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Forage yield, rate of CO_2 assimilation, and quality of temperate annual forage species grown under artificial shading conditions

Produção de forragem, taxa de assimilação de CO_2 e qualidade de espécies forrageiras hibernais cultivadas sob níveis de sombreamento artificial

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ABSTRACT

*In this study, it was evaluated the effect of shade on forage yield, rate of CO_2 assimilation, and the quality of annual ryegrass (**Lolium multiflorum** L.) cv. 'BRS Ponteio' and black oat (**Avena strigosa** Schreb) cv. 'IAPAR 61', grown under three shading conditions (0%, 25%, and 50% shade) using slatted wooden structures. The experimental design was completely randomized with four replications. Slatted structures were efficient in simulating the proposed shading conditions. Shading plants significantly decreased forage yield and CO_2 assimilation by both species. Ryegrass cv. 'BRS Ponteio' performed better under shade, with higher forage production under all shading conditions. Rate of CO_2 assimilation was reduced by 13 and 22 percentage points compared to the same species grown in the open field (0% shade), under 25% and 50% shade, respectively. These shading conditions did not affect crude protein (CP) content, neutral detergent fiber (NDF) concentration, or the leaf:stem (L:S) ratio compared to those grown in the open field. Between the species evaluated, ryegrass had the greatest potential for use as forage in a silvopastoral system.*

Key words: *grass, light restriction, photosynthesis, silvopastoral system.*

RESUMO

*O estudo objetivou avaliar o efeito do sombreamento sobre a produção de forragem, a taxa de assimilação de CO_2 e qualidade de azevém (**Lolium multiflorum** L.) cv. 'BRS Ponteio' e aveia preta (**Avena strigosa** Schreb), cv. 'IAPAR 61', cultivadas sob três níveis de sombreamento artificial (0, 25 e 50%), obtidos por meio de estruturas de ripado de madeira. O delineamento experimental foi inteiramente casualizado, com quatro repetições. As estruturas de ripado simularam eficientemente os níveis de sombreamento propostos. O sombreamento diminuiu significativamente a produção de forragem e a taxa de assimilação de CO_2 de ambas as espécies testadas. O azevém foi mais tolerante ao sombreamento, com maior produção de forragem em todos os níveis de sombreamento testados. O valor da taxa de assimilação de CO_2 foi reduzido em 13 e 22 pontos percentuais em relação ao céu aberto, nos níveis de 25% e 50% de sombreamento, respectivamente. Em comparação a pleno sol, os níveis de sombreamento não afetaram os teores de proteína bruta (PB), fibra em detergente neutro (FDN) e relação lâmina:colmo. Entre as espécies avaliadas, o azevém foi considerado a espécie com maior potencial em um sistema silvipastoril.*

Palavras-chave: *fotossíntese, gramínea, restrição luminosa, silvipastoralismo.*

INTRODUCTION

Silvopastoral systems simultaneously integrate the cultivation of trees and forage for ruminant production within the same area. These integrated production systems optimize resource use and alleviate market risk in a sustainable way. However, the main limitation of silvopastoral systems is the light constraint, which limits the growth potential of forage species growing under trees. Therefore, to make these systems feasible, it is necessary to conduct a study of the behavior of forage species grown under reduced light conditions, to select species tolerant to this adverse condition. Tolerance, according to KIRCHNER et al. (2010), is the ability of a forage species to have a minimal decrease in forage production in shaded environments, relative to what would have been produced under full sunlight.

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In Brazil, most studies on the shade tolerance of forage species are conducted with tropical species. However, in temperate regions, there is a demand for parameters of cool-season (i.e., temperate) species in silvopastoral systems, such as oats and ryegrasses, which are commonly grown by farmers. In addition, less sunlight and lower temperatures during winter months may produce different results from studies conducted in tropical climates with C4 species.

