UNIVERSIDADE ESTADUAL PAULISTA – Unesp
CÂMPUS DE JABOTICABAL

THE IMPACT OF INTENSIFICATION PROCESS ON ENVIRONMENTAL AND PRODUCTIVE PARAMETERS DURING GROWING AND FINISHING PHASE OF BEEF CATTLE RAISED IN PALISADEGRASS GRAZING SYSTEM

Laís de Oliveira Lima
Zootecnista

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: THE IMPACT OF INTENSIFICATION PROCESS ON ENVIRONMENTAL AND PRODUCTIVE PARAMETERS DURING GROWING AND FINISHING PHASE OF BEEF CATTLE RAISED IN PALISADEGRASS GRAZING SYSTEM

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Laís de Oliveira Lima – born in Jundiaí -SP on March 25, 1996, daughter of Ademir de Oliveira Lima and Marcia Raquel Gomes Lima. Animal Scientist by the Faculty of Agricultural and Veterinary Sciences, UNESP Jaboticabal Campus (2018). She was grant with FAPESP Scientific Initiation Scholarship during her undergraduate studies. In March 2019, she joined the Post Graduate Program in Animal Sciences, master's degree, at the same institution, with a FAPESP scholarship, under the guidance of prof. Dr. Euclides Braga Malheiros and Dra. Marcia Fernandes as co-advisor.

EPIGRAPH

“Quero viver

Muito além das fronteiras

Dos que só sabem ser

Pedras de atiradeira”

(Almir Sater)

To God, who light up my way as I pursue my dreams.

To my grandparents Domingos and Sebastião (in memoriam), pillars of my family and consequently responsible for the human being that I became. I know that from up there you always looked and took care of me.

I dedicate to you!

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SUMMARY

UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Câmpus de Jaboticabal

CEUA – COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o projeto de pesquisa intitulado **"Impacto da intensificação sustentável da produção de bovinos de corte em áreas tropicais na mitigação das mudanças climáticas"**, protocolo nº 007979/18, sob a responsabilidade da Prof.ª Dr.ª Marcia Helena Machado da Rocha Fernandes, que envolve a produção, manutenção e/ou utilização de animais pertencentes ao Filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica (ou ensino) - encontra-se de acordo com os preceitos da lei nº 11.794, de 08 de outubro de 2008, no decreto 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), da FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS, UNESP - CÂMPUS DE JABOTICABAL-SP, em reunião ordinária de 14 de junho de 2018.

Vigência do Projeto	01/11/2018 a 30/09/2020
Espécie / Linhagem	Bovinos (*Bos taurus indicus*)
Nº de animais	238
Peso / Idade	210 a 510 kg / 15 a 27 meses
Sexo	Macho
Origem	Fazenda externa / Compra

Jaboticabal, 14 de junho de 2018.

Fabiana Pilarski

Profª Drª Fabiana Pilarski
Coordenadora – CEUA

THE IMPACT OF INTENSIFICATION PROCESS ON ENVIRONMENTAL AND PRODUCTIVE PARAMETERS DURING GROWING AND FINISHING PHASE OF BEEF CATTLE RAISED IN PALISADEGRASS GRAZING SYSTEM

ABSTRACT

Due to the concern arising from the environmental impacts caused by beef cattle, this study aimed to identify the environmental and productive impact of the beef cattle intensification process in order to develop a comprehensive set of indicators for the sustainable intensification of beef cattle chain. The experimental area consisted of 24 ha of *Urochloa brizantha* Hochst ex A. Rich Stapf cv. Marandu divided into 12 paddocks of approximately 2 ha each. Were used 48 tester Nellore young bulls with an average weight of 273.7 ± 7.6 and regulating animals were used to maintain the canopy height at 25 cm, using a grazing method in continuous stocking and the “put and take” technique with variable stocking. The treatments were of different intensification levels: low (0 nitrogen [N] ha^{-1}) intermediate (75 kg N ha^{-1}) and high (150 kg N ha^{-1}) in a completely randomized with three treatments design with four replications (paddocks). The fertilization was with ammonium nitrate (32% N). At backgrounding, all animals received a mineral mixture *ad libitum*. At the finishing phase, the animals of the low level of intensification were supplemented with 2% of body weight in the pasture, while the animals of intermediate and high intensification were finished in feedlot. Animals from all treatments received only human-inedible feed during the entire experimental period. Pasture evaluation included the determination of forage mass and the determination of nutritional components of forage. Animal response variables include, performance, intake and digestibility of nutrients, emission of enteric methane (CH_4), nitrogen balance (N), carbon footprint and net protein contribution (NPC). Crude protein (CP) intake and N balance increased linearly with the intensification levels (P < 0.05). Crude protein digestibility increased at a decreasing rate (quadratic effect, P < 0.05) with increasing intensification. In addition, N fertilization resulted in a linear increase in SR and average daily gain (ADG) from 1.75 animal unit (AU = 450 kg) ha^{-1} and 0.62 kg d^{-1} (0 kg N ha^{-1}) to 3.75 AU ha^{-1} and 0.82 kg d^{-1} (150 kg N ha^{-1}), respectively. Individual CH_4 emissions were not affected by treatment (P > 0.05). Carcass production increased with the intensification levels (P < 0.05), however GHG emissions intensity (kg CO_2e kg $carcass^{-1}$) also increased with the intensification levels (P < 0.05). Enteric methane was the main contributor to total greenhouse gases (GHG) emissions in all systems in both phases. Conversion efficiency of beef cattle (HePCE) was similar for all systems in all phases (P > 0.05). Net protein contribution (NPC) was above 1 for all systems and phases, indicating each system was positively contributing to supply human protein requirements. Improvements in grazing management is a powerful tool to mitigate environmental impact of grazing systems and the beef production system is a net contributor to the human protein supply without competing for food.

Key Words: cattle; by-products; environment; fertilization; forage

IMPACTO AMBIENTAL E PRODUTIVO DO PROCESSO DE INTENSIFICAÇÃO DA RECRIA E TERMINAÇÃO DE BOVINOS DE CORTE MANEJADOS EM CAPIM MARANDU

