

Impact of beef cattle on eucalyptus trees in a silvopastoral system

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Research Article

Keywords: Sustainable intensification, beef cattle, agroforestry, C3 grasses

Posted Date: February 8th, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-3914348/v1>

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Additional Declarations: No competing interests reported.

Abstract

Eucalyptus species are widely adopted in silvopastoral systems in Brazil due to their adaptive potential to different climates and soils. However, damages caused by cattle to trees may compromise the system's success. The aim of this study was to determine the impact of beef cattle on *Eucalyptus grandis* clone GPC 23 trees during the grazing period in an integrated crop-livestock with trees (CLT) system of *Avena strigosa* + *Lolium multiflorum*. The effect of two N levels (50 x 150 kg/ha) on animal and forage production were also evaluated, with the integrated crop-livestock system (CL) serving as control. The experimental design was randomized blocks of treatments arranged in a 2x2 factorial scheme (2 systems x 2 N levels), with three replicates. In winter 2022, forage production and animal performance, assessed as average daily gain (ADG) and live weight gain (LW) per area per day (Gha/day), were evaluated during 139 days of grazing. Total forage production, ADG, and Gha/day were higher in CL (7972 ± 775.7 kg DM/ha, 0.799 ± 0.0392 kg/animal/day and 4.27 ± 0.259 kg LW/ha/day, respectively) than in (6478 ± 350.9 kg DM/ha, 0.638 ± 0.0546 kg/animal/day and 2.91 ± 0.259 kg LW/ha/day), even at similar sward heights (between 22 and 24 cm). The animals damaged the bark of the trees, even after the trees had reached a diameter at breast height of 9.9 cm. The damage was classified as high intensity in 91.1% of the trees, affecting their quality as sawn wood. Preventive measures must be adopted regarding the use of *E. grandis* in a silvopastoral system with cool-season grasses.

1. Introduction

Integrated crop-livestock systems (ICLS) integrate crop, livestock, and forestry components in a variety of spatial and temporal arrangements (Carvalho et al., 2014; Moraes et al., 2014; Balbinot Jr et al., 2009). Such systems combine valuable elements in food production systems because they are strategically designed to maximize synergy by mimicking the natural environment (Lemaire et al., 2014). In the face of climate change and food insecurity, the diversification of production systems through the use of ICLS represents an important alternative for the sustainable intensification of land use (Lemaire et al., 2023), as well as to avoid the opening of new agricultural frontiers (Strassburg et al., 2014). Silvopastoral systems, a modality of ICLS, have been shown to act as a sink for greenhouse gases (Morales et al., 2023).

Eucalyptus spp. are the predominant tree species used in silvopastoral systems, which are present in 7.4 million hectares cultivated with trees because of their adaptive potential to different climates and soils (IBGE-PEVS, 2020). According to Oliveira and Pinto Junior (2021), when correct crop management is applied, the implementation of trees such as eucalyptus in a production system offers advantages such as the maintenance of soil fertility, prevention of erosion, control of diseases and pests, and animal welfare. However, the successful implementation of the arboreal component requires some care because of the possibility of cattle interfering with its development. Animals tend to break branches and remove bark from the trees. This behavior is often related to mineral deficiency or a low dietary fiber concentration and may also be caused by behavioral problems (Guerreiro et al., 2015). For this reason,

the ideal situation is that trees go through a period without the action of animals to allow growth to the point that they can withstand the damages caused by cattle and prevent the animals from reaching the thinner twigs and branches (Silva et al., 2017). Porfírio-da-Silva et al. (2009) suggest a diameter at breast height (DBH) of trees > 6 cm at the time when the animals enter the system. Tree pruning also helps reduce the incidence and intensity of damage caused by cattle in silvopastoral systems (Triches et al., 2020). Furthermore, Guerreiro et al. (2015) highlighted the importance of animal density and other available feed sources.

Despite the cited benefits of the presence of trees in silvopastoral systems, they can affect the development of intercrops (e.g., Pontes et al., 2021) by light restriction and competition for water and nutrients. In the case of forage species, the production, structure, and nutritional value of the pasture can be altered in wooded environments (Ford et al., 2017; Pezzopane et al., 2020; Pontes et al., 2017), with the impact of such changes being variable throughout the development of trees and their density in the system.