Photon energy is the only energy source used by plants, and the level of irradiance can affect their growth and development (MARCHESE et al., 2008). Thus, the growth rate of fodder is rapidly restricted due to the limited light energy required for photosynthetic processes. Light restriction also promotes abnormal conditions and stresses the cultivation of fodder. However, forage adapts to new environmental conditions, resulting in morphological, histological, and biochemical changes (GOBBI et al., 2011). Thus, each species has different ways of adapting to and tolerating shading.

The objective of this study was to evaluate the effect of three artificial shading conditions on the physiological response, production and nutritional quality of two annual winter forage species, black oat (***Avena strigosa*** Schreb) cv. 'IAPAR 61' and ryegrass (***Lolium multiflorum*** L.) cv. 'BRS Ponteio', grown in a subtropical Paranaense environment of southwestern Brazil.

MATERIALS AND METHODS

The experiment was conducted from May 19 to September 13, 2011, in an experimental field of the Agronomy Department at the Federal Technological University of Paraná, Pato Branco Campus (26° 10'S, 52° 41'W; altitude: 767m). The site lies in a transition area between Cfa and Cfb climate types, according to Köppen classification (MAACK, 1968). Precipitation during the experimental period was 873mm, and the average maximum and minimum temperatures were 21.5 and 10.8°C, respectively.

Soil in the experimental area was classified as dystrophic RED LATOSOL clay (EMBRAPA, 2006). A chemical analysis, at a depth of 0-15cm, obtained the following values: $pHCaCl_2$=5.1; P=3.46mg dm^{-3}; K=0.65$cmol_c dm^{-3}$; O.M.=dm 46.91g^{-3}; Al^3=0.00$cmol_c dm^{-3}$; Ca=4.93$cmol_c dm^{-3}$; Mg=3.21$cmol_c dm^{-3}$; and V=60.41%. The experimental field was fertilized at a rate of 60kg ha^{-1} with P_2O_5, and then top-dressed with two applications of urea (100kg N ha^{-1}) 30 and 60 days after sowing.

Experimental treatments consisted of three artificial shade conditions (0%, 25%, and 50%) and two temperate forage species: 'BRS Ponteio' ryegrass and 'IAPAR 61' black oat. The experimental design was completely randomized in a 3 × 2 factorial scheme (levels of artificial shade × cool-season forage species) replicated four times.

Oat and ryegrass seeds were sown on May 19, 2011, in a no-till system on flat land with line spacing of 0.17m in 6.25m² plots and sowing densities of 60 and 35kg ha^{-1}, respectively. Shade was provided by slatted wooden structures. Each slat was 2.5m long, 0.15m wide, and 0.02m thick. To simulate 25% and 50% shading, slats were spaced 0.45m and 0.15m apart, respectively.

The wooden structures were placed in the field in a north-south direction, perpendicular to the forage sowing lines (east-west), after sowing. Each structure was square with sides measuring 2.5m and was composed of transversely mounted boards covering a graduated wooden stand, such that the slats were always 0.3m above the top of the canopy. During the experimental period the slats were raised relative to increases in plant height, following the methodology described by VARELLA et al. (2010).

Light intercepted by the plant canopy in each plot was assessed with a ceptometer (Sunfleck Ceptometer; Decagon Devices, Pullman, Washington, USA). In each plot, two readings were taken at 12:00 hours on clear days, to assess how much photosynthetically active radiation (PAR) each slatted structure was blocking at the time of maximum PAR incidence (VARELLA et al., 2010; PERI et al., 2002). PAR readings were made both above and below each shaded structure. The ceptometer bar was 81cm long and 1.5cm wide, and was positioned in the east-west direction, below and perpendicular to the slatted structure. The average PAR between sun and shade intercepted by the structures was assessed. The percentage of light intercepted by the structure in each plot was calculated as the amount of PAR intercepted using the following equation: PAR (%) = [(PAR above slats - PAR below slats) ÷ PAR above slats] × 100.

