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Research Paper

Performance and methane emissions by beef heifer grazing in temperate pastures and in integrated crop-livestock systems: The effect of shade and nitrogen fertilization

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ABSTRACT

Methane (CH_4) emissions from enteric fermentation by cattle are the main source of greenhouse gases in livestock systems, but scarce information is available on the effect of production scenarios on CH_4 emissions. The objective of this study was to assess animal performance and CH_4 emissions by beef heifers grazing in a mixed *Lolium multiflorum* × *Avena strigosa* pasture in two different types of integrated systems, crop-livestock only (CL) or crop-livestock-tree (CLT), and with two nitrogen (N) supply levels (90 and 180 kg N ha^{-1}, N90 and N180, respectively). The study was performed during the winter season (*i.e.,* stocking season) over three years (2012–2014). Pasture shading by 6- to 8-year-old trees in the CLT system led to a reduction in the total annual herbage accumulation of approximately 2.6 Mg dry matter ha^{-1} (−51%) and a reduction in winter carrying capacity of 0.5 stock units ha^{-1} in comparison to the CL system. Average daily gain (ADG) was reduced by 32% in CLT compared to CL. Average CH_4 emissions were 163 ± 9.12 g CH_4 day^{-1} in heifers with an initial average live weight (LW) of approximately 250 kg. Emissions of CH_4 per kg of LW did not differ between treatments ($P > 0.05$) with a mean of 0.58 ± 0.030 g kg^{-1}. However, there were significant differences between treatments and among years when CH_4 was expressed in g kg ADG^{-1} and kg ha^{-1} day^{-1}. Per unit area, CH_4 production ranged between 0.51 ± 0.05 (CLT N180) and 0.86 ± 0.12 kg ha^{-1} day^{-1} (CL N180). Possible strategies to reduce losses in animal production in the CLT systems are discussed, as well as the potential of C sequestration by woody biomass of eucalyptus trees to mitigate CH_4 emissions.

1. Introduction

Globally, interest in integrated crop-livestock systems as a strategy for sustainable land use has been increasing due to their potential to allow more income diversification and create fewer negative impacts on the environment (Lemaire et al., 2014; Moraes et al., 2014). The incorporation of a tree component in no-till, integrated crop-livestock systems may increase these systems' productivity and provide ecosystem services such as C sequestration both in the soil and in tree woody biomass (Udawatta and Jose, 2012). The growing market for animal products that have been produced under humane conditions has further increased the interest in this kind of system (Yates et al., 2007). Therefore, integrated crop-livestock systems with trees present opportunities for important contributions to global food security and sustainable livelihoods.

Tree cover tends to ameliorate extremes in temperature and reduce wind speed, which is a benefit to animal welfare (Yates et al., 2007; Lopes et al., 2016). However, changes in the microclimate become more pronounced as the trees grow, which might also affect the growth of the understory crop (Lin et al., 1999). Tree density, spacing and management (e.g., pruning and thinning) are other factors that determine how rapidly these changes come into play (Lin et al., 1999; Peng et al., 2009). Therefore, the issue is to quantify these changes in understory crop composition and microclimate caused by tree cover and the

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resulting effects on animal production and provision of ecosystem services.

The relative effects of shading on the production and nutritive value of grasses are not well described because understory plants can exhibit alterations in anatomy and physiology to compensate for low light quantity and distinct quality (Niinemets et al., 1998; Cavagnaro and Trione, 2007) and consequently increase or decrease herbage yield and nutritive value (Lin et al., 2001; Pontes et al., 2016). For example, some studies have suggested negative effects of shading on nutritive value (Wilson and Wong, 1982; Samarakoon et al., 1990) due to a decrease in the soluble carbohydrate level in plants accompanied by an increase in cell wall content, which reduces overall digestibility. In contrast to these findings, there are reports of higher nutritive value – primarily from increases in crude protein content – in plants grown in shade than in plants grown in full sunlight conditions (Lin et al., 2001; Peri et al., 2007; Abraham et al., 2014). It is worth noting that species responses to shading are also dependent on nutrient availability, particularly nitrogen (Pontes et al., 2016). These inconsistent responses lead to differences in the quantity and quality of the ingested herbage and thus alter animal performance and methane (CH_4) emissions.

Understanding how integrated crop-livestock systems may contribute to the reduction of greenhouse gases is essential for the development of public policies for environmental preservation (Savian et al., 2014). The need to mitigate ruminant CH_4 emissions is particularly important in Brazil, which is the second largest beef producer in the world (Paulino and Duarte, 2014). However, CH_4 emissions in integrated crop-livestock systems with trees have yet to be comprehensively studied (Molina et al., 2016).

According to Shibata and Terada (2010), the most promising and cost-effective way to reduce CH_4 emissions from cattle is to improve the efficiency of livestock production by, for example, improving feed quality and livestock management. For instance, grazing on less-mature pastures with lower fiber and higher soluble carbohydrates reduces CH_4 production (see Eckard et al., 2010 for a review). This tactic may help reduce CH_4 emissions per unit of animal product (Knap et al., 2014). Regardless, multiple strategies to mitigate greenhouse gas emissions should be evaluated on a broad scale while also considering the context of each production system (Berndt and Tomkins, 2013).