RESUMO

Devido à preocupação decorrente dos impactos ambientais causados pela pecuária de corte, este estudo objetivou identificar o impacto ambiental e produtivo do processo de intensificação da produção pecuária, a fim de desenvolver um conjunto abrangente de indicadores para a intensificação sustentável dos sistemas. A área experimental foi composta por 24 ha de *Urochloa brizantha* Hochst ex A. Rich Stapf cv. Marandu dividida em 12 piquetes de aproximadamente 2 ha cada. Foi utilizado e método de pastejo continuo com taxa de lotação variável. Foram utilizados 48 bovinos testers Nelore, com peso médio inicial de 273.7 ± 7.6 e animais reguladores, para manter a altura do dossel em 25 cm. Os tratamentos foram diferentes níveis de intensificação: baixo (0 nitrogênio [N] ha^{-1}), intermediario (75 kg N ha^{-1}) e alto (150 kg N ha^{-1}), em delineamento inteiramente casualizado, com três tratamentos e quatro repetições (piquetes). A adubação foi realizada com nitrato de amônio (32% N). Durante a recria, todos os animais receberam uma mistura mineral ad libitum. Na terminação, os animais de baixo nível de intensificação foram suplementados com 2% do peso corporal no pasto, enquanto os animais de intensificação intermediária e alta foram terminados em confinamento. Os animais de todos os tratamentos receberam apenas alimentos não comestíveis por humanos durante o período experimental. A avaliação da pastagem incluiu a determinação da massa de forragem e componentes nutricionais da forragem. As variáveis de resposta do animal incluíram consumo e digestibilidade dos nutrientes, emissão de metano entérico, balanço de nitrogênio (N), desempenho, pegada de carbono e contribuição líquida de proteína (NPC). O consumo de proteína bruta (PB) e o balanço de N aumentaram linearmente com o aumento da intensificação ($P <$ 0,05). A digestibilidade da PB aumentou em uma taxa decrescente (efeito quadrático, $P <$ 0,05) com o aumento da intensificação. Além disso, a intensificação resultou em um aumento linear taxa de lotação (SR) e ganho médio diário (GMD) de 1,75 unidade animal (AU = 450 kg) ha^{-1} e 0,62 kg d^{-1} (0 kg N ha^{-1}) para 3,75 UA ha^{-1} e 0,82 kg d^{-1} (150 kg N ha^{-1}), respectivamente. As emissões individuais de metano (CH_4) não foram afetadas pelos tratamentos ($P >$ 0,05). A produção de carcaça aumentou com os níveis de intensificação ($P <$ 0,05), porém a intensidade das emissões de gases do efeito estufa (GEE; kg CO_2e kg^{-1} carcaça) também aumentou com os níveis de intensificação ($P <$ 0,05). O CH_4 entérico foi o principal contribuinte para as emissões totais GEE em todos os sistemas em ambas as fases. A eficiência de conversão de bovinos de corte (HePCE) foi semelhante em todos os sistemas em todas as fases ($P >$ 0,05). A NPC foi acima de 1 em todos os sistemas e fases indicando que cada sistema estava contribuindo positivamente para suprir as exigências de proteína humana. Melhorias no manejo do pastejo são uma ferramenta poderosa para mitigar o impacto ambiental dos sistemas de bovinos de corte em pastejo e produção de bovinos de corte é um contribuinte de proteína líquida para o atender os requerimentos de proteína humana sem competir por alimento.

Palavras-chave: adubação; bovinos; forragem; meio ambiente; subproduto

CHAPTER 1 – GENERAL CONSIDERATIONS

1. Introduction

Brazil is one of the world leaders in beef production, with the largest world herd (213,68 million head), occupying an area of approximately 162 million hectares of pasture (ABIEC, 2020). The livestock gross domestic product (GPD) contributes with 8.7% to the total Brazilian GDP. Despite its great relevance to national and international economy, livestock in Brazil has often been perceived negatively by public opinion for its impact on the deforestation process and its contribution to the emission of greenhouse gases (GHG; Tonato et al., 2013). In addition, despite the overall improvement in productivity over the last decades, grazing systems with low technological level and productive indexes are still common (Romanzini et al., 2020), which results in pastures that are often degraded or below their production potential (Machado et al., 2011).

The concepts of sustainable intensification focus on the awareness of climate change and food shortage risks and is an important tool that aims to increase the productivity of the beef production chain. In addition, it also aims to contribute to a gradual and proportional reduction of the environmental impact (Tedeschi et al 2015). Grazing management combined with fertilization is an auxiliary tool to improve animal performance, increase stocking rates, meat production per unit of area, improve carcass and meat quality as well as to reduce the background time to slaughter (Berndt and Tomkins 2013). Another intensification strategy is feedlot, in which an increase in the proportion of concentrate and physically effective fiber in the diet is adopted leading to higher energy intake, nutritional value, feed efficiency, meat quality and a decrease in methane and carbon monoxide emissions (Marcondes et al., 2011).

Unfortunately, adoption of sustainable intensification might incur in controversies, which are often based on incomplete information or lack of sound science (Tedeschi et al., 2015). Moreover, inconsistencies in the estimation and consolidation of emission and sequestration values of greenhouse gases related to Brazilian livestock have been reported. These problems are mainly related to limitations in experimental protocols and the use of emission factors generated in temperate climates (Tonato et al., 2013). Thus, in order to identify alternatives that minimize their environmental impacts it is crucial to develop reliable scientific information that quantifies more accurately the environmental impact of cattle production in tropical systems.

Therefore, the hypothesis of this work is that sustainably intensified systems (i.e. systems which adopt grazing management, pasture fertilization and supplementation) are a viable strategy for mitigating climate change and food shortage. Therefore, the objective of this study was to evaluate the environmental and productive impact of beef cattle intensification process of *Urochloa brizanta* cv. Marandu grazing systems during background and finishing phase.

2. Literature review

2.1 Livestock production

From the 20th century onwards, the world was marked by a strong demographic explosion, in an environment where the free movement of capital and goods prevailed. This high density of the human population, increased urbanization and per capita income have driven the increase of protein intake from animal origin in detriment of the intake of grains (Barros et al., 2011), enlarging the animal protein demand worldwide.

Brazil stands out for having the largest cattle herd and being the second largest beef producer. National production is expected to play an effective role in meeting the growing demand for animal products (ABIEC, 2020). Despite its great relevance to the economy, livestock in Brazil has often been perceived negatively by national and international public opinion since national livestock production is based on grazing systems with low technological input. These systems are classified as extensive with low nutritional quality forage available for feeding (Romanzini et al., 2020) and account for about 87% of the total national beef production. The pastures used in these systems are composed of native forage or cultivated forage and usually do not follow technical recommendations for pasture management (Cezar et al., 2005). In these systems, profitability and sustainability are compromised due to the low production rate and by the indirect involvement with deforestation process as well as its contribution to the emission of greenhouse gases (GHG; Tonato et al., 2013).

However, with technological advances and increased demand for beef, semi-intensive and intensive systems are becoming more popular amongst cattle producers. The use of feedlot, especially in the finishing phase, is the component that distinguishes intensive systems (Cezar et al, 2005). During the dry season, when pasture produces declines and there is high animal load, the animals are moved to drylotes, where they will receive high amounts of concentrate. In the semi-intensive system, the animals remain in the pasture. However, in this system some technological tools such as pasture management, mineral and grain supplements are adopted. In 2019, 6.09 million heads of cattle finished in feedlot were slaughtered, representing about 14% of the total animals slaughtered in the country.

2.2 GHG emission

The livestock production system is responsible for the emission of some gases associated with the greenhouse effect, among which methane (CH_4), nitrous oxide (N_2O) and dioxide carbon (CO_2) are the most relevant ones.