The productivity of cool-season crops can be optimized by nitrogen fertilization. When applied in winter to ICLS, nitrogen fertilization can also eliminate or reduce the need for fertilization in summer succession crops (Assmann, 2002; Farias et al., 2020). In view of both economic and environmental factors, efforts are currently being made to reduce the use of nitrogen through more appropriate and sustainable management, increasing the nitrogen utilization efficiency by plants and/or systems (Berger et al., 2020; Deifeld et al., 2021). Therefore, the challenge of ICLS with trees is to maximize positive interactions (complementarity) and to minimize negative interactions (competition) between components of the system (Jose et al., 2017). Within this context, the aim of the present study was to determine the impact of the action of beef cattle on the development of trees 42 months after planting, as well as to evaluate the effects of two different N doses and the absence or presence of trees on animal performance and forage production in an ICLS.

2. Materials and Methods

Study area

The experiment was conducted at the Experimental Station of the Model Farm of the Rural Development Institute of Paraná (IAPAR-Emater) in Ponta Grossa-PR (25°07'22" S, 50°03'01" W), southern region of Brazil. The climate is humid subtropical or Cfb of the Köppen classification. The soil is a transition from typical dystrophic Haplic Cambisol and typical dystrophic Red Latosol, with a sandy texture and slope of 4 to 9% (Embrapa, 2006).

The experimental area measuring 13.2 ha was divided into 12 plots (i.e., experimental units). Since winter 2010, cattle have been grazing during winter on ryegrass (*Lolium multiflorum*) + black oat (*Avena strigosa*) pasture; during summer, corn or soybean has been grown in the same area by direct planting. In November 2019, *Eucalyptus grandis* clone GPC 23 was planted in 6 of the 12 plots at a spacing of 3 × 14 m in the same rows where trees had previously been cultured since 2006 (see Pontes et al., 2021 for

further details regarding the first cycle). Thus, a second cycle with trees was started. The objective of including the trees was to produce sawn wood.

In winter 2022, the black oat + ryegrass mixture was sown using 60 and 20 kg of seeds/ha, respectively, and 70 kg/ha of P_2O_5 at baseline. Two doses of N were applied ~ 40 days after sowing, i.e., 50 (N50) × 150 (N150) kg N/ha.

Each plot received three tester animals and a variable number of regulator animals using the put-and-take method to maintain the desired pasture height of 20 cm (Kunrath et al., 2014). Purunã beef heifers with an initial age of 10 months, weighing 190 ± 3.34 kg at the beginning of the experiment, were used. Grazing started on June 14, 2022, and continued for 139 days.

Treatments and experimental design

A randomized block design was used in which the treatments were arranged in a 2×2 factorial scheme of two N doses (50 and 150 kg/ha) and two systems [crop-livestock (CL) and crop-livestock-forest (CLT)], resulting in 4 treatments with three replicates each.

Pasture measurements

Sward height was assessed every 15 days by measuring 100 random points per paddock using a sward stick (Barthram, 1986). Herbage mass (kg dry matter [DM]/ha) was estimated approximately every 21 days, with five cuts at ground level in each paddock within a quadrat measuring 0.25 m² (50 x 50 cm). From these samples, sub-samples were manually separated into fractions containing leaf blade, stem + sheath, dead material, and other species. The leaf proportion was determined as the leaf blade mass in relation to the weight of the sub-sample. Samples and sub-samples were dried at 60°C for 48 h and then weighed. Herbage accumulation rates were determined using three grazing exclosure cages in each paddock (Klingman et al., 1943). The herbage allowance (HA, %LW) was calculated according to the following equation: $HA (\%LW) = ((HM/n + HAR)/SR) \times 100$, where LW = live weight, HM = average herbage mass of each stocking period (kg DM/ha), n = number of days of the stocking period, and SR = stocking rate of each stocking period (kg LW/ha) (Sollenberger et al., 2005).

Total herbage accumulation was calculated as the sum of the accumulated herbage during each period (accumulation rate × number of days during period) and the herbage mass at the beginning of the grazing period (Kunrath et al., 2014).

