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Meteorological, light and grass characteristics under trees in a Silvopasture in the Brazilian cerrado

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Abstract

Meteorological data and light information were collected during a one-year period between 2011 and 2012, under a silvopastoral system (SPS) and an open pasture (OP). The SPS was composed of adult native trees *Pterodon emarginatus* with a density of 156 trees per hectare and 30-year-old *Urochloa brizantha* (signal grass) pasture. There were seasonal variations in photosynthetically active radiation (PAR) in both systems: SPS and OP and in leaf area index (LAI) on the SPS. A resource incongruity was verified in the different seasons; whereas there was humidity and heat during summer, the amount of light transmitted under the trees was diminished by the increase in LAI and nebulosity (cloud cover). When there was more sunlight passing through the trees and there was less cloud cover, less humidity was observed and the temperature restricted the growth of tropical grass. Shade tolerance must not be the only criterion by which to choose pasture species to be integrated with trees in SPS. The grass dry matter (DM) yield was 65% less in the SPS than in the OP, with amounts of 97.4 and 149.8 g m^{-2}, respectively. This reduction in yield was similar to the reduction in PAR under the trees, 69%.

Keywords: leaf area index, photosynthetically active radiation, resource incongruity, shade, silvopastoral system, *U. brizantha*.
Abbreviations: AFS_Agroforestry System, ha_hectares, DM_dry matter, LAI_leaf area index, OP_open pasture, PAR_ photosynthetically active radiation, tPAR_total photosynthetically active radiation (over canopy), ttPAR_total photosynthetically active radiation transmitted (under canopy), SPS_silvopastoral system.

Introduction

The Brazilian Cerrado or savanna occupies 200 million ha and represents 23% of the country's area. The main climate categories are, according to the Köppen climate classification, "Aw" and "As", tropical savanna climate or tropical wet and dry climate, which have monthly mean temperature above 18°C and typically a pronounced dry season (5 to 7 months), with the driest month having precipitation less than 60 mm. The dry season occurs during the time of lower sun and shorter days, because of the reduction in or lack of convection (winter and spring). The wet season has longer days but also more cloud cover. Moura et al. (2000) observed a reduction of 28.5% in PAR on the Amazon forest floor under trees during cloudy days with high nebulosity.

Photosynthetically active radiation (PAR) is defined as radiation in the 400 to 700 nm waveband which plants use to photosynthesize. PAR is the general radiation term which covers both photon terms and energy terms (McCree, 1972). In a silvopastoral system in Sao Paulo, Brazil, the tree canopy of *Pera glabrata* withheld up to 94.2% of the luminosity, compared to open pasture of *U. decumbens* (Martins, 2001). The factors that influence this light retention are related to the type, size and leaf density and canopy. Caldas et al. (1997) described a peculiar characteristic of a legume tree species called *Pterodon emarginatus*, which is the main tree species of this experiment. These Cerrado native trees have paraheliotropic leaflet movements, which are the capacity to change the leaflets' orientation during the day, reducing the leaf area exposed to vertical radiation by as much as 40% at midday and allowing PAR to reach the under-canopy grass.

Leaf area index (LAI) is the ratio between the total leaf area and the unit of soil cover. It is considered an important parameter in ecosystem models (White et al., 2000). It is an important variable in most carbon and hydrological cycle models because of LAI influence over energy, water vapor and carbon dioxide exchange between terrestrial ecosystems and the atmosphere. LAI is also related to light availability under the canopy because of tree density and height. The position, angles and spatial relations of canopy elements affect light passage through the trees (Gower et al., 1999). Despite LAI importance as a determinant factor in ecological and biophysical processes in terrestrial ecosystems, there are few studies with LAI in savanna areas worldwide, especially in the Neotropics. In the West African humid savanna, Le Roux and Mordelet (1995) showed that seasonal variation of the canopy CO_2 assimilation rate is dependent on LAI variation.

