Australian Journal of Crop Science AJCS

Aust J Crop Sci. 19(09):972-977 (2025) | https://doi.org/10.21475/ajcs.25.19.09.p356 ISSN:1835-2707

Effect of eucalyptus (*Eucalyptus* spp.) shade on the agronomic and morphological responses of marandu grass (*Urochloa brizantha*) pasture in a silvopastoral system

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Submitted: 01/04/2025

Revised: 05/05/2025

Accepted: 16/07/2025

Abstract: The objective of this study was to evaluate the productivity of marandu grass (*Urochloa brizantha*) between rows of eucalyptus (*Eucalyptus* spp.) with variations in spatial arrangements in a silvopastoral system. The study was conducted in a randomized block design with five treatments, consisting of spatial arrangements of eucalyptus in silvopastoral systems, with three system replications and plots subdivided in time: T1 - single row arrangement 10×2, with 500 trees/ha; T2 – single row arrangement 20×2, with 250 trees/ha; T3 – double row arrangement 3×3+15, with 370 trees/ha; T4 – double row arrangement 3×3+20, with 290 trees/ha; T5 – exclusive pasture of marandu grass (control). There was no effect of the eucalyptus spatial arrangements on the total dry mass, leaf blade, stem and dead material and leaf blade proportion of marandu grass. The spatial arrangements of eucalyptus did not affect the production and proportion of botanical fractions of the forage. However, tillers number in marandu grass was greater in canopies growing without eucalyptus and statistically similar to the 3×3+20 arrangement (1011 and 945 tillers m^{-2}, respectively; $P<0.05$). The spatial arrangements of eucalyptus did not affect the production and proportion of forage botanical fractions. To not harm the tillering of the pasture, it is recommended to plant the eucalyptus seedlings at 20×2 spacing.

Keywords: low carbon agriculture; spatial arrangements; agroforestry systems, integrated system.
Abbreviations: dry matter (DM); forage mass (FM); hectare (ha); silvopastoral system (SSP); synonymy (Syn.).

Introduction

Climate change are imposing challenges to the agriculture and cattle raising in order to keep production at satisfactory levels. Agroforestry systems are alternative models of sustainability, consolidated on economic principles of rational use of renewable resources, under sustainable exploitation, being able to generate social benefits, without affecting the productive potential of ecosystems (Lima et al., 2019). The silvopastoral system is one of the agricultural developments that has been encouraged in Brazil as an alternative for low-carbon agriculture (Schinato et al., 2023). Being an economically viable livestock farming practice due to the commercialization of milk, animals and wood for firewood or sawmilling (Schettini al., 2021), promotes a more comfortable environment for animals (Schinato et al., 2023; Guamán-Rivera et al., 2024), providing benefits through the provision of ecosystem services (Gomes et al. 2019), improving water use efficiency and increasing biodiversity (Santos et al., 2019).

Among the many advantages of the silvipastoral system, one of the most important currently is related to carbon sequestration, contributing to the reduction of the greenhouse gases effect and global warming, because besides having carbon fixation in forages, tree wood and roots are also important carbon sinks (Cardinael et al., 2017; Feliciano et al., 2018). However, it is necessary to evaluate the effects of the tree presence on forage over time, because trees in silvopastoal systems exert a great influence on the productivity and persistence of cultivated forage grasses and legumes due to shading (Lima et al., 2020; Pereira et al., 2021).

For a silvopastoral system to be sustainable, it is necessary to use shade-tolerant forage species that have good productive capacity for several subsequent years. Shade-tolerant forages usually show changes in their morpho-physiological characteristics when grown in shade that give them greater production compared to non-tolerant species under low-light cultivation (Paciullo et al., 2017).

Pereira et al. (2021) observed that silvopastoral systems with eucalyptus established at 8 years are not able to support forage and animal production similar to a monoculture pasture, emphasizing that more studies are needed to determine the appropriate trees management to reduce the competition with pasture. Geremia et al. (2018) reported changes in microclimate when trees are present, which affects forage production and plant morphology. Therefore, there is still a gap regarding to the persistence and sustainability of silvipastoral systems that can better understand the potential of these systems over the years (Lima et al., 2019).