Methane emission is a consequence of the fermentation process that occurs in the rumen (Moss et al., 2000; Beauchemin et al., 2008). In the rumen environment, CH_4 is generated anaerobically by methanogenic microorganisms from the Archaebacteria domain (Moss, 1993) and its production is mainly modulated by the presence of free carbon dioxide (CO_2) and hydrogen (H_2), reducing these gases to CH_4 and water (H_2O) (Beauchemin et al., 2008) (Equation 1).

$$\boldsymbol{CO2 + 4H2 \rightarrow CH4 + 2H2O}$$

This emissions account for 85 to 90% of the total CH_4 emitted by the livestock system, and the rest being produced from the manure of these animals. Globally, CH_4 accounts for 65% of livestock non-CO_2 GHG emissions (Herrero et al., 2013), and of the CH_4 from enteric fermentation, around 77% comes from cattle (Gerber et al., 2013).

Nitrous oxide is formed through nitrification and denitrification processes. The N_2O is an important GHG due to its heating power 265 times greater than CO_2. The main livestock source of N_2O are from deposition of cattle urine in the soil and from nitrogen fertilization of pastures. In 2005, N_2O emissions from grazing animals represented 39.4% of the emissions of this gas in agricultural soils, with cattle being the main responsible for this contribution (MCTIC 2017). In addition, the excretions of N cause formation of nitrate which is a mobile compound in the soil that can leach contaminating and modifying the composition of surface and groundwater making them unsuitable for human consumption (BR Corte, 2010).

Carbon dioxide emissions are mainly associated with changes in land use in Brazil, especially by converting forests to pasture or agricultural systems. In addition, the inadequate management of forages and soil contribute to losses of soil organic matter and and consequently release carbon into the atmosphere. According to Cardoso et al. (2016) the lack of N and degradation of pasture can result in carbon loss of 57 g / m^2 per year to the atmosphere.

The Global Warming Potential (GWP) metric is adopted to compare and add the greenhouse gases emitted. In this system, the equivalent of carbon dioxide (CO_2e) is currently used for national inventories as a weighting factor to convert different gases emissions to the same unit. In 2015 the Brazilian agricultural sector contributed 33.6% of the national CO_2e emitted being 56.5% of these emissions from enteric fermentation (MCTIC 2020).

A life-cycle analysis of beef cattle production in Brazil considered five beef production scenarios along and showed that the GHG emissions from the most degraded system to the most intensified system dropped from 79.15 CO_2e /kg carcass to 34.17 CO_2e /kg carcass (Cardoso et al., 2016). These results highlight the importance of reducing land use in order to spare natural resources, improving the efficiency of feedstuff utilization to reduce enteric CH_4 emission and limiting energy-intensive N fertilizers to reduce CO_2 and N_2O emissions and other water quality and landscape diversity problems.

2.3 Sustainable Intensification

Sustainable intensification of livestock aims to increase animal production per unit area considering alternatives that fully address the three pillars of sustainability: social, environmental, and economic (Figure 1; Tedeschi et al., 2015).

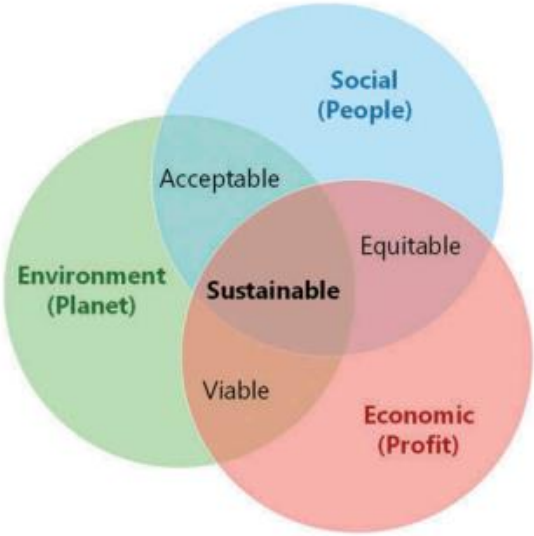

Figure 1. From Tedeschi et al., 2015. The three pillars of sustainability. Source: Based on 'sustainable development' from Wikimedia.org under Creative Commons licensing, and further adapted from United Nations (1987), IUCN (2005), Makkar (2013), and Makkar and Ankers (2014).

It seems to be possible to increase livestock efficiency and mitigate GHG emissions through the adoption of technologies such as improved pastures, genetic selection of animals and land-use conservation practices since these measures can directly reduce livestock emissions per kilo of product by increasing the productivity of grazing systems and reducing of GHG emissions (Thornton and Herrero, 2010). The intensification of production may also contribute to reduce indirect emissions through the effect of land sparing. In this sense, greater stocking rates would allow reductions in total grazing area which potentially could lead to cattle production areas be converted into other activities such as bioenergy production or conservation (Cohn et al., 2011, Cardoso et al., 2016).

The intensification of livestock can be an alternative to reduce the environmental impacts caused by the activity (Dias-Filho, 2011; Martha Junior et al., 2012, Delevatti et al., 2019) given that strategies that improve animal performance and/or productivity will consequently decrease the amount of emissions per kilo of product and the need to explore more grazing areas (Dumortier et al., 2010). This can be achieved by applying grazing management techniques allied with fertilization based on recommendations which consider soil fertility. These practices can allow grazing systems to become atmospheric carbon sequestrators in order to increase from 50 to 150 kg of sequestered carbon per hectare (Paulino, 2010).

Although it is impractical to reconcile the maximum gain per animal with the maximum gain per area, since increasing the stocking rate, aiming to increase the gain per area, the supply of forage per animal decreases and, consequently, there is a fall in individual gain (Mott, 1960), strategies such as fertilization and supplementation can improve both gains without losing the equilibrium point (Barbero et al., 2017).

2.3.1 Intensification via grazing management

The animal performance in grazing systems is determined, mainly by the forage supply, however great variations in its composition and structure can be found according to its management. Thus, grazing management plays a key role in the animal feed context, since the adoption of specific grazing managements strategies result in changes in the defoliation intensity of the plants, which causes changes in the canopy architecture, changing the proportions of the morphological and botanical components (Santos et al., 2018)

The grazing management has the function of adjusting intake, represented by defoliation caused by animals, in the act of grazing, and regrowth, a defense mechanism of plants, aiming at maintaining their life cycle, thus enabling an optimum point between production and use of forage. The increase in forage leftovers, caused by flaws in grazing management, results in greater senescence, tissue death and less efficient use of forage, reducing the potential animal production in the area (Oliveira 2014).

During the growth period of the pasture, grazing systems developed under continuous stocking, if efficiently managed, allow animals to constantly consume young leaves, which have greater digestibility when compared to rotational or intermittent grazing systems (Hodgson 1985).