Forage production values were obtained by cutting one sample per plot, in an area of 0.25m^2, from the center of each experimental unit. Subsequently, the plots were made uniform by mowing to the same height as the sample cuts. The height of the cut simulated cattle grazing at 10cm and 7cm from the soil, for black oat and ryegrass, respectively. The cut plant material was dried for 72 hours in a forced ventilation oven at 55°C and weighed, and the values were expressed in kg of DM ha^{-1}. Four cuts were made when the average sward canopy height reached 30cm for black oats and 25cm for ryegrass, according to recommendations cited by MORAES & LANG (2006). Total forage production (kg DM ha^{-1}) values were obtained by adding the weight of all cuts.

To determine the CO_2 assimilation rate, we used an open system for measuring gas exchange equipped with an infrared gas analyzer (IRGA) model LI-6400XT (LI-COR, Lincoln, Nebraska, USA) containing an artificial source of red/blue light and a CO_2 injection system. Evaluations were conducted at 10:00 hours on the youngest fully developed, healthy leaf from two plants per plot in vegetative tillers. The microclimatic conditions in the sample analysis chamber were: a) CO_2concentration held at 380μmol CO_2 mol^{-1}; b) PAR was provided by an artificial red/blue light source coupled with IRGA, and values were defined according to preliminary readings taken in the field using a ceptometer (SunfleckCeptometer; Decagon Devices, Pullman, Washington, USA) in order to assess plants under natural environmental conditions.

The leaf:stem ratio (L:S) was obtained from a sample cut from an area of 40 × 17cm. The L:S evaluation was carried out during the same period as forage production was collected for analysis, as well as the respective height cuts for each species. Cut plant material, after its components were separated (i.e., leaf from stem), dried for 72 hours in a forced ventilation oven at 55°C and weighed on a precision balance. The value of leaf blade and stem mass of all cuts was added, and the ratio between these values resulted in the L:S values.

The same forage samples that were used to determine forage production were ground in a Wiley mill and analyzed for crude protein (CP) and neutral detergent fiber (NDF) contents using the near infrared reflectance spectroscopy (NIRS) method.

Data were subjected to analysis of variance (ANOVA) and significant differences ($P<0.05$) between means were compared by the Tukey test with a 5% error probability.

RESULTS AND DISCUSSION

Values for the true percentage of PAR blocked by the slatted structures at 12:00 hours indicated that the structures were effective in simulating the shading conditions proposed in this research. Above the slats, the PAR was 1,335μmol m^{-2} s^{-1}, whereas below the slats (i.e., above the canopy) the PAR were 978 and 644μmol m^{-2} s^{-1} at 25% and 50% shading, respectively (i.e., in reality, the slats intercepted 26.7 and 51.8% of the incident PAR).

According to the ANOVA, there was no significant interaction between plant species and shading condition ($P=0.3034$) for forage production; however, there were differences between plant species and between shading conditions (Table 1).

Shading decreased forage production by each forage species at 25% shading, average forage yield per hectare between plant species was 72%, and at 50% shading, the production was 48% compared with plants exposed to direct sunlight. Among plant species, ryegrass was more productive (4,242kg DM ha^{-1}) and was more tolerant to low light (Table 1).

Considering that in integrated crop-livestock systems with no-till, a residue of 2000kg DM $ha^{-1}$is necessary for nutrient cycling and system maintenance (ASSMANN et al., 2003), ryegrass could be produced for animal consumption, in addition to the mass required for cycling, which was approximately 992kg DM ha^{-1} under the 50% shading condition. Conversely, black oat was not very tolerant to the 50% shading condition, and produced less than what is required to maintain the no-till system (Table 1).

Ryegrass also showed higher production under all shading conditions. By contrast, black oat

Table 1 - Forage production of two annual winter forage species subjected to three artificial shading conditions.

