower rainfall, respectively; however, Gliricidia did not follow the rainfall pattern as Mimosa has a lower HAR occurring in May (41 kg DM ha<sup>-1</sup> d<sup>-1</sup>).

**Figure 4.** Cont.



**Figure 4.** Crude protein of green leaf blade (A) and crude protein of green stem (B) ( $\text{g kg}^{-1}$ ) in signalgrass growing under Gliricidia and Mimosa during the experimental period. Data were averaged across replications and years. Small case letters are comparing treatments within each month in Figure 3A, and capital letters are comparing evaluations in Figure 3B. In both cases, equal letters are not different by the PDIFF adjusted by Tukey ( $p > 0.05$ ). SPS = silvopasture system.

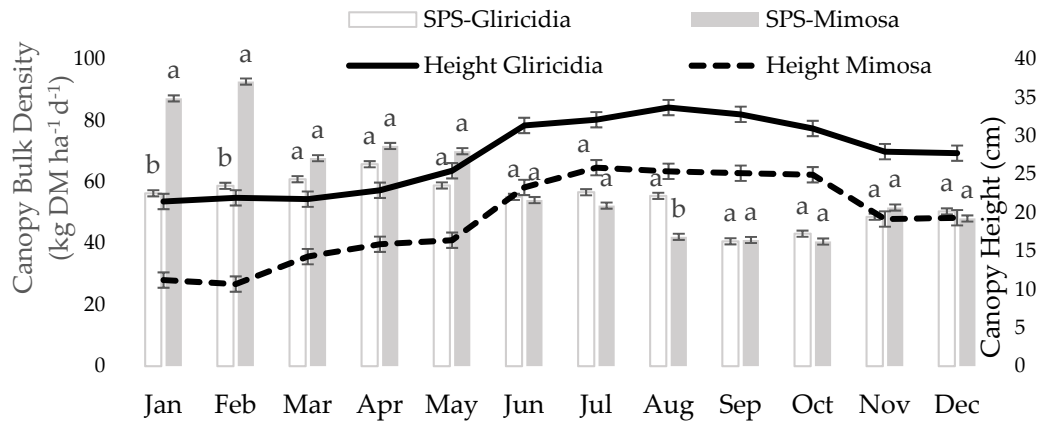


**Figure 5.** Herbage accumulation rate for Gliricidia and Mimosa during the experimental period ( $\text{SE} = 1.5 \text{ kg DM ha}^{-1} \text{ d}^{-1}$ ). Letters are comparing treatments within each evaluation month. Similar letters are not different according to PDIFF adjusted by Tukey ( $p > 0.05$ ). SPS = silvopasture system.

### 3.5. Canopy Bulk Density (CBD) and Canopy Height

There was a treatment  $\times$  evaluation interaction for CBD (Figure 6). Mimosa had greater CBD in two out of twelve evaluations, and Gliricidia had greater CBD in one out of twelve evaluations, with the remaining evaluation indicating similar CBD. Overall, the Mimosa treatment had greater canopy height (28 cm) throughout the experimental period when compared to the Gliricidia (19 cm).