Seasonal variations in LAI in Australian savannas has a strong contribution from deciduous and semi-deciduous eucalyptus species (O'Grady et al., 2000). In the Brazilian Cerrado, Miranda et al. (1997) described seasonal changes in LAI and demonstrated a reduction of 35% in the photosynthetic index in the ecosystem by the reduction of LAI during the dry season. Plant transpiration increased with LAI in all species studied in the Cerrado region, during the wet and dry seasons (Bucci et al., 2008). A study conducted in a dense Cerrado area to evaluate spatial heterogeneity and seasonal changes in canopy cover and their relationship with PAR under the canopy showed that plants under the canopy did not receive enough light to achieve 50% of their photosynthetic capacity during the wet season. In contrast, during the dry season, light saturation was observed in more than 50% of the researched sites that had deciduous trees. Variability in understory light was higher during the dry than the wet season, this heterogeneity being related to the spatial complexity of canopy cover (Lemos-Filho et al., 2010).

The challenge of tree association with crops and/or grass is to find the fine-tuning to determine the limit of the stress of the under-canopy species in relation to insufficient PAR, water and nutrient competition, temperature reduction affecting evapotranspiration and animal disturbance during grazing (ingestion, nutrient exportation, trampling and compaction). The shade might influence and promote changes in the grass's nutritive value, increasing protein and fiber and decreasing minerals and digestibility. This alters the grazing behavior of cattle. There are also physiological changes in the under-canopy grass, such as reduction in the root:aerial part relationship in order to adapt to less light. The plants decrease their root system in favor of the photosynthetic parts in order to survive. This can reduce recuperation capacity after grazing and may lead to pasture degradation in the SPS if the pasture management is not corrected in time.

Results and discussion

Meteorological data

During the experimental period, March 23rd, 2011 and March 26th, 2012, there was rainfall of 1,296 mm, which was 10% less than the average rainfall of the region (INMET, 2012). The average maximum temperature was 28.9°C and the average minimum was 15.3°C (Table 1). The total annual evaporation (1,432 mm) was 11% higher than the annual rainfall (1,296 mm), in the analyzed period (Apr/11 to Mar/12). Seven of the twelve months analyzed, namely May, June, July, August, September 2011 and February and March 2012, had total evaporation (942 mm) more than five times greater than rainfall (146 mm). The month with the highest evaporation rate was September (209.5 mm), with no rain. The Sucupira trees lost almost all their leaves in August and September (Lorenzi, 2002), probably as a water defense mechanism.

Solar radiation

The total photosynthetic active radiation (tPAR) above the trees varied according to the seasons ($P<0.05$). The tPAR transmitted to the pasture under the trees (ttPAR) was higher in the summer and lower in the winter ($p<0.05$), while fall and spring had intermediate values (Table 2). On the other hand, the percentage of site openness was greater during winter and lower during spring ($p<0.05$), with intermediate percentages in summer and fall. The average annual ttPAR was 69% of the tPAR, which represented an average of 31% of shade (Table 3). This shade diminished the pasture dry matter production by 35%.

The highest percentage of site openness and consequently lower shading is due to senescence and fall of leaves during the fall and winter. The *Pterodon* trees are deciduous plants, so their leaves fall in winter and sprout again during the spring (Lorenzi, 2002). However, this period was found to have a lower total amount of transmitted radiation (direct + diffuse) ($p <0.05$) below the treetops, in relation to other seasons, even with more hours of sunshine (8.5 h) low cloud cover and 11.3 hours of light per day. The regrowth of the leaves in the spring meant a lower percentage of open area and greater shading, but the light transmitted to the grass was intermediate to high, even with the lower number of hours of sunshine per day (due to more cloudiness) compared to other seasons. The summer (which began on 22/12/2011 and ended on 20/03/2012) showed the highest total amount of light transmitted compared to the other seasons, even with intermediate percentages of open and shaded areas. There were 7 hours of sunshine per day, with high cloud cover but with a greater amount of light per day. During summer there were 44 rainy days (49% of the period) with 461 mm of rainfall recorded. At that time, there was congruence of light resources, humidity and temperature. The repetition of this phenomenon would probably explain the system's survival for so many years.

Paciullo et al. (2011) also observed variation in incident light in the understory at different times of the year. The formation and maintenance of living parts of plants depend on many genetic and environmental factors. Among the environmental factors, the availability of PAR and water have great importance. In the dry season, soil moisture is a limiting factor, which hinders the formation and maintenance of living plant tissues (Souza, 2009).