Species	---Shading (%)---			Mean
	0	25	50	
	---Forage production (kg DM ha^{-1})---			
Black Oat	3,443 (100%)[2]	2,427 (70%)	1,324 (38%)	2,398 b[1]
Ryegrass	5,602 (100%)	4,132 (74%)	2,992 (53%)	4,242 a
Overall Mean	4,523 A (100%)	3,280 B (72%)	2,158 C (48%)	

[1]Means followed by different letters, uppercase (rows) and lowercase (columns), were significantly different (Tukey test at 5% probability).
[2]Figures in parentheses: percent relative performance.

was sensitive to light restriction (50% shading), producing only 38% of what is normally produced in direct sunlight.

Regarding the CO_2 assimilation rate, there was a significant interaction between plant species and shading condition (P=0.01). As shade increased, there was a significant reduction of CO_2 uptake by each forage species (Table 2). Under 25% and 50% shade, the average of the two species was reduced by 13% and 22%, respectively, when compared to plants grown in direct sunlight (i.e., 0% shading).

There were no significant differences (P=0.14) between plant species; both are temperate forage from the same family (***Poaceae***) and share the same photosynthetic pathway (C_3) with similar photosynthetic responses.

By comparing the results for the rate of CO_2 assimilation (i.e., photosynthetic rate) and forage production (Tables 1 and 2), it was observed that these variables did not decrease by the same proportion as shading increased. This may be explained by other morphological features that influenced the quantity and quality of forage, as reported by GARCEZ NETO et al. (2010), who also reported no significant changes in the morphology of perennial ryegrass, ***Dactylis***, and red clover following the reduction of the incident radiation caused by shading. Any changes in area, length, thickness, and orientation of the leaf blade, number of leaves, and/or the L:S ratio interferes with light interception by the sward canopy, which can change the photosynthetic area and, consequently, production.

Furthermore, PERI et al. (2002) evaluated the effect of irradiance fluctuations (from 0% to 100% shade), occurred in a silvopastoral system on the net photosynthetic rate of ***Dactylis glomerata***, explaining that when the plant goes through a shift from high to low irradiance, there is photosynthetic deactivation due to a reduction in stomatal conductance and the deactivation of enzymes. When the plant returns to high irradiance, there again is a delay to achieve the maximum photosynthetic rate. In this context, it is clear that the photosynthetic rate of leaves is impaired when the plant is shaded, but when irradiance levels increase the plant can recover and increase its photosynthetic rate. In addition, depending on light intensity and the time spent under shade, the photosynthetic rate does not appear to be greatly impaired by fluctuations in irradiance. However, according to these authors, plants shaded for longer durations require more time and will achieve lower levels of the maximum photosynthetic rate, resulting in an overall decrease in carbon gain throughout the day, and, consequently, a reduction in forage accumulation, directly affecting production when grown under shade in silvopastoral systems.

The differences in findings between species for forage production and the CO_2 assimilation rate can also be explained by morphological and structural changes in the vegetation as an adaptation to shading (GOBBI et al., 2011). There was a significant difference in forage production between plant species (Table 1); however, there was no significant difference in the CO_2 assimilation rate (Table 2). It is possible that ryegrass has better morphological and structural features in comparison to oats, such as a greater leaf area index, which favors its production, and according to LEMAIRE & CHAPMAN (1996), this is determined by the final length of the leaf, density of the tillers, and the number of live leaves per tiller.

There was no effect (P>0.05) of shading on crude protein (CP) and neutral detergent fiber (NDF) content, or L:S ratio on the forage species studied (Table 3). For CP and NDF, there were no statistical differences between species (P<0.001). Oat contained a higher content of CP and a lower content of NDF compared to ryegrass. Regarding the L:S ratio, there was no statistical difference between the species studied.

Table 2 - CO_2 assimilation rate (photosynthetic rate) of two annual winter forage species subjected to three artificial shading conditions.