This study focuses on animal performance and CH_4 emissions from cattle grazing on mixed Italian ryegrass (*Lolium multiflorum* L.) × black oat (*Avena strigosa* Schreb.) pasture (*i.e.*, two C_3 cool-season grasses) in rotation with soybean (*Glycine max* L. Merril) or maize (*Zea mays* L.) in two integrated crop-livestock systems, with and without trees and at two N supply levels (90 and 180 kg N ha^{-1}). This study was performed over three years (2012–2014) in 6–8-year-old tree plantations growing in a subtropical climate. We hypothesized that the responses of understory species to combined shade and N effects provoke differences in the quantity and quality of the herbage ingested and thus alter animal production and CH_4 emissions from grazing animals. Our results provide data on animal production and CH_4 emissions to assist in the evaluation of tree inclusion in integrated crop-livestock systems. We also discuss the potential of C sequestration by woody biomass to further mitigate CH_4 emissions from cattle.

2. Materials and methods

2.1. Study area

A field experiment was conducted at the Agronomic Institute of Paraná, Ponta Grossa-PR (25°07′22″S, 50°03′01″W) in Southern Brazil. The local climate is humid subtropical, or Cfb in the Köppen classification system (Köppen and Geinger, 1928), with frequent occurrence of frosts and a mean annual temperature of 17.6 °C ranging from 14 °C in July to 21 °C in January. The mean annual rainfall is 1400 mm. The soil is a Cambisol and Ferralsol (Embrapa, 2006) with 19%, 3% and 78% clay, silt and sand in the upper 20 cm, respectively. In 2006, three tree species (eucalyptus, *Eucalyptus dunnii;* pink pepper, *Schinus molle;* and silver oak, *Grevillea robusta*) were planted in 6 of 12 experimental units. The species were interspersed in the same rows running crosswise in relation to the slope with a predominantly east-west orientation at 3 × 14 m spacing (238 trees ha^{-1}). The experimental area had been managed as an integrated crop-livestock system using no-till since 2009. Since winter 2010, the production system integrated cattle grazing on cool-season pasture (black oat + ryegrass) and warm-season maize (*cv*. IPR164) or soybean (*cv*. BRS232) crops on the same area and in the same cropping year. During the summer of 2013, the experimental area was thinned to 159 trees ha^{-1} by removing pink pepper trees, many of which had been damaged by cattle activity (Porfírio-da-Silva et al., 2012).

The black oat + ryegrass mixture was sown each year in rows with a seeding density of 45 and 15 kg ha^{-1}, respectively, in May/2012, April/2013 and May/2014 and 400 kg ha^{-1} of commercial formula 4-30-10 (N-P-K) was applied. Fertilizers were also applied annually for maize (400 kg ha^{-1} of commercial formula 10-30-10 + 270 kg urea ha^{-1}) or soy (400 kg ha^{-1} of commercial formula 0-20-20). Soybean and maize were sown in alternate years at the beginning of November.

2.2. Treatments and the experimental design

The experimental design was a randomized complete block with three replicates (paddocks). Two nitrogen fertilization treatments (90 and 180 kg N ha^{-1}, or N90 and N180, respectively) were crossed with two integrated crop-livestock systems: crop-livestock only (CL) and crop-livestock with trees (CLT). The four resulting treatments were: CL N90, CL N180, CLT N90 and CLT N180. Nitrogen fertilizer (as urea) was applied in a single application during every stocking season at ~40 days after pasture was sown. The fertilizer N supply was chosen to provide limiting (N90) and non-limiting (N180) N nutrition according to Alves (2002).

The experimental area of 13.07 ha was divided into 12 paddocks ranging from 0.77 to 1.22 ha (see Fig. 1). Each experimental unit (paddock) received three tester animals (permanent animals that remained throughout the experimental period) and a variable number of animals periodically adjusted to maintain the desired sward height of 20 cm ("put-and-take" method, Mott and Lucas, 1952). According to Kunrath et al. (2014), managing mixed annual ryegrass and black oat pastures at 20 cm under continuous stocking leads to several soil-plant-animal system benefits. This management criterion was adopted for both CL and CLT to allow for inter-comparability although no information is available regarding optimal sward height for ruminant weight gain and forage production for the species studied in association with trees.

The experimental animals were Purunã (¼ Aberdeen Angus, ¼ Canchim, ¼ Caracu, and ¼ Charolais) beef heifers with an average age

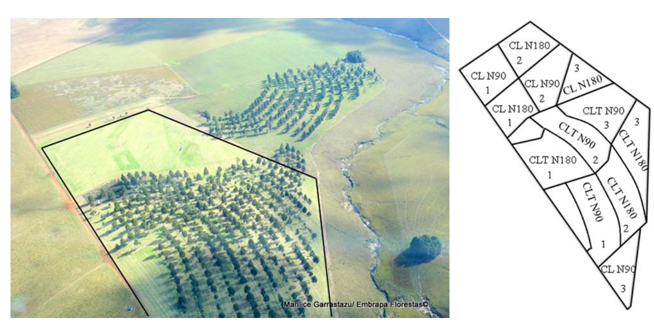

Fig. 1. The aerial view of the experimental site at Ponta Grossa, Paraná, Brazil (Photo: Marilice Garrastazu, Embrapa Florestas). The marked area in the picture is the map of the experimental area on the right with the 12 paddocks and their treatments: two integrated crop-livestock systems, *i.e.*, crop-livestock only (CL) and crop-livestock with trees (CLT), and two N levels, 90 and 180 kg N ha^{-1}, *i.e.*, N90 and N180, respectively. The numbers indicate the three blocks.