An efficient management tool for both continuous and rotational grazing systems is related to the 95% light interception criterion, based on the grazing height. This criterion considers that 95% of the light incident in the canopy is being intercepted by the leaves (Hay & Walker, 1989) and consequently the rate of forage accumulation is the maximum, in such a condition (Parsons et al., 1988).

Based on the concept of the highest net forage accumulation when grass achieves 95% incident light interception (Barbero et al., 2015; Koscheck et al., 2020), a sward height of 25 cm has been reported to be optimal for palisadegrass under continuous stocking (Santana et al., 2017). Gomes et al., 2019 state that the height of 25 cm of palisadegrass pastures is the most suitable for continuous stocking systems, as it provides high nutritional value combined with an adequate forage supply. In view of this, the adoption of height as a management criterion allows the control of the forage mass and the stocking rate, which favors the simultaneous determination of the quality and quantity of forage and the maintenance of the sustainability of the system.

In this context, pastures kept under continuous stocking and effectively managed, with stocking rate adjustment determined by management criteria, such as the height, and 95% light interception (Santana et al., 2017), provide continuous ingestion of young leaves by the animals, so that the digestibility of the forage consumed is high (Reis et al., 2012).

The knowledge and use of recommendations, such as the light interception criterion, based on the grazing height is fundamental to any production systems that use forage as the main food source.

2.3.2 Intensification via fertilization (Ammonium nitrate)

Nitrogen fertilization is a technique that increases the supply of nutrients in the soil to improve production of tillers, besides having significant benefits in the nutritional value and morphological characteristics of the pasture (Corsi, 1984)

The association of management of grassland pastures in a tropical climate based on the interception of 95% of incident light with nitrogen fertilizers can result in high forage production, nutritional value, and animal performance (Barbero, et al., 2015; Koscheck, et al., 2020).

The availability of nitrogen is one of the factors that can affect plant growth (Lemaire et al., 2008; Lemaire 1997). This nutrient promotes several physiological changes in forage grasses, such as an increase in the number, size, weight, and rate of appearance of tillers and leaves, and elongation of the stem, which are important factors in the production of dry mass and are directly related to the nutritional value of the plant. forage, resulting in the increase of animal production indexes (Santana et al, 2017). Additionally, N fertilization increases the protein content of the plant and its apparent digestibility (Blaser, 1964). Delevatti et al. (2019) observed in studies with palisadegrass under continuous stocking that the application of N fertilization resulted in an increase in the crude protein values of the forage due to the increase in the contents of amino acids and protein synthesis, increasing the fractions A, B1 and B2 of the forage, in addition to increasing the herbage mass, forage accumulation rate, and nutritive value of the forage leading to improvement of animal performance.

Moreover, studies have shown that intensive management of tropical grasses are able to store significant amounts of carbon in the soil as a consequence of the high productivity of these pastures when fertilized (Braz, et al. 2013) because of stimulation of root development in depth favouring the process of accumulation of organic matter in the soil and contributing to mitigate the emission of greenhouse gases (Roscoe, et al. 2006).

The beneficial effects of fertilizers on production are unquestionable. However, the challenge of modern agriculture is to produce food for the growing world population without causing greater damage to the environment. (Aquino, 2009).

The crucial issue of the use of chemical fertilizers in the soil refers to the environmental risks associated with overuse. An example of this are nitrates (NO_3^-), which are highly soluble and can easily be leached out of the root absorption zone leading to direct effects on water quality for human consumption (Rosolem et al., 2003). In tropical pastures, ammonia (NH_3) volatilization is also one of the main loss pathways, mainly when urea is applied at the end of the rainy season (Martha Jr., 2004; Primavesi et al., 2001). When applied to the soil, urea rapidly undergoes hydrolysis by the action of the enzyme urease, releasing ammonium (NH_4) and carbon dioxide (CO_2) into the atmosphere (Jenkinson, 2001). This reaction promotes an increase in the pH of the soil close to the fertilizer granules, due to the consumption of H^+ into the medium, favouring the transformation of NH_4^+ (ammonium) into NH_3, a gaseous form susceptible to loss through volatilization. The sum of these factors has led to the need to use protection mechanisms in order to reduce losses and increase crop productivity.

A study in Jaboticabal (Corrêa et al., 2018) using three levels of N top-dressed (90, 180 and 270 kg N ha^{-1}) and three sources of N (urea, ammonium nitrate and ammonium sulphate) on palisadegrass showed that total N-NH_3 losses increased linearly with the increase of N level, irrespective of N source, However, ammonia volatilization reduced in up to 85% for N fertilizations with nitric and ammoniacal N forms when compared with Urea. The sources of nitrogen were ordered based on N losses by volatilization: urea>ammonium nitrate>ammonium sulphate. Urea has amidic N with higher susceptibility to urease, while the ammoniacal form of ammonium sulphate do not favours ammonia volatilization in soils. The utilization of N fertilizations with nitric and ammoniacal N forms could be an efficient strategy to decrease N losses by volatilization in tropical pasturelands.

There is a lack of studies combining the effects of ammonium nitrate fertilization on forage and animal performance, especially in *Urochloa brizantha* cv. Marandu. This is the most studied and adopted forage species in Brazil, therefore it is necessary to have a better understanding of the effects of alternative fertilize sources which can provide N to tropical grass pastures as well as decrease of environmental problems associated with N losses.

2.3.3 Intensification via supplementation at finishing phase

The use of concentrated supplements for grazing animals, especially during the finishing phase that coincides with the dry season, allows the supply of specific nutrient deficient in the forage maximizing the digestion activity of the fibrous fraction and making more effective use of structural carbohydrates (Reis et al., 2011) in addition to reducing the emission of enteric CH_4.

The production of enteric CH_4 depends on factors related to the animal and related to the animal diet (Berchielli et al., 2012). Higher CH_4 emissions are associated with higher levels of dry matter intake and with lower levels of digestible energy density in the diet (Van Lingen et al., 2019). The increase in the proportion of digestible nutrients provides ruminal conditions that lead to a higher proportion of propionate, resulting in lower methane emissions (Hart et al., 2009; Figure 2).

Acetato:

$$\text{Piruvato} \longrightarrow C_2H_4O_2 + CO_2 + 4H \text{ (1)}$$

Propionato:

$$\text{Piruvato} + CO_2 \longrightarrow \text{fumarato} + 2H \longrightarrow C_3H_6O_2 + CO_2 \text{ (via succinato)}$$

$$\text{Piruvato} \longrightarrow \text{lactato} + H_2O \longrightarrow \text{acrilato} + 2H \longrightarrow C_3H_6O_2 \text{ (via acrilato)}$$

Butirato:

$$\text{Piruvato} \longrightarrow C_4H_8O_2 + CO_2 + 2H$$

Figure 2. Production of the main short-chain fatty acids. Van Soest (1994) adapted.