Species	---Shading (%)---			Mean
	0	25	50	
	---CO_2 assimilation rate ($\mu mol_2\ m^{-2}\ s^{-1}$)---			
Black Oat	22.17 aA[1] (100%)[2]	19.50 aAB (88%)	17.39 aB (78%)	19.69
Ryegrass	20.77 aA (100%)	18.09 aAB (87%)	16.17 aB (78%)	18.34
Overall Mean	21.47 (100%)	18.79 (87%)	16.78 (78%)	

[1]Means followed by different letters, uppercase (rows) and lowercase (columns),were significantly different (Tukey test at 5% probability).
[2]Figures in parentheses: percent relative performance.

Table 3 - Crude protein, neutral detergent fiber content, and leaf:stem ratio of two annual winter forage species subjected to three artificial shading conditions.

Species	Shading (%)			Mean
	0	25	50	
	Crude protein (% DM)			
Black Oat	28.9	29	30.2	29.4 a[1]
Ryegrass	22.8	23.4	23.1	23.1 b
Overall Mean	25.9 A	26.2 A	26.7 A	
	Neutral detergent fiber (% DM)			
Black Oat	37.4	37.1	36.9	37.2 b
Ryegrass	40.9	41.3	41.2	41.2 a
Overall Mean	39.2 A	39.2 A	39.1 A	
	Leaf:stem ratio[2]			
Black Oat	2.9	3.5	3.1	3.2
Ryegrass	2.9	3.4	3.4	3.2
Overall Mean	2.9	3.4	3.3	

[1]Means followed by different letters, uppercase (rows) and lowercase (columns), were significantly different (Tukey test at 5% probability).
[2]The mean comparison test was not applied because the F test detected no significant difference between the factors.

The results of our study do not concurred with those obtained by KIRCHNER et al. (2010), who observed higher levels of CP and NDF in shaded treatments for oat and ryegrass. We suggested that this increase in CP is due to a higher L:S ratio that took place in shade, because the L:S ratio is an important structural indicator of forage, since a higher proportion of leaves indicates a higher nutritional value of the pasture. However, SOUSA et al. (2007) ported no differences in the L:S ratio of ***Brachiaria brizantha*** cultivated in a silvopastoral system exposed to full sun, and they further explained that reduced light intensity resulted in taller plants with longer stems to compensate for lower light intensity.

BARRO et al. (2008) evaluated differences in responses between two years in Rio Grande do Sul, Brazil. In 2005, they reported no significant difference in CP content between shading conditions in a cultivation system of ryegrass, white oat, and black oat grown amongst ***Pinus elliottii***. In 2006, under lightly shaded conditions, these forage species contained a higher CP content (9.9%) relative to the protein content of plants exposed to full sun (8.9%). Therefore, variations and minor differences are acceptable, because the research was conducted in situations differing in ecosystem, time, plant genetics, soil and climate conditions.

Regarding the NDF content, SOUSA et al. (2007) studied the effect of shading on the production of ***Brachiaria brizantha*** and also reported no significant differences in the NDF content between plants grown under shade or no shade. However, PACIULLO et al. (2007) reported that fodder presented a trend of lower NDF percentages and increased digestibility *in vitro* when shaded.

Our results for the L:S ratio confirm those obtained by GOBBI et al. (2009), who studied ***Brachiaria decumbens*** at 0%, 50%, and 70% shading and concluded that there was no effect from shading on the L:S ratio. For the same variable, KIRCHNER et al. (2010) also reported no difference between light levels for oat; however, ryegrass had the highest proportion of leaves when grown in the shade.

The results of this study indicate that for black oat and ryegrass grown in silvopastoral systems, management should be conservative; grazing should be moderate, compared with the management practices adopted for crops grown in full sun. VARELLA et al. (2009) recommended the same conservative practice, because when plants are cultivated in the shade, the force of regrowth is less than what is observed in full sun, due to a reduced rate of photosynthesis.

CONCLUSION

Shading reduces the rate of CO_2 assimilation in plants, and, consequently, the production of fodder. However, between black oat and ryegrass, ryegrass is more tolerant to shading, producing more forage under all shading conditions studied in this research. For this reason, ryegrass has greater potential for use as forage in silvopastoral systems.

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