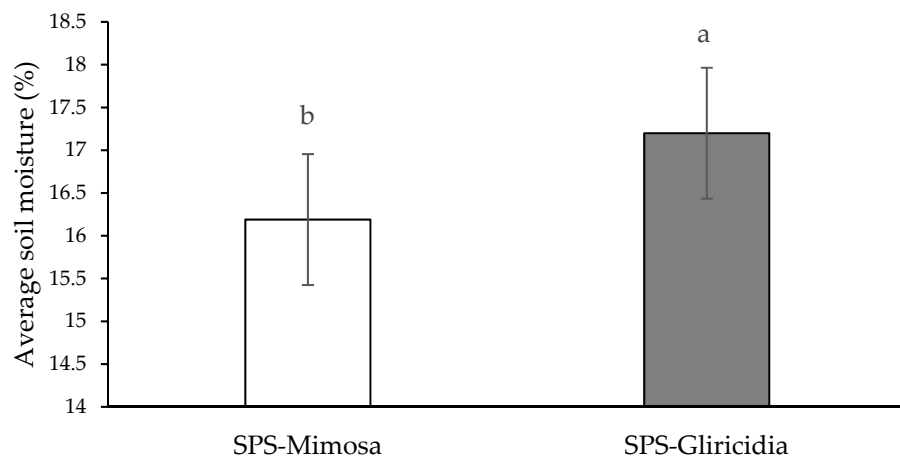




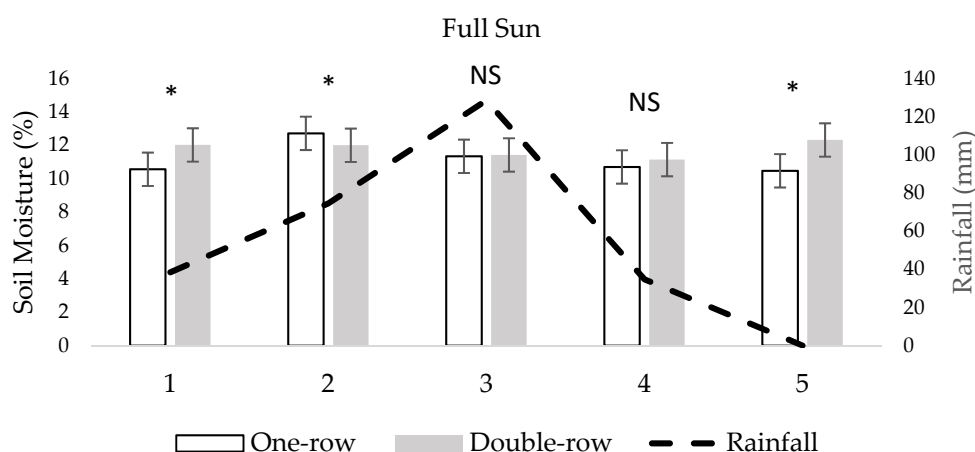
**Figure 6.** Canopy bulk density and canopy height of signalgrass growing in Gliricidia and Mimosa silvopasture systems during the experimental period. Letters are comparing treatments within each evaluation month. Similar letters are not different according to PDIFF adjusted by Tukey ( $p > 0.05$ ). SPS = silvopasture system.

### 3.6. Soil Moisture

Soil moisture was lower in Mimosa (16.2%) compared with Gliricidia (17.2%) ( $p = 0.004$ ; Figure 7). There was also an interaction for harvest management  $\times$  evaluation  $\times$  sampling point affecting soil moisture ( $p \leq 0.05$ ). There was no significant difference in soil moisture when comparing harvested and unharvested areas. However, soil moisture under the full sun was greater for the unharvested area in two evaluations and greater for the harvested area in one evaluation, with no differences found in the two other evaluations (Figure 8).



**Figure 7.** Average soil moisture in Mimosa and Gliricidia silvopasture systems. Values are averages across months, replications, collection points, and harvesting management. SPS = silvopasture system.



**Figure 8.** Soil moisture between trees and in full sun for harvested and unharvested area. Values are averages of different months, replications, collection points, and harvesting management (SE = 0.92). NS indicates that LSMEANS are not different according to PDIFF adjusted by Tukey ( $p > 0.05$ ) and \* denotes significance ( $p < 0.05$ ) using the same procedure.

#### 4. Discussion

##### 4.1. Total and Green Herbage Mass

The amount of herbage mass is the net product of plant growth, senescence, and grazing. Shade from trees might reduce the incidence of sunlight directly on the ground and decrease evapotranspiration and keep soil moisture for longer periods [23]. However, this effect was not observed in the Mimosa in this trial, as shown in previous experiments in the same area [24–26]. The Gliricidia, however, had greater total herbage mass, likely due to lesser competition from water from Gliricidia compared with Mimosa, which provides more shade and less forage under the crown.

Different species and planting densities promote variability in understory microclimate [27] and may affect pasture and livestock production. Although the drier months have greater forage mass, most of this material was not green forage. A reduction in cumulative dry mass and in herbage accumulation rate meant that the grass suffered greater interference from trees during the rainy season with *Urochloa brizantha* in a silvopasture system using *Eucalyptus grandis* × *E. urophylla* [28].

The one-row harvest management provided more space and light, which allowed greater growth of signalgrass in most evaluations. The production of most forage grasses is affected with over 40% shading [29], which was confirmed in this study by the lesser herbage accumulation under double-row treatments, compared to one-row. Although signalgrass shows phenotypic plasticity for moderate shade tolerance [30], in this trial, such mechanisms were not enough to provide the same pasture productivity under denser tree canopy. Similar outcomes were found by [31], who reported decreasing herbage accumulation rate of *Urochloa brizantha* under intense artificial shading.

Green forage mass productivity for both treatments was directly proportional to the rainfall. The same behavior was reported by [32], who reported green forage productivity of 5625 and 3701 kg DM ha<sup>-1</sup>, according to the rainiest (May) and least rainy season (November), respectively.