Grass composition and production

The *Urochloa brizantha* pasture in the SPS had higher nitrogen (N) levels and consequently crude protein (CP) (calculated by N x 0.625) than the OP pasture ($p<0.05$), except during winter (Table 4). The crude protein content of the SPS grass was 20 and18% higher than the OP grass during the spring and summer seasons, respectively. This was also found by Sousa et al. (2010), in whose study the CP content was 22% higher in signal grass harvested 30 cm above ground in SSP with Aroeira trees (Myracrodruon urundeuva) during the summer. Paciullo et al. (2011) found CP content in *Brachiaria decumbens* grass of 9.7%, 10.7% and 14% for full sunlight, and 20% and 70% in shade, respectively. This corresponds to increases of 10% and 52% compared to full sunlight, respectively.

The grass under the SSP showed over 19% more P and 21% more S, but 11% less Ca in grass leaves, on average for all seasons ($p <0.05$). Ca is motionless in plants, so it is less accumulated. Reis (2007) also observed an increase of 57% in P in SPS when the grass was cut up to 30 cm high, but did not see differences in the Ca content in the leaves.

There was no difference ($p> 0.05$) in ADF and NDF, which was also not observed by Reis (2007) and Sousa et al. (2010) on signal grass in silvopastoral systems in the cerrado region. There was no difference ($p> 0.05$) in K, Mg and MM between systems.

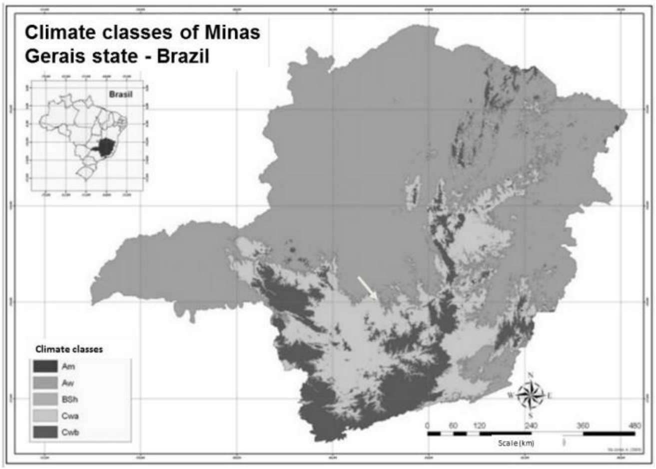

Fig 1. Climate classes of Minas Gerais state – Brazil and experimental site location. Source: Sa Junior, 2009.

On the other hand, the production of grass cut close to the ground within the 1m^3 cages located in SPS was significantly lower than in the open pasture, except for the autumn season (Table 5). The DM yields in the cages in all seasons were compared; the SPS DM production was 65% of the OP production (97.4 and 149.8 g m^{-2}, respectively). This lower SPS production can be related to the lower total photosynthetic active radiation transmitted to the under-canopy grass, which averaged 69% of the total PAR. Dias Filho (2000) observed 75% reduction in dry matter production of the aerial part of *U. brizantha* in pots under artificial shade with 70% light interception. The relative reduction in root weight was above 90%, caused by shading. Paciullo et al. (2011) found no differences in production of *Brachiaria decumbens* (*Urochloa decumbens*) cut 5 cm above ground in SPS with tree density of 105 trees ha^{-1} and 29% of shading. Pastures under shade reduce the tillering, increase elongation of leaves and stems and decrease the root:shoot relationship, which reduces regrowth capacity and forage productivity (Paciullo et al., 2011).

There was recovery of nutrients recycled by the falling leaves of the trees and the grass and their respective roots. According to Aguiar (2008), up to 165 kg of N ha^{-1}yr^{-1} can be available to the plants due to the mineralization of soil organic matter, 10 kg N ha^{-1}yr^{-1} from N-atmospheric, animal excrement, dead grass material decomposition (shoot and roots). This recycled amount of N implies a DM production potential without application of this nutrient, of approximately 9000 kg DM ha^{-1}yr^{-1} (Aguiar, 2008). The nutrient extraction by the grass under frequent cuts was lower in the SPS than in OP (Table 6) in the different seasons because the grass in the SSP had lower dry matter production due to the lower amount of photosynthetically active radiation available under trees, even with higher levels of some nutrients (N, P, S). This lower production and lower extraction probably justify this system's stabilization for over 30 years, under low stocking rate grazing under the trees.

