Interactive tree and N supply effect on six C_4 forage grasses productivity

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Introduction

Silvopasture is a type of agroforestry that intentionally combines trees, forage crops, and livestock into a structural system of planned interactions (Perry *et al*., 2009). They appear as available options to change the land use and to reach economic, social and environmental sustainability (*e.g.* greater return on land investment, carbon storage, productivity, etc), particularly in pastoral tropical/sub-tropical regions. However, the challenge is to optimize silvopastoral outputs through the selection of trees and forage species as well as through fertilization inputs, in order to reach an adequate management. It might be supposed that forage species growing under tree canopies would respond differently to fertilization inputs as a consequence of the differences in their ecology and, particularly, due to the effect of trees on the soil (*e.g.* lower bulk density, higher water holding capacity and nutrient content, Wilson, 1996). The aim of our study was to determine both the shading (due to a five-year-old plantation of *Eucalyptus dunnii*) and nutrient availability (*i.e.* nitrogen supply) effects on above-ground dry matter yield of six C_4 forage grasses species in a sub-tropical region. Under full sun, rotational stocking using 95% canopy light interception (LI) as a criterion of utilization frequency has been recommended to use C_4 species to their fullest potential and optimize ruminant weight gains on pasture (Silva and Carvalho, 2003). Therefore, in order to secure proper management practices, we adopted the criterion of 95% of LI as a cutting frequency. Furthermore, the residual forage material in this experiment was kept at 50% of canopy height at 95% LI, since low cutting intensity favors forage harvesting with a high nutritive value. We simulated rotational defoliation by mechanical cutting in order to easily compare several species and control the extent of the plant parts removed.

Materials and methods

The study was based on six perennial C_4 grasses (*Axonopus catharinensis* (Ac), *Cynodon spp.* hybrid Tifton 85 (Cs), *Hemarthria altissima* cv. Florida (Ha), *Megathirsus maximus* cv. Aruana (Mm), *Paspalum notatum* cv. Pensacola (Pn) and *Urochloa brizantha* cv. Marandu (Ub)) that are widely used in Brazilian livestock, and also have been recommended (*e.g.* Soares *et al*., 2009) for using on silvopastoral systems (SS). The experimental site was located at the Agronomic Institute of Paraná, Ponta Grossa-PR (25°07'22''S, 50°03'01''W). The species were planted in pure stands in 2010 (4.5 m² in unshaded *vs.* 100 m² in a shaded area with 155 trees of *Eucalyptus dunnii* ha^{-1}). Trees were planted in 2007 according to a double row arrangement using 3m between plants within rows and 4 m between rows, spaced 20 m apart (3x4x20 m). Treatments were arranged in a split-split plot experimental design, with three replicates. Shaded (*i.e.* an emulated SS) *vs.* unshaded conditions were the main plots, species were the subplots and two contrasting N levels (zero and 300 kg N $ha^{-1}year^{-1}$, N0 and N300, respectively) were assigned to sub-subplots. Plots were cut when the LI of swards were 95%. At this moment, the sward height was measured (10 measures per plot using a sward stick), and 50% of this height was harvested. Dry matter yield (DMY, above cutting height) was evaluated from representative samples (dried at 60°C for 48h and weighed), from spring

2011 until the first frost in July 2012. During this period, the total DMY of each plot was calculated as the sum of the cuts performed. N was applied on October, 13th, 2011. Phosphorus and potassium were applied according soil analysis. LI was monitored regularly with a ceptometer (Decagon LP-80 AccuPAR) placed at ground level and above the grass canopy. Shading percentage was measured using photosynthetic activated radiation sensors (PAR bars containing a series of five amorphous silicon cells) installed between ranks of trees (2,4,10,16 and 18 m), at 1 m above soil level. Mean shading percentage was calculated as 100 minus the difference between sensors in both systems. The results of DMY and number of cuts for each plot were subjected to Analysis of Variance (ANOVA) using the PROC MIXED feature of SAS (Statistical Analysis System, version 9.2.).

Results and discussion

During the experimental period, the mean percentage of light reduction recorded under the trees compared to unshaded condition was 34 ± 8.57%. Outputs of the analysis of variance for DMY are shown in Table 1. Only significant interactions for at least one variable are presented. *P. notatum* had the lowest DMY (4.2 ± 0.66 t ha^{-1} in 2.2 ± 0.24 cuts), while the other species displayed a similar DMY (9.8 ± 0.47 t ha^{-1} in 5.3 ± 0.24 cuts). The DMY was higher in unshaded condition (10.5 ± 0.63 t ha^{-1} in 5.2 ± 0.32 cuts) than under shaded condition (7.1 ± 0.60 t ha^{-1} in 4.3 ± 0.37 cuts). A decrease in DMY at shaded compared to unshaded condition ranged from 7% (*H. altissima*) to 56% (*P. notatum*). The highest decrease on productivity of *P. notatum* could point out the low potential of this species to grow in SS. On the other hand, despite a large decline on DMY of *Cynodon spp.* under shaded condition (-47%), this species remained with a high potential yield (*e.g.* 9.7 ± 0.96 t ha^{-1} in N300) when comparing to the others species studied (Figure 1). An increase of 3.8 t ha^{-1} (+2.1 cuts) in DMY was observed at N300 compared to N0. Interesting enough, on average the N effect was slightly higher than the shading effect. The increase on DMY with N supply (N300 *vs.* N0) ranged between 0.35 and 6.42 t ha^{-1} for *H. altissima* and *Cynodon spp.*, respectively.