The interaction between system components has raised many questions, highlighting the need for further research into the benefits of restoring degraded land and pastures, particularly in fragile ecosystems (Pereira et al., 2021). Grasses of the genus *Urochloa* and eucalyptus hybrid (*Eucalyptus* spp.) trees are the most commonly used components for implementing silvopastoral systems and crop-livestock-forest integration in Brazil (Paciullo et al., 2021; Meo-Filho et al., 2021; Lameira et al., 2023; Almeida et al., 2024; Monteiro et al., 2024). This is due to the tolerance of *Urochloa* to shade (Paciullo et al. 2017), but this combination can be affected by the intensity of shade, which is influenced by very dense spatial arrangements and by the age and height of the trees (Paciullo et al., 2021; Lameira et al., 2023; Monteiro et al., 2024).

Tree density is an important factor for the silvipastoral system success (Geremia et al., 2018; Gomes et al., 2019). Thus, arrangements with tree spacing's larger among the trees in implementation moment should be evaluated to favor the growth of tropical forage grasses, ensuring profitable cattle ranching while the trees grow.

Therefore, quantifying the production and morphological composition of forage can help to understand the forage mechanisms response to shading in silvopastoral systems (Santos et al., 2018). In view of the above, this study aimed to evaluate the production and morphophysiological responses of *Urochloa* (Syn. *Brachiaria*) *brizantha* cv. marandu submitted to different eucalyptus spatial arrangements in silvipastoral system.

Results

The pasture production and canopy height of marandu palissadegrass growing in different eucalyptus arrangements are showed in Table 1. The canopy height was 16.5% smaller at no tree treatment compare to silvopastoral systems with different eucalyptus arrangements ($P<0.001$). The total FM, leaf mass, stem mass and dead material mass were similar among treatments ($P>0.05$).

The tiller density (tillers m^{-2}) and morphological components proportions (%) of marandu palissadegrass growing in different eucalyptus arrangements are showed in Table 2. Tillers number was greater in canopies growing without eucalyptus and statistically similar to the 3×3+20 arrangement (1011 and 945 tillers m^{-2}, respectively; $P<0.05$). The presence of trees increased the stem mass percentage in the arrangements 3×3+15 and 20×2 in relation to the area in full sun, respectively ($P<0.05$). The Eucalyptus arrangements of 20×2 showed a lower proportion of dead material in the FM compared to the full sun pasture. Leaf mass proportion did not differ between treatments ($P>0.05$).

Forage production (kg ha^{-1}) over time of marandu palissadegrass growing in different eucalyptus arrangements was shown in Figure 1. There was an effect of months on the forage production of marandu palissadegrass in eucalyptus arrangements ($P<0.01$). Maximum production occurred in the month of March, and the months that showed the lowest forage production were August, September and October (2.599 vs. 805, 874 and 628, respectively).

Morphological components proportion (%) over time of marandu palissadegrass growing in different eucalyptus arrangements are described in figure 2. From July to October, which preceded the experiment uniformization in October, the proportion of dead material in FM was higher and leaves proportion was lower. On the other hands, after October, the pattern of the morphological component's proportions changes, where the proportion of leaf in FM was higher and dead material proportion was lower.

Discussion

The plant adaptation under restricted light implies a substantial carbon investment in the leaf area expansion, leaf and stem elongation in order to increase light capture. This fact is confirmed by the results obtained in this study, in which greater heights were observed in the pastures that had the tree component, regardless of the arrangement (Table 1). In the pastures shaded by eucalyptus, the average canopy height was 39.11 cm; in the pasture without eucalyptus, this height was around 32.64 cm.

As marandu palissadegrass is a tropical grass, it was expected that the FM would be higher in the pasture without trees, especially in summer-autumn, due to the higher solar incidence that causes an increase in the plant photosynthetic rate and consequent forage accumulation (Lima et al., 2019; Lima et al., 2020).