Studies conducted at FCAV / UNESP (Barbero et al. 2015, San Vito et al. 2016 and Dallantonia et al. 2017) with the association of grazing management and supplementation observed average methane emission of 41. 48. 46 and 43 kg of CH_4 / year per animal, respectively, these values are lower than the values established by the IPCC (2019) (Yona et al., 2020) which were 55 kg and 58 kg of CH_4 / year in high and low productivity systems, respectively.

In addition, supplementation combined with grazing management is an auxiliary tool to improve animal performance, increase stocking rate, meat production per unit area, improve carcass and meat quality, as well as reduce the breeding period and fattening of grazing animals (Reis et al., 2011).

Another intensification strategy is feedlot, which allows expanding the supply of beef in the off-season as the cattle do not lose weight increasing the productivity of the herd and decreasing the length of the finishing phase. Generally, in feedlot there is an increase in the proportion of concentrate in the diet which increases the energy supply of the diet improving its nutritional value. The higher nutritional value leads to better feed efficiency and meat quality as well as less emission of GHG (e.g. methane and carbon monoxide) (Marcondes et al., 2011).

Therefore, sustainable intensification appears to be a promising way to increase productivity and competitiveness of livestock in relation to other activities. It reconciles greater production per area with a reduction in the production cycle in addition to functioning as an indirect tool for reducing the pressure for deforestation.

2.4 Human-inedible food for animal feed

Meat products are often criticized by consumers as a source of protein in human diets due to concerns related to competition for food (Baber et al., 2018). Indeed, production of the world supply of food of animal origin, which make up 18% of the global calorie intake requires substantial feed resources. Considering the increase in 26% of the global population projected by the United Nations by the year 2050, large additional amounts of animal feedstuffs will be required. Thus, the opportunity in hand is to develop strategies in order to meet the challenge of providing high-quality food to a growing human population while reducing the environmental footprint in an effective, economical, and timely fashion (Tedeschi et al., 2015).

Some believe that livestock always competes with human grain supplies (e.g. corn) assuming that the use of livestock for food production is an inefficient or wasteful use of resources (Capper et al., 2013). However, grain usage in cattle feeding mainly occurs in the finishing phase in feedlot where meat production in this system corresponds to only 7 to 13% of the total meat produced worldwide (FAO. 2009; Gerber et al., 2015; Mottet et al. 2017)

In addition, it is important to consider that the prospects for increasing supplies based on food for animal production involve resources that cannot or are not consumed by man due to limiting factors such as accessibility, digestibility, palatability (human-inedible materials) and those that can be consumed by humans, like cereal grains (human edible). In total volume on a global basis the first group is by far the largest.

The usage of by-products for animal feed increases every year which decreases the waste-disposal problem. A by-product feedstuff is a product obtained during the harvesting or processing of a commodity from which human food or fiber is derived which has value as an animal feed. In Brazil, the main co-products and by-products of the industry with potential for use in animal feed are cottonseed, corn germ, citrus pulp, soybean meal, raw sugar cane bagasse, cane molasses, crude glycerin, dry distiller grain (DDG) and soybean hulls among many other.

Brazilian meat production is essentially pasture-based. Around 90% of the meat produced is raised in grazing systems (ABIEC, 2020), a product that is not consumable by humans. Ruminants are efficient in converting vast renewable resources from rangeland, pasture, and crop residues or other by-products into food edible for humans

(Mottet et al., 2017). The rumen serves as fermentation chamber containing the microbial enzyme cellulase, the only enzyme able to digest cellulose which is the most abundant plant product. In addition, large portion of grazed areas is not suitable for crop production of human food. Thus, the benefits of livestock production include conversion of poor and erodible land into cultivate and productive, conversion of human-inedible feed into high-quality food (Ertl et al., 2015, Gill 2013), preservation of ecosystems (i.e. grasslands) recycling of organic matter and nutrients with consequently preservation of ecosystems, besides many social aspects associated with livestock (Cheeke 1998; Janzen 2011).

3. Hypothesis

The hypothesis is that livestock intensification, achieved by fertilization of pastures combined with grazing management and feed supplementation is a viable strategy for mitigating climate change by reducing GHG emission intensity of the activity and increasing the net protein contribution of the cattle ranching production to supply the human protein requirements without competing for food. After evaluating the results, the best intensification scenario can be analyzed, compared, and identified in terms of lower GHG emissions and higher carcass production.

4. Objectives

Under three levels of system intensification determined by nitrogen fertilization doses and grazing management, it is proposed to assess the impact on forage production and quality, intake, nutrient digestibility, urinary excretion, animal performance, animal growth, GHG emissions and, to estimate beef's contribution to meeting human protein requirements.

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CHAPTER 2

The following chapter is written according to the publication rules of the Journal: Tropical Animal Health and Production

CHAPTER 2 - ENVIRONMENTAL AND PRODUCTIVE IMPACT OF NELLORE YOUNG BULLS GRAZING TROPICAL PASTURE FERTILIZED WITH INCREASING NITROGEN DOSES

Abstract: This study evaluated the intake, digestibility, nitrogen balance, enteric methane production, and performance of Nellore bulls on palisadegrass (Uruchloa brizantha cv. Marandu) pasture fertilized with increasing nitrogen doses, in a continuous stocking with a variable stocking rate (SR) grazing method and target canopy height of 25 cm. Treatments consisted of different annual doses of nitrogen (N) fertilization: 0, 75, and 150 kg N ha^{-1}, using ammonium nitrate (32% N) as the nitrogen source. The experimental design was completely randomized, with three treatments and four replications (12 paddocks). Intake, digestibility, urinary excretion, and methane emissions were measured in eight animals per treatment. Crude protein (CP) intake and N balance increased linearly with the increase in N fertilization ($P < 0.05$). Crude protein digestibility increased at a decreasing rate (quadratic effect, $P < 0.05$) with increasing N fertilization. In addition, SR, and average daily gain (ADG) linearly increased from 1.75 animal unit (AU = 450 kg) ha^{-1} and 0.62 kg d^{-1} (0 kg N ha^{-1}) to 3.75 AU ha^{-1} and 0.82 kg d^{-1} (150 kg N ha^{-1}), respectively. Individual methane emissions were not affected by treatment with an average emission of 164.7 g d^{-1} ($P > 0.05$). Annual N fertilization with ammonium nitrate between 75 and 150 kg N ha^{-1} in palisadegrass pastures under continuous stocking enhances animal performance per unit area without affecting individual methane emissions and methane energy loss in relation to gross energy intake (Ym).

Keywords: cattle, intensification, methane, nitrogen, performance, tropical pasture

1. Introduction

Beef production in tropical regions, like Brazil, is primarily based on pastures. The total Brazilian grassland area is approximately 162 million hectares, supporting approximately 87% of the total national cattle herd of 215 million head (ABIEC, 2020). Despite their significance, tropical pastures have often been criticized for their low livestock productivity indices due to improper animal and grazing management, resulting in pastures that are often degraded or below their production potential (Romanzini et al., 2020). However, increasing concerns about environmental impact and sustainability have promoted the use of input technologies to enhance profitability, sustainability, and efficiency of pasture-based production systems (Cardoso et al., 2020).