Materials and Methods

Location

The experimental field was located at Campo Alegre Farm, Itapecerica county, in the eastern part of Minas Gerais state, Southeastern Brazil (20º18'16.71"S; 44º55'28.57" W) The altitude varies from 725 meters to 788 meters above sea level. The meteorological data was collected from the official weather station of the Instituto Nacional de Meteorologia, located near the research area (20°10'23.94"S; 44°52'29.08" W). The climate type according to Köppen classification is Cwa (humid temperate with dry winter). The average rainfall of the experimental region is 1,471 mm, and the average minimum and maximum temperatures are 15.1 and 27.9^{o}C, respectively (Somar Meteorologia, 2013) (Figure 1).

Pasture and trees

The pasture in our experiment was signal grass, *Urochloa* (Syn. *Brachiaria*) *brizantha* (Hochst ex A. Rich.) Stapf. var. Marandu, established 30 years before, in an area of 61.8 ha that had been used for grazing beef and dairy cattle. The silvopastoral system (SPS) had an area of 35.3 ha, contained indigenous trees more than thirty years of age, mostly White Sucupiras (*Pterodon emarginatus*). These deciduous trees, belonging to the *Leguminosae* family, are typical of the poor soil regions of the Cerrado. Therein, the SPS presented an irregular but dense distribution of 156 trees ha^{-1}. The OP, with an area of 26.5 ha, had a few scattered trees (less than 25 ha^{-1}), representing the common tree density for most OP farms in the region.

Experimental design

Ten random blocks were chosen inside both the SPS and OP areas. Hemispheric photographs were taken under the trees in each block in the SPS, on March 23rd, 2011, June 28th, 2011, September 23rd, 2011 and December 22nd, 2011, marking the changes between fall, winter, spring and summer in Brazil, respectively. A digital Nikon Coolpix® 5.400 camera with fisheye Nikon® FC-E9 lens was used to take the pictures under the trees, oriented to the zenith and facing north. A GPS Garmin GPSMAP 60CSx® was used to indicate the geographic north. The pictures were taken from 8 to 10:00 AM or 4 to 6 PM to avoid excess light. Those pictures were processed by the GLA 2.0 software (FRAZER, 1999). The program uses math models to compute canopy and site openness, effective leaf area index (eLAI), sunfleck frequency distribution and daily duration, and the amount of above- and below-canopy (transmitted) direct (dirPAR), diffuse (difPAR) and total (tPAR) solar radiation. The

Table 1. Meteorological data of the experimental period (April 2011 to March 2012) according to the INMET meteorological station, Divinopolis, Minas Gerais, Brazil.

Month	Rainfall mm	Rainning days	Max. Temp. (°C)	Min. Temp. (°C)	Evaporation Piché (mm)	Potential evapo-transpiration (mm)	Direct sun light (hour)	Cloud cover(1-10)	Light period (hour)	% sun light/ light period	Relative humidity (%)
Apr/11	139	9	29.6	16.4	89	78	7.6	6.0	11.5	66	72.1
May/11	8	2	27.3	12.8	91	52	7.8	4.9	11.0	71	71.6
Jun/11	22	3	26.2	10.2	91	38	8.2	3.1	10.8	76	69.5
Jul/11			27.2	10.1	125	45	7.8	3.3	10.9	71	60.4
Aug/11			30.6	12.2	198	73	9.4	2.6	11.3	83	48.7
Sep/11	1	2	30.9	13.5	210	80	8.4	4.1	11.9	71	44.0
Oct/11	171	15	28.1	17.5	125	90	6.1	8.2	12.5	49	67.9
Nov/11	142	11	28.5	17.3	121	91	7.3	7.4	13.0	56	68.6
Dez/11	451	25	28.1	19.0	75	100	4.5	8.9	13.2	34	79.3
Jan/12	248	21	29.4	18.7	80	103	6.3	8.9	13.1	48	73.8
Feb/12	38	6	31.0	18.1	123	105	8.0	6.8	12.7	63	61.2
Mar/12	78	13	30.3	18.1	105	99	7.3	7.0	12.2	60	67.6
Total/month	1,296	107	28.9	15.3	1,432	955	7.4	5.9	12.0	62	65.4

Source: Instituto Nacional de Meteorologia (INMET 2013).

Table 2. Photosynthetic active radiation, above the canopy direct (PAR_{dir}), above diffuse (PAR_{dif}), above total (PARt), transmitted under the canopy direct ($PARt_{dir}$), transmitted diffuse ($PARt_{dif}$), transmitted total ($PARt_t$), effective leaf area index integrated over the zenith angles 0 to 60° (LAI_4) and 0 to 75° (LAI_5), at different seasons, determined by the GLA program in the analysis of hemispheric pictures. Fazenda Campo Alegre, Itapecerica - MG, Brazil.