Pereira et al. (2021) evaluated an integrated system of pasture with eucalyptus with 8 years of establishment and observed that in summer and autumn, the pasture of Piatã grass showed higher DM production (63 kg day^{-1}) compared to integrated systems with eucalyptus (15 and 1 kg day^{-1}, in systems with 227 and 357 trees ha^{-1}, respectively). According to these authors, the drastic reduction in forage production due to the eucalyptus presence of is also due to a well-developed root system, competing strongly with pasture for moisture and nutrients present in the soil.

Several aspects should be considered to explain why we did not observe an effect on FM between the eucalyptus arrangements (Table 1). The eucalyptus cultivar used (GG100), with an average height of 12 m, did not produce a very bulky canopy, thus allowing solar radiation

Table 1. Pasture production of marandu palissadegrass growing in different eucalyptus arrangements.

Eucalyptus arrangements	Height (cm)	Pasture production (kg DM ha^{-1})			
		Total forage mass	Leaf mass	Stem Mass	Dead Material Mass
3×3+20[1]	38.15a	6,489	1,709	2,306	2,474
3×3+15[2]	39.56a	6,217	1,629	2,262	2,327
20×2[3]	39.48a	6,084	1,690	2,199	2,195
10×2[4]	39.24a	5,871	1,483	2,029	2,359
No tree[5]	32.64b	5,887	1,737	1,909	2,241
Media	37.81	6,110	1,649	2,141	2,319
CV[1] (%)	13.12	17.22	26.59	26.77	27.55

Averages followed by different lowercase letters; the averages are different by the Tukey test at 5% significance. [1] Coefficient of variation. Eucalyptus arrangements in silvipastoral systems: [1]3×3+20: double rows of 3×3 m, spaced by 20 m (290 trees ha^{-1}); [2]3×3+15: double rows of 3×3 m, spaced by 15 m (370 trees ha^{-1}); [3]20×2: single row of 20×2 m (250 trees ha^{-1}); [4]10×2: single row of 10×2 m (500 trees ha^{-1}); [5]No tree: pasture without eucalyptus as a control.

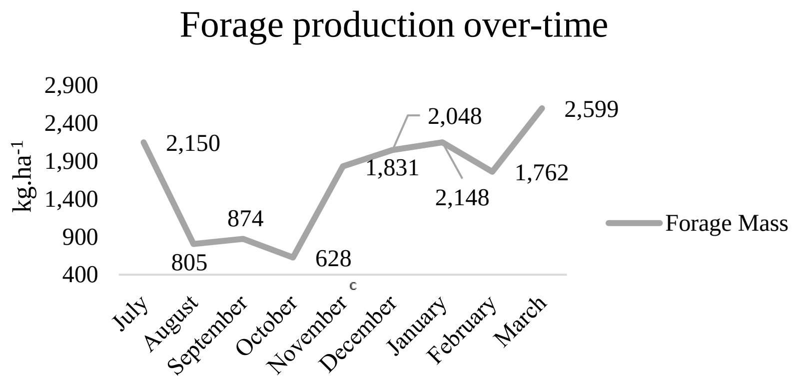

Figure 1. Forage production (kg.ha^{-1}) over time of marandu palissadegrass growing in different eucalyptus arrangements.

Table 2. Tiller density (tillers m^{-2}), and leaf, stem and dead material proportions (%) of marandu palissadegrass growing in different eucalyptus arrangements.

Eucalyptus arrangements	Item			
	TD[1] (tillers m^{-2})	Leaf (%)	Stem (%)	Dead material (%)
3×3+20[1]	945ab	31.08	35.80ab	33.12ab
3×3+15[2]	785bc	31.95	36.68a	31.37ab
20×2[3]	763bc	32.80	36.36a	30.84b
10×2[4]	707c	31.46	34.85ab	33.69ab
No tree[5]	1011a	32.67	32.47b	34.86a
Media	842	31.99	35.23	32.78
CV[2] (%)	12.07	16.35	14.03	14.22

Averages followed by different lowercase letters, the averages are different by the Tukey test at 5% significance. [1] Tiller density (tillers m^{-2}); [2] Coefficient of variation. Eucalyptus arrangements in silvipastoral systems: [1]3×3+20: double rows of 3×3 m, spaced by 20 m (290 trees ha^{-1}); [2]3×3+15: double rows of 3×3 m, spaced by 15 m (370 trees ha^{-1}); [3]20×2: single row of 20×2 m (250 trees ha^{-1}); [4]10×2: single row of 10×2 m (500 trees ha^{-1}); [5]No tree: pasture without eucalyptus as a control.