Grazing management and fertilizer application, among other interventions, have been reported to improve forage production. Additionally, a sward height of 25 cm has been reported to be optimal for palisadegrass under continuous stocking, resulted from the highest net forage accumulation when grass achieves 95% incident light interception (Santana et al., 2017). In addition to grass management, nitrogen (N) fertilization has been demonstrated to increase stocking rate (SR) and, consequently, animal production per unit area, contributing to sustainable intensification systems (Delevatti et al., 2019a, Cardoso et al., 2020). Moreover, increasing N levels associated with pasture management strategies was observed to improve forage quality, increase crude protein (CP) content, and reduce cell wall contents (Delevatti et al., 2019), and might increase forage intake and fiber digestibility, as well, contribute to decreased methane emissions. Nonetheless, to the best of our knowledge, there is a lack of studies evaluating the impact of N fertilization doses in grazing systems on individual methane production and methane energy loss in relation to gross energy intake (Ym). In addition, a previous study revealed that increasing levels of urea application from 0 to 270 kg ha^{-1} year^{-1} on palisadegrass pastures under continuous stocking increased forage N content but decreased N use efficiency, suggesting the application of moderate amounts of N annually of between 90 and 180 kg ha^{-1} (Sales et al., 2019). Compared with urea, ammonium nitrate causes less N loss by volatilization; thus, smaller doses would be required for the same productivity level.

Therefore, we investigated the most appropriate N fertilization dose using ammonium nitrate to optimize Nellore bull performance (per animal and unit area) on palisadegrass pasture under continuous stocking without adversely affecting the environment. Variables of interest were performance, intake, digestibility, nitrogen balance, and enteric methane emissions. We hypothesized that livestock intensification, achieved by fertilization of pastures combined with grazing management, is a viable strategy for mitigating climate change, firstly by increasing animal productivity and secondly, by decreasing methane emission intensity.

This research is part of solutions for livestock sustainable intensification practices whose envisaged productivity increases are congruent with environmental preservation through increasing production per unit area, shortening the production cycle, and maximizing nutrient utilization efficiency.

2. Material and Methods

Experimental area, design, and management

The experiment was conducted at the Beef Cattle Center of São Paulo State University "Julio de Mesquita Filho," Jaboticabal, SP, Brazil (21°15′22″ S 48°18′08″ W, 595 m altitude). The typical climate is humid subtropical, with mild, dry winters and hot, wet summers. The experimental period lasted from December 2018 to May 2019, during which the average temperature was 23.3 ± 2.1°C, and the total rainfall was 869.5 mm.

The experimental area comprised 24 ha of Marandu palisadegrass *(Urochloa brizantha* Hochst ex A. Rich Stapf 'Marandu') divided into 12 paddocks. The treatments consisted of different annual nitrogen (N) fertilization doses at 0, 75, and 150 kg N ha^{-1} of ammonium nitrate (32% N). The experimental design was completely randomized, with three treatments and four replications (paddocks). Fertilization was divided into three doses of the same amount according to precipitation distribution.

Animal and grazing management

The grazing method was continuous stocking with a variable stocking rate (SR) to maintain the canopy height at 25 cm, considering a 95% light interception (IL) (Santana et al., 2017).

Forty-eight Nellore bulls (*Bos taurus indicus*) with an initial body weight (BWi) of 273.7 ± 7.6 kg were used to measure animal performance. Animals were identified, weighed, and randomly distributed in groups of four bulls per paddock. The remaining animals (*n* = 28) were used to maintain the pre-established grazing height, using the put-and-take methodology. Animals received a mineral mix *ad libitum* (14.5% Ca, 8% P, 1% Mg, 4% S, and 13% Na on a dry matter basis) from December to March and a mineral supplement (14.5% Ca, 8% P, 1% Mg, 4% S, 13% Na, and 32.4 % crude protein on dry matter basis) at a rate of 1 $g \cdot kg^{-1}$ BW daily from April to May.

During the experimental period, a maximum temperature of 32.7°C and a minimum of 16.4°C were recorded. Accumulated precipitation was 88.2, 148.1, 282.6, 115.2, 97.6 and 24.2 mm, for December 2018, January, February, March, April, and May 2019, respectively (https://www.fcav.unesp.br/ #!/station).

Forage sampling

Canopy height was measured weekly, based on the measurement of 80 random points per paddock using a ruler graduated in centimeters at the curvature of the upper leaves. Adjustments in SR were performed to maintain the canopy height at 25 cm. Herbage mass was estimated every 28 days (from January to May 2019) at four average sward height sites per paddock, after clipping, at soil level, all plants within the perimeter of a rounded rim (0.25 m^2) representing the mean forage mass of paddocks. Samples were then separated into dead material, stem + sheath, and green leaves and dried at 55°C to a constant weight to estimate forage DM per hectare. In March 2019, additional forage samples were hand-plucked (Bonnet et al., 2011) to determine the chemical composition. Data on canopy characteristics and chemical composition of the hand-plucked forage samples are shown in Table 1.

Table 1. Characteristics of Marandu palisadegrass *Urochloa brizantha* Hochst ex A. Rich Stapf cv. Marandu pastures at different levels of nitrogen fertilization during backgrounding (wet season).

	N fertilization, kg ha^{-1}.year		
Pasture[1]	0	75	150
Herbage mass (10^3 kg DM ha^{-1})	4.6 ± 1.15	5.3 ± 1.58	5.0 ± 1.06

Green leaves (%)	24.5 ± 3.80	30 ± 6.20	33.1 ± 5.8
Stem + sheath (%)	16.2 ± 6.0	25.1 ± 8.9	28.6 ± 5.5
Dead material (%)	59.3 ± 7.5	44.9 ± 13.4	38.3 ± 7.6
Forage allowance (kg DM kg BW^{-1})	3.0 ± 0.85	1.9 ± 0.74	1.6 ± 0.40
Leaf allowance (kg DM kg BW^{-1})	0.78 ± 0.19	0.59 ± 0.25	0.54 ± 0.14
Chemical composition[2]			
Organic matter (% of DM)	91.4 ± 0.37	91.8 ± 0.31	92.4 ± 0.48
Crude protein (% of DM)	11.0 ± 0.25	14.7 ± 0.40	17.3 ± 0.47
aNDF (% of DM)	47.8 ± 8.9	48.9 ± 4.3	47.5 ± 1.6
ADF (% of DM)	21.5 ± 4.7	19.9 ± 3.6	21.6 ± 2.6
iNDF (% of DM)	19.5 ± 2.2	17.2 ± 0.66	16.9 ± 2.6
GE (MJ kg DM^{-1})	17.0 ± 0.06	17.3 ± 0.05	17.6 ± 0.07

[1]Means from January to May 2019, ± standard deviation.
[2]Hand plucked forage samples on March 2019. BW = body weight; DM = dry matter; aNDF= neutral detergent fiber exclusive of ash; iNDF = indigestible aNDF; GE = gross energy

Intake, digestibility, and urinary excretion

Individual intake, digestibility, and urinary excretion were measured in 24 animals (eight animals per treatment; two animals per paddock) in March 2019. Dry matter intake (DMI) of grazing bulls was calculated using two markers, chromium and indigestible neutral detergent fiber (iNDF). To estimate fecal excretion, chromium oxide was supplied orally for ten days, at a rate of 10 g·Cr_2O_3·day^{-1} per animal, with the first seven days allocated for acclimatization and the last three days for fecal collection at 12 h intervals. Feces were oven-dried (55°C for 72 h), ground, and separated by animal. Fecal excretion was calculated based on the marker concentration determined using atomic absorption spectrophotometry (Williams et al., 1962).