Animal performance

The average daily weight gain (ADG) of the tester animals was determined as the difference in live weight between successive weight recordings and the number of days that had passed. The animal load [kg live weight (LW)/ha/day] was calculated as the weighted average of the sum of weights of testers and put-and-take animals present in each plot. Daily weight gain per hectare (Gha) was determined by multiplying the ADG by the number of animals per day/ha. All animals had unrestricted access to shade

in the CLT plots and to clean water and mineral supplements throughout the experiment in the CLT and CL plots.

Tree measurements

The first forest inventory was carried out when the trees were 12 months old, one tree was sample for every 9 trees existing along the rows, corresponding to 10% of the trees in the area. Circumference at breast height (CBH) and total tree height were measured with a tape measure and a digital clinometer, respectively, in October 2022. Using the CBH, the DBH was calculated as follows: $DBH = CBH/3.14 (\pi)$. Five DBH classes were defined: class 1 (9.55–12.098 cm), class 2 (12.099–14.64 cm), class 3 (14.64–17.19 cm), class IV (17.19–19.74 cm), and class 5 (19.74–22.29 cm). The relative frequency of trees according to DBH was then calculated for each plot to define how many trees of each DBH class would need to be evaluated in order to identify damages caused by the animals.

In November 2022, the damages caused by the animals to the trees was assessed. The damages caused by animals were classified according to the parts of the plant involved: Tb = breakage of the main stem or trunk; Ti = trunk injury reaching the wood due to removal of the cambial tissue; Bb = breakage of twigs/secondary branches; Bi = bark injury that does reach the cambial tissue; Sb = stem breakage and leaf foraging or browsing, and Li = large injury (> 5 cm in diameter). A system of weights and scores was established for the different types of damage: Tb = 10.0; Ti = 4.0; Bb = 2.0; Bi = 1.5; Sb = 1.0, and Li = 1.0. The final score for each individual was the sum of the respective frequencies of damage, except for Tb damage whose frequency received the maximum score, regardless of the occurrence of other types of damage. Five classes of damage intensity (d) were established: d0 = zero ($d_0 = 0$); d1 = low ($0 < d_1 \leq 3$); d2 = medium ($3 < d_2 \leq 6$); d3 = high ($6 < d_3 < 10$), and d4 = extreme ($d_4 = 10$) (Porfírio-da-Silva et al., 2012).

After 174 days of damage assessment of the arboreal component, a period during which the area received the corn crop and not grazing animals, a new forest inventory was carried out in order to determine whether there was tree development even after the damages caused by animals.

Statistical analyses

Data were submitted to analysis of variance at a 5% level of significance using the R software (R Core Team, 2021) within RStudio IDE (RStudio Team, 2020). Mixed linear models (lme) were used that included systems and N levels as fixed effects and the measurements (during the stocking period) and plots/block as random effects. The measurements during the stocking period were considered to be repeated measures. Data were transformed to improve the normality and homogeneity of the residuals, if necessary. The following packages were used: tidyverse (Wickham et al., 2020), lme4, and car. One-way ANOVA was applied to evaluate the effect of DBH class on the sum of the respective frequencies of damage for each individual.

3. Results

Animal performance and forage production

No significant differences were observed in animal load between the integrated systems studied, with a mean LW of $1,091 \pm 54.3$ kg/ha. Some pasture variables were also not influenced by the systems studied, such as leaf accumulation rate, total forage supply, leaf supply, leaf percentage, stem percentage, and total DM production, with mean values of 24.1 ± 1.91 kg DM/ha/day, $7.6 \pm 0.39\%$, $3.3 \pm 0.25\%$, $45.2 \pm 1.64\%$, $32.4 \pm 1.1\%$ and $7,225 \pm 464.2$ kg DM/ha, respectively.

The different doses of nitrogen fertilization significantly affected pasture height ($F = 7.91$, $P = 0.005$) and forage mass ($F = 7.77$, $P = 0.006$), with higher values in the treatments that received 150 kg N/ha (23.7 ± 0.81 cm and $1,006 \pm 15.6$ kg DM/ha, respectively) versus 21.9 ± 0.82 cm and 971.6 ± 15.77 kg DM/ha in the treatment with 50 kg N/ha.