Variável	Fall			Winter			Spring			Summer		
PAR_{dir}	20.26b	±	1.2	13.72d	±	0.7	20.08c	±	1.4	24.33ª	±	1.4
PAR_{dif}	20.26b	±	1.2	13.72d	±	0.7	20.08c	±	1.4	24.33ª	±	1.4
PARt	40.52b	±	2.5	27.43d	±	2.6	40.17c	±	5.7	48.66ª	±	2.7
$PARt_{dir}$	15.34b	±	3.3	9.90b	±	1.9	14.95b	±	3.5	18.30ª	±	4.0
$PARt_{dif}$	13.34b	±	2.5	9.80b	±	1.4	12.36b	±	2.7	15.66ª	±	3.8
$PARt_t$	28.69b	±	5.5	19.70c	±	2.6	27.31b	±	6.1	33.96ª	±	7.1
LAI_4	0.54ab	±	0.3	0.46b	±	0.2	0.66a	±	0.3	0.59ab	±	0.3
LAI_5	0.54b	±	0.2	0.41c	±	0.1	0.66a	±	0.3	0.54b	±	0.2

The units for the photosynthetic active radiation (PAR) are mol m^{-2} day^{-1}.

Medians in the lines, followed by the same lowercase letters, are equivalent by Tukey test ($p<0.05$).

Table 3. Total photosynthetic active radiation above and trasmitted under canopy, luminosity and nebulosity, at different seasons, determined by the GLA program in the analysis of hemispheric pictures. Fazenda Campo Alegre, Itapecerica - MG, Brazil.

Season	Site openness %	LAI	tPAR Mol m^2 d^{-1}	ttPAR Mol m^2 d^{-1}	%	Shade %	Direct sun light hours day^{-1}	Light period hours day^{-1}	% sun light / light period	Cloud cover (1-10)
Winter	63a	0.46	27d	20c	72	28	8.5	11.3	76	3.1
Spring	47b	0.66	40c	27ab	68	32	6.4	12.8	50	7.8
Summer	53ab	0.59	49a	34a	70	30	7.0	12.8	55	8.7
Fall	52ab	0.61	41b	26bc	67	33	6.8	11.3	60	5.9
Avg.	54	0.58	39	27	69	31	7.2	12.0	60	6.2

Medians in the columns, followed by the same lowercase letters, are equivalent by Tukey test (p<0.05).

Table 4. Bromatological analyzes of signal grass (U. brizantha) in the SPS and OP during 2011 seasons – Fazenda Campo Alegre – Itapecerica MG.

Nutrient	N g kg^{-1}		PB g kg^{-1}		P g kg^{-1}		K g kg^{-1}		Ca g kg^{-1}		Mg g kg^{-1}		S g kg^{-1}		MM g kg^{-1}		ADF%		NDF%	
Season	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP
Fall	18.3Ba	16.2bB	11.4bA	10.1bB	1.7	1.4	21.5	23.9	4.9	5.6	3.1	3.2	1.1	0.9	51.3	51.3	32.3	32.9	63.7	61.8
Winter	17.8bA	17.1bA	11.1bA	10.7bA	1.3	1.2	17.4	18.6	5.0	6	2.7	2.8	1	0.9	45.2	46.5	35.9	36	66.7	61.4
Spring	24.6aA	20.5aB	15.4aA	12.8aB	1.4	1.1	26.3	25.2	4.7	5.1	2.4	2.4	0.9	0.7	60.4	54.9	31.3	32.8	59.4	57.3
Summer	17.6bA	14.9bB	11.0bA	9.3bB	1.2	1	15.8	17.7	5.1	5.5	2.9	2.9	0.9	0.7	43.6	42.7	35.2	34.6	62.6	60.7
Annual	-	-	-	-	1.4A	1.2B	20.3	21.3	4.9B	5.5A	2.8	2.8	1.0A	0.8B	50.1	48.8	33.7	34.1	63.1	60.3

Different lowercase letters between lines and capital letters among columns, are different (p<0.05 Tukey test)

Table 5. Dry matter (DM) levels of signal grass (U. brizantha) under SPS and OP during different seasons of 2011 – Fazenda Campo Alegre – Itapecerica MG Brazil.