Individual forage intake was estimated using iNDF content as an internal marker. To represent the diet (forage) consumed by grazing animals in each paddock, forage samples were hand-plucked (Bonnet et al., 2011) during the same period. The iNDF content of the forage and fecal samples was estimated according to Valente et al. (2011). Forage intake was estimated as described by San Vito et al. (2016). The urine of grazing animals was collected as a spot sample during spontaneous urination in the morning for three consecutive days. Daily urinary volume was estimated based on creatinine excretion, as described previously (Santos et al., 2016). Approximately 40 mL of pure urine was separated for analysis of total nitrogen.

Allantoin in urine was analyzed colorimetrically as described by Chen and Gomes (1992). Uric acid concentrations in urine were estimated according to Santos et al. (2016). The urinary purine derivatives (PD) excretion was calculated from the sum of total allantoin and uric acid excretions obtained by multiplying their concentrations by the daily urinary volume. The ruminal synthesis of microbial N was estimated based on urinary excretion of PD, using the equations proposed by Chen and Gomes (1992). Microbial crude protein efficiency was calculated as the ratio of microbial crude protein (g) to digestible OM ingested (kg).

Enteric methane

Enteric methane (CH_4) produced through eructation was measured using the tracer gas [sulfur hexafluoride (SF_6)] method according to the manual of Global Research Alliance on Greenhouse Gases in Agriculture (Primavesi et al., 2004) in the same animals whose intake was measured. Briefly, capsules with a constant release of SF_6 (128.5 ± 5.91 µg/h) were introduced into the rumen orally. The sampling apparatus comprised a polyvinylchloride collection vessel and a capillary tube extending from the collection canister to just above the animals' mouth and nostrils. The canister was attached to a collar around the bull's neck. To initiate sample collection, the attached canister was connected to the transfer line, and a valve on the collection vessel was opened. The collection vessel was changed daily for six consecutive days at 24 h intervals. Additionally, an empty canister was placed in the paddocks daily to measure the background CH_4 concentration. Gas chromatography (Shimadzu GC2014 Gas Chromatograph; Shimadzu Corporation, Kyoto, Japan) was used to analyze CH_4 and SF_6 concentrations. Daily enteric CH_4 emissions were calculated as described previously (Berça et al., 2019).

Chemical Analysis

Samples of hand-plucked forage and feces were dried at 55°C for 72 h in a forced-air oven for dry matter (DM) determination and ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA, USA) through 1- and 2-mm screens. Dried and 1-mm ground samples were analyzed for DM (method 934.01; AOAC, 1990), ash (method 942.05; AOAC, 1990), total N content (FP, Leco Instruments Inc., St. Joseph, Michigan, USA), neutral detergent fiber exclusive of ash (aNDF), and ADF (Ankom 200 fiber analyzer; Ankom Technologies, Fairport, NY, USA). Dried and 2-mm ground samples of forage and feces were analyzed for iNDF content, according to Valente et al. (2011). Urine was analyzed for DM and N content (method 978.02; AOAC, 1990).

Performance

The average daily gain was measured in 48 animals (16 animals per treatment; 4 animals per paddock) by the difference between weight at the beginning and end of the experimental period, after a 14-h feed and water withdrawal. In addition, bulls were weighed every 28 days (without prior fasting) to calculate stocking rate, total herbage allowance, and the gain per hectare (GPH). The GPH was calculated using the individual average gain and the number of bulls in each paddock during the evaluation period. The stocking rate was calculated based on the number of bulls in each paddock (sum of the bulls used in the animal-performance evaluation and put-and-take bulls) and the weight of those bulls. The animal unit (AU) was used in this evaluation to represent 450 kg BW.

Statistical analyses

The data were analyzed in a completely randomized design using the MIXED procedure of SAS (version 9.4; SAS Institute, Cary, NC, USA). Data on intake, digestibility, nitrogen balance, ADG, BW, and methane emissions considered the animal as the experimental unit, and the statistical model used was:

$$Y_{ijk} = \mu + N_i + A_j(P_k \, x \, N_i) + \varepsilon_{ijk},$$

where Y = the observed parameter, N_i = fixed effect of nitrogen level, $A_j(P_k \times N_i)$ = random effect of animal nested to paddock and nitrogen level, and ϵ_{ijk} = the residual error. Data from stocking rate and GPH considered the paddock as the experimental unit, and the statistical model used was:

$$Y_i : \mu + N_i + \varepsilon_i,$$

where Y= the observed parameter, N_i = nitrogen level, and ϵ = the residual error associated with each observation as a random effect. When significant, the effect of N fertilization levels was decomposed into two orthogonal polynomial contrasts (linear and quadratic). Significance was declared at $P \leq 0.05$, and tendency when $0.05 < P < 0.10$.

Residuals were plotted against the predicted values to check the model assumptions regarding the homoscedasticity, independence, and normality of the errors. A data point was deemed an outlier and removed from the database if the Studentized residual was outside the ±3.0 range values. One data point for the variables, enteric methane (g kg^{-1} ADG) and N balance were removed.

3. Results

Crude protein intake of bulls increased linearly, and its digestibility showed a quadratic effect ($P < 0.05$) when grazing on pastures with increasing levels of N fertilization, whereas intake and digestibility of DM, OM, and NDFom were not influenced ($P > 0.05$; Table 2).

Table 2. Intake, digestibility, and nitrogen balance of bulls grazing palisadegrass pasture at different levels of nitrogen fertilization.