A higher herbage accumulation rate, ADG, and Gha/day were observed in the CL system compared to the CLT system (Table 1), regardless of the N dose.

Table 1

Result of analysis of variance and mean ($\pm$ standard variation) of pasture variables of *Avena strigosa* + *Lolium multiflorum* and animal performance in integrated crop-livestock (CL) and integrated crop-livestock-forest (CLT) systems.

Variable	CL	CLT	F	P
Herbage accumulation rate (kg DM/ha/day)	24.3 ± 22.08	23.8 ± 17.50	6.59	0.0113
Average daily gain (kg/animal/day)	0.799 ± 0.0392	0.638 ± 0.0546	12.33	0.0009
Gain per area (kg LW/ha/day)	4.27 ± 0.259	2.91 ± 0.259	22.83	0.0000

DM, dry matter; LW, live weight.

There were no significant interactions between system and N doses ($P > 0.05$) for any of the variables evaluated.

Impact of beef cattle on eucalyptus trees

At the time of entry of the animals, the trees had a mean DBH greater than 9.9 cm and a mean height of 6.9 m, based on sampling carried out on September 29, 2021.

All trees suffered at least one type of damage, with 91.1% accumulating Bi, Li and Ti damages, resulting in a score of 6.5 classified as high intensity, followed by low damage in 6.3% of trees, medium damage in 1.8% of trees, and extreme damage in 0.9% of trees. Figure 1 shows the frequency of each damage class according to the different diameter classes of the trees.

To determine whether the damages caused by cattle had an impact on the development of the trees, height and DBH measurements were repeated on May 16, 2023, 174 days after damage assessment. At the time of damage assessment, the trees had a mean DBH of 16.7 ± 2.76 cm and a mean height of 11.9

± 2.18 m. At the end of the corn crop phase, i.e., after a period without grazing, the mean DBH of the trees was 21.4 ± 3.0 cm and the mean height was 16.1 ± 2.38 m. The development of the trees (DBH and height) according to DBH class is shown in Table 2.

Table 2
Mean (± standard deviation) of diameter at breast height (DBH) and height of the trees of the different diameter classes in October 2022 (i.e., during impact assessment of animals on trees) and in May 2023 (i.e., after a period without grazing).

DBH class	2022		2023	
	DBH (cm)	Height (m)	DBH (cm)	Height (m)
1	10.7 ± 0.77	8.5 ± 2.21	19.0 ± 5.77	15.5 ± 4.29
2	13.3 ± 0.91	9.7 ± 1.05	20.3 ± 3.38	15.3 ± 3.98
3	15.9 ± 1.28	11.6 ± 1.91	20.4 ± 4.83	15.5 ± 3.76
4	18.4 ± 0.79	13.2 ± 1.52	20.4 ± 4.25	15.3 ± 3.87
5	21.1 ± 0.75	13.6 ± 1.29	21.7 ± 4.43	15.0 ± 3.60

Class 1: 9.55–12.09 cm; class 2: 12.09–14.64 cm; class 3: 14.64–17.10 cm; class 4: 17.19–19.74 cm; class 5: 19.74–22.29 cm.

Despite the high intensity and severity of damage observed, the *E. grandis* clone GPC 23 trees showed a mean annual increment, i.e., mean DBH in 2023 divided by the time elapsed since planting, of 5.7 cm in 3.5 years.

3. Discussion

Pasture height and total DM production were higher in the treatments that received 150 kg N/ha, corroborating the results of Bernardino et al. (2011) who observed that higher nitrogen fertilization doses result in higher DM production regardless of forage supply. These findings show that the availability of nitrogen in soil is not sufficient to meet the requirements of grasses.

Differences between systems were observed in the herbage accumulation rate, with a higher rate in CL compared to CLT (Table 1), even at similar pasture heights of the systems. Plants established in shady locations can accelerate leaf elongation, rapidly reaching the desired height; however, they have fewer tillers than plants that grow in full sun (Belesky et al., 2011). The increase in nitrogen fertilization did not compensate for this negative effect of competition with the trees.