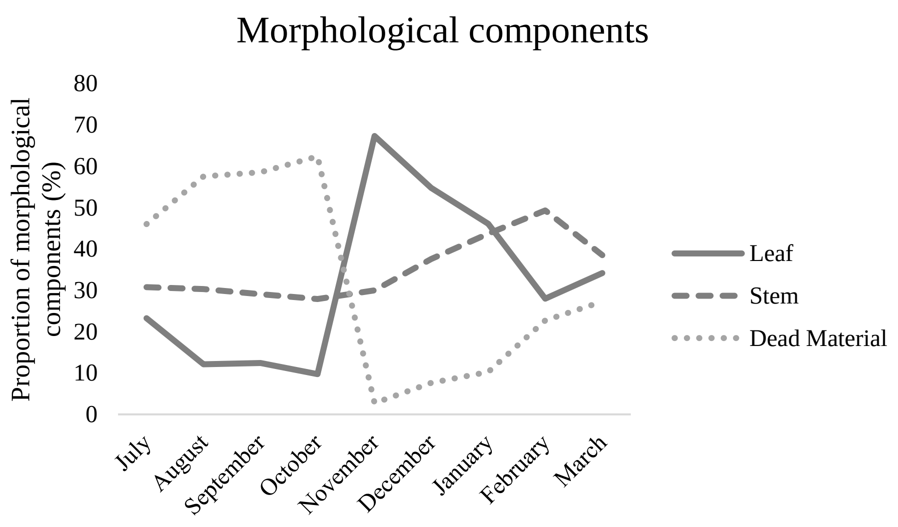

Figure 2. Morphological components proportion (%) over time of marandu palissadegrass growing in different eucalyptus arrangements.