Table 1. *F*-ratios and statistical significance of ANOVAs for dry matter productivity (DMY) and cutting number (CN).

		DMY		CN	
Source of variation	DF	*F*	*P*	*F*	*P*
Light condition (LC)	1	77	***	15	***
Species	5	17	***	31	***
LC*Species	5	3.40	*	1.74	NS
N	1	63	***	99	***
Species*N	5	3.78	*	6.51	***
LC*Species*N	5	3.62	*	1.86	NS

*, *P* < 0.05; ***, *P* < 0.001; DF, degree of freedom; NS, not significant.

The second order interaction between light condition (shaded *vs.* unshaded), species and N supply was significant for DMY (Figure 1). Therefore, the response to N levels within each system is species-specific. For *M. maximus*, *A. catharinensis* and *Cynodon spp.* the highest impact of N supply was on unshaded systems, and the opposite was observed for *U. brizantha* (Figure 1), which is well known as a shade tolerant species with high potential to be used on SS (Soares *et al*., 2009). However, it seems that when light becomes a limiting resource, the lack of N supply reduces the ability of plants to simultaneously compete for light, magnifying the negative effect of shading. Overall, tolerance to simultaneous stresses is still poorly understood, despite the ubiquitous coexistence of multiple stresses in nature (Valadares and Niinemets, 2008). Therefore, this discussion highlights the importance of gaining more conclusive insight into the species-dependent response to interactive light and nutrient availability gradients. As a perspective, studies on species-specific variations in plasticity may make possible a better understanding on species performance along light gradients with contrasting nutrient availability. Further, for instance, no significant differences between N levels were observed for *H. altissima* on both systems. Since basic information about the impact of management practices in shaded environments is limited, we therefore hypothesize that using 95% of LI as a tool to determine cutting frequency can limit the responsiveness of some C_4 forage grass species to N supply. Then, a research effort is needed to fully understand proper management interventions on SS.

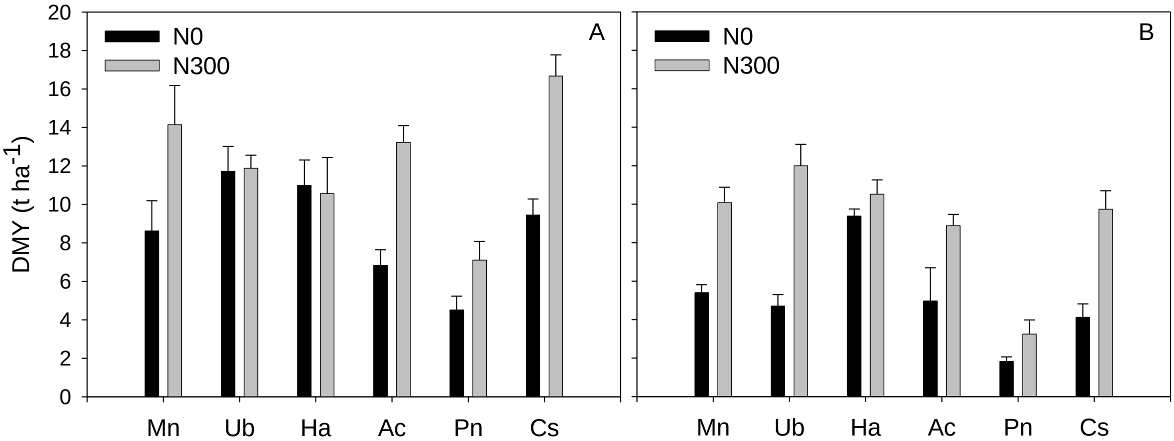

Figure 1. Dry matter yield (DMY, *n* = 3) within each light condition (A = unshaded and B = shaded by eucalyptus trees) and for each species (see Material and Methods for species codes). The bars show the standard error. N0, without nitrogen supply; N300, 300 kg de N $ha^{-1}year^{-1}$.

Conclusions

Our results show that responses to interactive light and nitrogen availability are species-dependent. Except for *P. notatum* cv. Pensacola, we believe that the others species studied have a great potential for utilization on silvopastoral systems (SS). On average over all species, 34% of shade reduced the DMY by 32%. However, other ecological functions and ecosystem services must be considered to better evaluate SS. For instance, SS offer many benefits in terms of microclimate modifications (*e.g.* extend the grazing season period, alleviate heat stress), which in turn could positively affect productivity.

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