##### 4.2. Herbage Accumulation Rate

The herbage accumulation rate was not affected by harvesting management. Herbage accumulation was greater in the rainiest months for both treatments, with growth changing seasonally, slowing down during the dry season. The herbage accumulation rate for signalgrass growing in Mimosa followed the same behavior of previous trials.

#### 4.3. Canopy Bulk Density—CBD and Canopy Height

Greater CBD observed in the Mimosa might have occurred due to lower canopy height when compared with greater values of canopy height for Gliricidia. In general, the canopy bulk density decreases with the height of the plants in the pasture. These results corroborate reports by [33] that the CBD decreases with the increase in the average height of the *Urochloa brizantha* cv. marandu under continuous stocking.

#### 4.4. Proportions of Green (Leaf Blade and Stem) and Senescent Material (Leaf Blade and Stem)

Signalgrass growing in Gliricidia had better nutritive value than the one growing in the Mimosa, likely because of its greater proportion of green material, even in the months with lesser rainfall, indicating a better association between signalgrass and Gliricidia. Trees can increase soil quality and water retention as well as carbon content in the soil [34,35]. Ref. [36] observed that *Nothofagus antarctica*, despite not being a nitrogen-fixing tree legume, enhanced N uptake by grasses due to improved environmental conditions such as water availability, in addition to reduced competition for inorganic N between soil microorganisms and plants.

In Gliricidia, the signalgrass had taller tillers likely to support their greater weight. Furthermore, in these areas of the pasture, it was possible that there was a competition for light among tillers and, as a consequence, the stem lengthened, as a way of exposing the younger leaves in the upper part of the canopy where the light was more abundant [37]. These arguments explain the mass of the green stem in the areas where the forage was tallest.

#### 4.5. Crude Protein of Green Leaf Blade and Green Stem

Competition between trees and grasses in the Mimosa contributed to the least values of CP in signalgrass leaves and stems. Signalgrass, however, might have benefited from the N fixed by the tree legumes present in the Gliricidia, resulting in greater CP. [38] reported that more than 50% of N in companion species might derive from N-fixing legumes. Furthermore, the greater proportion of green material in the double-row management contributed to this result, because the increased shade improved forage nutritive value. The effect of moderate and dense shade on the quality and nutritive value of 22 forages, including 16 grass species, and 6 legumes, was evaluated, and the results indicated that most grass and legume forages had quality equivalent or greater when grown in silvopasture compared to monoculture [39].

#### 4.6. Soil Moisture

Soil moisture under the trees was greater than at full sun, indicating the role of tree shading to reduce losses of soil moisture. [40] evaluated a pasture system of *Piatã palisadegrass* in monoculture and a silvopasture system with Eucalyptus rows. Soil water availability until 1-m depth was greater at the inter-row than under the trees, which indicates a faster water uptake by the trees; however, when the inter-row was shaded, soil water availability was lower at the open pasture than at the inter-row. This occurred because of the shading and windbreak effects on evapotranspiration. Soil water recharge, during rainy days, was faster near the trees as a result of large water interception by trees and its subsequent deposition into the soil, increasing the amount of soil water availability at this position.

Soil physical properties in the central northern region of Piauí State, Brazil, were different between silvopasture systems using two different grass species (andropogon grass mombaça grass); however, both systems differed from the native forest [41]. The presence of trees increased ground cover, reducing runoff. Rainfall was greater in June and March, resulting in greater soil moisture during these periods. Tree might have opened macropores, increasing infiltration rate, affecting soil moisture under the canopy, in addition to the tree evapotranspiration [42].

## 5. Conclusions

Signalgrass grew faster and had better nutritive value when growing under *Gliricidia* compared with *Mimosa* silvopasture systems. Competition of *Mimosa* with signalgrass, mostly for water and light, as indicated by the soil moisture data, is the likely explanation for changes in growth and quality of the grass. Trees kept soil moisture at higher levels compared with grass strips fully exposed to sunlight. Because of lesser competition, signalgrass pastures growing under *Gliricidia* had a greater proportion of green herbage mass and greater crude protein concentration in green leaf blades when compared to signalgrass growing under *Mimosa*. The combination of faster growth and better nutritive value of signalgrass in the *Gliricidia* indicates that this system is more beneficial if livestock production is the major goal of the operation. *Mimosa* does produce other products, such as timber and firewood, which might become important sources of revenue; however, livestock production is reduced. These aspects might be considered when deciding which system to adopt.

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