to enter between the eucalyptus rows. Pinto et al. (2011) studied six eucalyptus clones and among them was CG100 (58, 386, GG100, I042, I144, VM1), which showed lower height growth and lower production of aboveground DM and total DM.
In addition, the authors characterized the nutritional efficiency of eucalyptus clones, classifying the GG100 as one of the best, with high efficiency in nitrogen, phosphorus and potassium assimilation, however, with lower efficiency in the use of these nutrients in biomass production.
Due to the GG100 clone not being efficient in the use of these macronutrients for biomass production, the formation of the eucalyptus canopies was affected, since this area was established in 2011 and was properly managed. Forage responses to abiotic factors are broad and dependent on several factors, especially those inherent to the forest component.
Tree height, tree morphological characteristics, forest component arrangement, with inter-row and inter-plant spacing and planting orientation are among the important determinants of microclimatic conditions, which, together with soil characteristics, can influence forage growth in a crop-livestock-forest integration system (Pezzopane et al., 2018).
Leaf blade proportion in FM was similar among different eucalyptus arrangements (Table 2), coinciding with literature reports that have shown that shading does not influence the leaf production (Crestani et al., 2017). The stem proportion was higher and the proportion of dead material was lower in the FM of integrated systems with eucalyptus compared to monoculture pasture (Table 2). It can be speculated that marandu grass presents phenotypic plasticity and for this reason, there were no significant differences between the area with eucalyptus and without eucalyptus in relation to the proportion of leaf blade (Gomes et al. 2019).
The trees presence resulted in an increased percentage of thatch in the FM in the 3×3+15 and 20×2 arrangements in relation to the area in full sun. The number of tillers per m^2 was higher in the area without eucalyptus and statistically similar to the 3×3+20 arrangement. In this arrangement, even though the pasture was under shade, it was able to adapt, maximizing the efficiency of radiation use, maintaining adequate levels of photo-assimilates that could satisfy the demand for maintenance and production of new plant tissue. Among the spatial arrangements of eucalyptus, the 10×2 arrangement showed lower tiller numbers compared to the 3×3+20 arrangement.
The greater number of plants in the 10×2 arrangement (500 plants) in relation to 3×3+20 (290 plants) may have caused this significant difference in the number of tillers per m^2, probably due to the greater degree of shade imposed by these treatments in between the rows of eucalyptus. These results allow us to affirm that the tillers population density is lower in plants subjected to greater levels of shade, highlighting the importance of light for the emergence of new tillers (Lima et al. 2019).
The lower amount of irradiance penetrating in the forage canopy leads to lower tiller population density, as radiation allows the activation of axillary and basal buds for new tiller formation (Baldassini et al., 2018). Furthermore, at lower light incidences the reduced supply of photoassimilates is allocated preferentially to existing tillers, inhibiting the production of new tillers (Baldassini et al., 2018). There was an effect of the months on the forage production (Table 1) and the morphological components proportion (%) of marandu palisadegrass (Table 2), with an alteration in the canopy structure from October, due to mowing, the rainy season and fertilization.
Lower forage dry mass yields over the periods were expected in the SSPs compared to the full sun pasture. However, the forage accumulation of marandu grass in SSPs was probably favored by the soil moisture present in this system, because according to Gomes et al. (2019) more shaded pastures tend to increase soil moisture due to lower evapotranspiration.
Between July and October, evaluations were made during the dry season and it was observed that FM (kg ha^{-1}) decreased while the stem proportion did not change. This was due to the dry period, in which the grass did not regrow as vigorously due to the photoperiod, water deficiency, and low temperature.
From November on, the forage production increased over the months, reaching a productivity of 7,754 kg ha^{-1} in March, with a 40% increase in the proportion of leaf lamina due to the beginning of the rainy season. Canopy height (cm) and leaf mass (kg ha^{-1}) of the pasture decreased in the dry period, which corresponds from July to October obtaining on average 38.84 cm and 1,115 kg ha^{-1}, respectively.
As well as the FM, the canopy height (cm) of pasture decreased in the dry period, which corresponds from July to October, obtaining an average of 38.84 cm. This probably occurred due to environmental conditions of period that decreases the regrowth of the tillers and grazing by animals. From November 2018 to March 2019 (rainy period), the height of the pasture increased over the months arriving in March with 41.35 cm.
From the results that were obtained, we can observe that SSP is an excellent alternative for increasing land use by farmers, providing several benefits for the production system, such as increasing the variety of living organisms inhabiting the established area, contributing to soil conservation by preventing erosion, improving the chemical and physical properties of the soil, and obtaining multiple products in the same unit of area (meat, milk, and wood) allowing an increase in the farmer's income (Paciullo et al. 2017). In addition, SSPs allow animals' adaptation to climate change, as they reach lower values of temperature and humidity index compared to full sun pasture (Pezzopane et al., 2019).