DM (%)				DM g $(m^2)^{-1}$	
Season	SPS	OP	General	SPS	OP
Fall	26.9	27.3	27.1b	42.5aA	28.6bA
Winter	31.3	26.9	29.1b	13.3bA	30.8bA
Spring	26.6	27.9	27.3b	16.1bB	39.2abA
Summer	32.0	31.9	31.9a	25.5abB	51.1aA
				97.4	149.8

Different lowercase letters between columns and capital letters among lines, are different (p<0.05 Tukey test)

Table 6. Extrated nutrients by the leaves of frequent cut grass above ground in SPS and OP at the four 2011 seasons. Fazenda Campo Alegre, Itapecerica MG - Brazil

	N		P		K		Ca		Mg		S	
	Kg ha^{-1}											
Season	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP	SPS	OP
Fall	7.8	4.6	0.7	0.4	9.1	6.8	2.1	1.6	1.3	0.9	0.5	0.3
Winter	2.4	5.3	0.2	0.4	2.3	5.7	0.7	1.8	0.4	0.9	0.1	0.3
Spring	4	8	0.2	0.4	4.2	9.9	0.8	2	0.4	0.9	0.1	0.3
Summer	4.5	7.6	0.3	0.5	4	9	1.3	2.8	0.7	1.5	0.2	0.4
Annual	18.6	25.6	1.4	1.7	19.7	31.5	4.8	8.2	2.8	4.2	1	1.2
Average	4.7	6.4	0.4	0.4	4.9	7.9	1.2	2.1	0.7	1.1	0.2	0.3

effective LAI was calculated at ring 4 (which correspond to 0-60° of the zenith).

At each block, ten in SPS and ten in OP, a $1m^3$ wire cage was fixed over the pasture to prevent grazing. The grass under the cages was cut at ground level. Cuts were made at 30-day intervals during summer and fall and 50-day intervals during winter and spring.

Laboratory analysis

The grass samples were weighed and frozen, then dried in a forced air circulation oven at 60ºC until constant weight. The samples were ground to 0.5 mm and sent for mineral and bromatological analysis at the Universidade Federal de Uberlândia.

The bromatological composition, i.e. crude protein (CP) and acid detergent fiber (FDA), were taken by sequential method (Van Soest, 1991). The leaf mineral composition, N, P, K, Ca, Mg, S and mineral matter (MM) were analyzed in the soil laboratory of the Federal University of Uberlândia, using the permanganometry techniques, colorimetry and flame photometry.

Nutrient extraction model

The extraction of nutrients was calculated using the formula: Nut_{ext} MS = 0.0001 DM x NC (Primavesi et al., 2004), where: Nut_{ext} = nutrient extracted in kg ha^{-1}; DM = dry matter in kg ha^{-1}; NC = nutrient content in the leaf in g kg^{-1}.

Statistical analysis

The evaluated responses were analyzed by SAS, submitted to Lilliefors and Bartlett tests to check normal probability distribution and homoscedasticity, respectively. Data were analyzed in a completely randomized design. The 2x4 factorial (two systems in the plot and four seasons in the split plot) defined the split-plot design, with ten repeated measures. The Tukey test was used for comparing averages, assuming error rate $\alpha = 0.05$. More than one grass cut during a season was considered sample replicates of that season.

Conclusion

Meteorological studies are important tools for better understanding the complexity of natural processes that occur in integrated systems, such as agroforestry, in competition for resources: light, humidity, temperature. The seasons affect the leaf area index and photosynthetic active radiation above and below the canopy. There is a resource incongruity between the seasons: when there is moisture and heat in the summer, the amount of direct light undergoes effects of higher LAI from the tree cover and when the number of sunshine hours is greater, there is a lack of moisture and a lower temperature. This incongruence may be aggravated in agroforestry, and careful planning and execution must take place in the deployment of these systems. The shade tolerance criterion of forages chosen for a silvopastoral system should not be considered alone when planning the AFS. The photosynthetically active radiation transmitted down the trees was on average 69% of the total PAR throughout the year. This represented 65% of the grass dry matter yield, compared to the open area pasture. The lower production under the trees led to less nutrient extraction. The SPS pasture had higher levels of crude protein, phosphorus and sulfur, but a lower level of calcium in the grass leaves.

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