Lopes et al. (2008) reported values of 455 kg LW/ha and Kunrath et al. (2014) of about 370 kg LW/ha for a mixture of black oat + ryegrass in CL when the target sward height was 20 cm. Therefore, the Gha

obtained in the present study for both systems was similar and even higher than that observed with cool-season pastures in the CL system. The Gha is a consequence of ADG, animal load, and the number of grazing days (Carvalho et al., 2005; Martins et al., 2015). Thus, the lower ADG than expected for the species, up to 1.2 kg/animal/day (Sbrissia et al., 2017), was compensated for by the animal load and extensive grazing period (i.e., 139 days). Although an increase in the nitrogen fertilization dose would not produce a significant effect on any of the animal performance variables, such increase could later be compensated for by nutrient cycling in future grain production, thus requiring a complete assessment of the system.

A negative impact of immature trees can already be observed during this early phase of tree introduction, both on the herbage accumulation rate and on Gha and ADG (Table 1). The rapid growth of the trees (e.g., 5.97 cm in DBH/year), as well as the history of treatments in the area, for example, a greater deposition of residues (plant and animal) in CL compared to CLT throughout the first cycle with trees (Carpinelli et al., 2020), may have influenced these results.

Most trees exhibited injury greater than 5 cm in diameter, trunk injury reaching the wood due to the removal of the cambial tissue, and bark injury, which resulted in a score of 6.5 classified as high damage intensity, although the DBH was above the level generally recommended for the entry of animals. In a study of African mahogany, eucalyptus and parica, Silva et al. (2017) observed a lower incidence of removal of cambial tissue in trees. This fact may be related to the tree species, with the bark of different species exhibiting different characteristics. This layer may be removed more easily in *E. grandis*, and is then repeatedly damaged by animals (Gill, 1992). In a study evaluating the susceptibility of 10 eucalyptus species to cattle damage in a silvopastoral system, Guerreiro et al. (2015) found *E. grandis* to be the most affected, with 58% of the damage occurring in the bark and interfering with the quality of the wood. Similarly, Medrado et al. (2009) observed widespread damage to *E. grandis* at the age of 3 years in *Brachiaria brizantha* cv. Xaraés pasture, where 61% of the trees were affected. Despite the observed increase in DBH (28%) and height (38%), Porfírio-da-Silva et al. (2012) state that deep bark injuries generate epicormic shoots below the damaged area, reducing the value of the wood, which can probably no longer be destined for sawmilling.

Since in the present study mineral salt was offered to the animals *ad libitum*, the possibility of depraved appetite due to mineral deficiency (McDowell, 1996) is low. However, the high crude protein and low fiber levels resulting from the lower amount of structural components of temperate grasses may have influenced the behavior of the animals that damage trees in search of fiber (Mezzalana et al., 2014). Fibers are essential for ruminants since they stimulate chewing and help control rumen pH, thereby affecting rumen motility (Nicodemo et al., 2018).

The combined effects of palatability and bark thickness of *Eucalyptus grandis* clone GPC 23, together with the probably low DM content of the forage and low fiber availability, may be responsible for the damages observed (Nicodemo; Porfírio-da-Silva, 2018).

4. Conclusions

Forage production was lower in the CLT system compared to CL, with a negative impact on animal production. The increase in the N dose from 50 to 150 kg/ha did not compensate for the negative effect of the trees; however, future assessment of the impact of these doses on grain production in succession is necessary to determine the efficiency of the system as a whole. The magnitude of damages caused by heifers on *Eucalyptus grandis* clone GPC 23 trees under the conditions of the present study affects the objective of sawn wood production. New studies should evaluate whether the additional supply of dietary fiber (e.g., through the offer of hay) would minimize the intensity of damage to trees since the dietary DM and fiber content of cool-season grasses may be low for animals that had grazed on perennial summer pastures. Another alternative would be to protect immature trees, for example with electric fences, and the cost/benefit of this practice should therefore be assessed. Producers could also look for initiatives that add value to products obtained in CLT systems, which would contribute to minimizing productivity losses.

Declarations

Acknowledges

This work was supported by Fundação Agrisus (PA 3209/22) under grant agreement number 104344. All animal handling procedures were approved by the Ethics Committee of IDR-Paraná (No. 03/2020). LSP would like to thank CNPq for the fellowship granted (304426/2022-9).