Materials and Methods

Experimental sites, treatments and experimental management

The experiment was carried out at Campo Experimental Vale do Piranga belonging to the Empresa de Pesquisa Agropecuária de Minas Gerais - EPAMIG located in Oratórios, Minas Gerais state, Brazil.
The average annual maximum temperature is 21.8° C and the minimum is 19.5° C. The average annual precipitation is 1,250 mm. According to Köppen's classification, the region's climate ranges from humid tropical *Cwa* to semi-humid *Aw* with hot summers (Alvares et al., 2013). The evaluated systems were established in 2011, aiming the recovery of a degraded pasture.
In December 2011, *Urochloa brizantha* (Syn *Brachiaria brizantha*) cv. marandu grass was broadcast planted in sequence, the corn hybrid (*Zea mays* L.) for silage was sown with a five-row planter. After corn emergence, in January/2012, the eucalyptus seedlings were transplanted according to the experimental arrangements, using the cultivar GG100. Thus, the systems were 7 years old at the trial beginning, with the eucalyptus plants being around 12 m tall. Before the start of the evaluations, the area had been grazed within the routine of the experimental field, ensuring that there was no overgrazing.
We studied the eucalyptus spacing in silvipastoral systems: T1 - single row arrangement 10×2, with 500 trees/ha; T2 – single row arrangement 20×2, with 250 trees/ha; T3 – double row arrangement 3×3+15, with 370 trees/ha; T4 – double row arrangement 3×3+20, with 290 trees/ha; T5 – exclusive pasture of marandu grass (control). The experimental design used was a randomized block design with time subdivided plots. The evaluations were included in the experimental model as repeated measures over time, and analyzed as a subplot. There were three replicates, represented by areas of 11,000 m^2, totaling fifteen experimental units (5×3).

Experimental evaluations
Marandu grass assessments were carried out during the dry season (July to October) and the rainy season (November to March). After the evaluation in October the pastures were cut at 10 cm height for its uniformization. In addition, fertilization was performed in the experimental area with 350 kg ha^{-1} of 20-05-20 N-P-K fertilizer and another 350 kg ha^{-1} 60 days later.

The average height of the forage canopy was measured at 30 random points in the marandu grass pasture, using a graduated ruler, according to Barthram (1985). Forage sampling was carried out at 10 random points in the areas with marandu grass, with a square of 1 m^2. The forage collected in the square was divided into two subsamples to evaluate the DM concentration and separation of the morphological components.

Pasture height, FM and plant components (leaf blade, stem, and dead material), tiller density, and leaf/stem ratio were evaluated. After harvesting the forage, two subsamples of fresh material were taken for the evaluation of DM concentration and morphological separations. To estimate the DM concentration of the FM, a subsample was dried in an oven at 65°C for 72 h until constant weight. The FM was considered all forage present in the quadrat and then calculated per hectare (kg.ha^{-1}). Another subsample was separated into stem (stem + sheath), leaf (leaf blade), and dead material in order to quantify the forage components, oven-dried at 65° C for 72 h.

Before grazing in the rainy season, tiller density was obtained by collecting two samples in a 1 m^2 square. All marandu grass tillers within the square were weighed and counted.

Lactating and dry cows grazed in all treatments simultaneously in each block. The grazing method adopted was intermittent, in accordance with the recommendations of Difante et al. (2011) for marandu grass grazing management, with an entry height of around 35 cm and an exit height of around 15 cm.

Statistical analysis
The data were submitted to variance analysis in a randomized complete block design (three blocks with five treatments), considering the nine forage cuts (grazing cycles) as repeated measures over time. The means were compared using the Tukey test at 5% significance level. The analyses were performed using the SAS statistical computer program.

Conclusion

The spatial arrangements of eucalyptus did not affect the production and proportion of forage botanical fractions. Although the productivity of marandu grass was not similar among the spatial arrangements of eucalyptus in this study; to not harm the tillering of the pasture, it is recommended to plant the seedlings at 20 × 2 spacing.

Acknowledgements
This study was financed by FAPEMIG (PROCESSO Nº. CVZ-APQ 03674-14) which also granted the scientific initiation scholarships. We also thank the Financier of Studies and Projects FINEP and National Council for Scientific and Technological Development (CNPq) for investments in infrastructure. The authors acknowledge the support from interns and farm employees during the field trial setup.

Author contribution
LSS, DSQ and EAS conceived and designed the experiment; LSS, DSQ and EAS conducted the experiment; LSS, DSQ, EAS and JRMR supervised the experiment; LSS, DSQ, EAS and JRMR sample analysis; LSS, FKG and AHMA wrote the paper; DSQ, EAS, JRMR, FKG, AHMA and FOF reviewed the paper. All Authors approved of the manuscript.

Funding
This study was funded by Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Financiadora de Estudos e Projetos (Finep).

Declarations ethics approval
Not applicable.

Conflict of interest
We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organization related to the material discussed in the manuscript.

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