Author Contribution

Luiza de Souza Carneiro: Field data collection, data tabulation, article writing. Laíse da Silveira Pontes: Field data collection, data tabulation, article writing. Débora Rodrigues: Field data collection, data tabulation. Luiza Chieze Mendes: Field data collection, data tabulation. Vanderley Porfírio-da-Silva: Field data collection, article writing.

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Figures

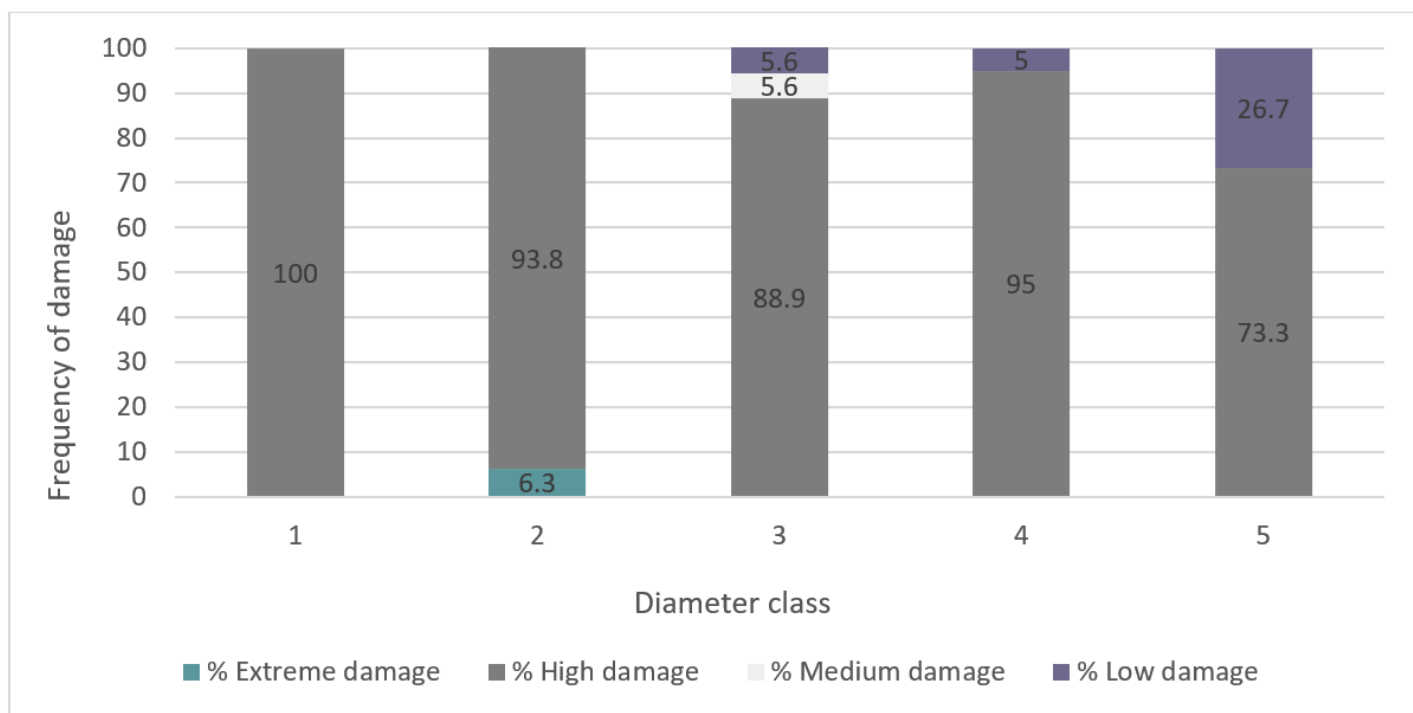


Figure 1

Frequency of the intensity of damage to *Eucalyptus grandis* clone GPC 23 in a silvopastoral system with Purunã beef heifers according to class of diameter at breast height (DBH). Class 1: 9.55 – 12.1 cm; class 2: 12.1 – 14.6 cm; class 3: 14.7 – 17.2; class 4: 17.3 – 19.7 cm; class 5: 19.8 – 22.3 cm. The effect of DBH class on the sum of damage scores for each individual was only significant at 10% ($P = 0.0509$), with scores ranging from 7.6 (class 2) to 6.1 (class 5).