	N fertilization, kg ha^{-1}						
Variables[1]	0	75	150	SEM	P-value	Linear	Quadratic
BW, kg	350	370	366	5.79	0.065	0.073	0.10
Intake per animal							
DM (kg d^{-1})	7.80	8.50	8.80	1.009	0.780	0.510	0.870
DMI, %BW	2.24	2.31	2.46	0.270	0.840	0.580	0.910
OM (kg d^{-1})	7.16	7.83	8.14	0.930	0.750	0.470	0.880
CP (kg d^{-1})	0.87	1.26	1.53	0.160	0.036	0.001	0.780
aNDF (kg d^{-1})	3.81	4.21	4.17	0.490	0.820	0.610	0.720
CP (g kg^{-1} OMD)	222	271	353	16.80	<0.001	<0.001	0.450
Digestibility (g g^{-1})							
DM	0.51	0.55	0.50	0.021	0.210	0.900	0.086
OM	0.55	0.59	0.55	0.022	0.250	0.960	0.110
CP	0.45	0.57	0.56	0.024	0.007	0.008	0.040
NDF	0.52	0.56	0.54	0.026	0.420	0.630	0.220
N balance							
N intake (g d^{-1})	138.7	201.1	245.4	25.45	0.036	0.012	0.780
N feces (g d^{-1})	74.7	84.6	103.6	8.200	0.150	0.063	0.720
N urine (g d^{-1})	48.4	66.5	66.1	10.20	0.370	0.230	0.440
N balance (g d^{-1})	8.6	49.9	75.7	23.80	0.150	0.059	0.770
Ratio Nfeces $Nurine^{-1}$	1.61	1.58	1.72	0.390	0.960	0.850	0.850
Microbial N production	44.7	55.8	31.3	9.33	0.190	0.330	0.120

($g\ d^{-1}$)							
NUE (% Ni)	6.7	21.97	24.09	9.12	0.350	0.180	0.530
Eff. CP microb ($g\ kg\ OMD^{-1}$)	75.6	79.7	72.6	13.81	0.930	0.880	0.730

[1]BW = body weight, DM = dry matter, OM = organic matter, DMI = DM intake, CP = crude protein; aNDF= neutral detergent fiber exclusive of ash, OMD = digestible OM intake, NUE = nitrogen usage efficiency, Eff. CP microb. = microbial crude protein efficiency.

Increasing N fertilization levels of palisadegrass pastures resulted in a linear increase in N intake ($P < 0.05$) but did not affect N excreted in the feces and urine of bulls (Table 2). The N balance of bulls was similar ($P = 0.059$) when grazing on pastures with increasing N application levels, but nitrogen use efficiency (NUE) was not affected ($P = 0.17$; Table 2). Although the ratio of CP intake to digestible OM intake (OMD) increased linearly, ruminal synthesis of microbial N and microbial crude protein efficiency ($g\ kg\ OMD^{-1}$) did not differ ($P > 0.05$) when bulls grazed on pastures with increasing N fertilization levels (Table 2).

Stocking rate increased linearly ($P < 0.0001$) in pastures fertilized with increasing N levels. Similarly, the ADG of bulls increased linearly ($P = 0.0009$), resulting in a linear increase in gain per hectare in pastures fertilized with increasing N levels (Table 3). Nevertheless, enteric CH_4 emissions from bulls were not affected by nitrogen fertilization ($P > 0.05$; Table 3).

Table 3. Performance of Nellore cattle reared in Marandu grass pastures, managed under continuous stocking and different levels of nitrogen fertilization, during the wet season.

	N fertilization, $kg\ ha^{-1}$						
Variable	0	75	150	SEM	P	Linear	Quadratic
Stocking rate							
($AU\ ha^{-1}$)	1.75	3.06	3.75	0.220	<0.001	<0.001	0.250
BWi. (kg)	273	273	278	2.710	0.340	0.180	0.570
BWf. (kg)	379	404	418	6.510	<0.001	<0.001	0.490
ADG. ($kg\ d^{-1}$)	0.62	0.78	0.82	0.046	<0.001	<0.001	0.110
GPH ($kg\ BW\ ha^{-1}$)	130.6	261.5	357.9	26.02	<0.001	<0.001	0.600
Enteric Methane							
CH_4. ($g\ d^{-1}$)	141.2	173.3	179.6	14.77	0.18	0.080	0.340
Y (%)	6.20	6.90	7.10	1.030	0.66	0.400	0.750
CH_4. ($g\ kg\ DMI^{-1}$)	19.1	21.7	22.5	3.220	0.56	0.300	0.750
CH_4. ($g\ kg\ ADG^{-1}$)	252.4	228.6	217.9	18.78	0.38	0.180	0.730

AU = animal unit, 450 kg BW; BW = body weight; BWi = initial BW; BWf = final BW; ADG = average daily gain; GPH = gain per hectare, CH_4 = methane; Y = methane energy loss in relation to gross energy intake; DMI = dry matter intake

4. Discussion

Currently, concerns regarding food supply in the face of global population growth have given rise to a new concept, aptly termed "sustainable intensification." In a livestock context, sustainable intensification (SI) of animal husbandry justifies the need to increase animal production per area, accounting for sustainable production alternatives that fully address the social, environmental, and economic pillars of sustainability (Tedeschi et al., 2015). Thus, it is possible to increase livestock efficiency and mitigate greenhouse gas (GHG) emissions simultaneously by adopting technologies such as improved pastures. Based on the objectives of SI, we assessed the effect of varying doses of ammonium nitrate fertilizer on the performance and enteric methane emissions of Nellore cattle grazing on palisadegrass pasture under continuous stocking. Accepting our fist hypothesis, we observed that mild N fertilization (up to 150 kg N ha^{-1}) in palisadegrass pastures improved short-term carrying capacity and the ADG of animals without affecting individual CH_4 emission and urinary N excretion, the principal sources of GHG in livestock.

In pastoral production systems, there is a critical relationship between stocking rate and gain per animal (Mott, 1960), where it is impractical to reconcile the maximum gain per animal with the maximum gain per area. This occurs because as the number of animals per area (i.e., the stocking rate) increases, in a bid to increase the gain per unit area, the supply of forage per animal decreases; consequently, reducing individual gain (Mott, 1960). Nevertheless, strategies such as fertilization and supplementation of grazing animals can improve both gain per unit area and animal without deviating from the equilibrium point (Koscheck et al., 2020). Accordingly, our results support the latter and show that the increase in N fertilization resulted in linear increases in both SR and ADG. The increase in SR is likely a consequence of increased N supply to the plant, promoting plant tissue growth, combined with the adopted management practice (maintaining canopy height at 25 cm). Thus, to maximize the harvest and intake of expanded leaf blades, it is necessary to increase the stocking rate, preventing leaf senescence (Gastal & Lemaire, 2015).

Moreover, the positive linear increase in the ADG of bulls was presumably a result of the greater forage nutritional value of fertilized pastures. For instance, fertilized pastures had a greater proportion of green leaves and forage CP content in the canopy (Table 1). As a matter of fact, the augmentation of CP content in N fertilized pastures encourages the increase of CP intake and a positive N balance in bulls grazing pastures fertilized with increasing N levels, considering that DMI was similar between treatments. It is possible, therefore, that higher CP intake might have contributed to higher ADG. According to Rotta et al. (2016), daily CP requirements of 350 kg Zebu cattle raised on pasture increased from 690 to 936 g d^{-1} as ADG increased from 0.5 to 1 kg d^{-1}. Likewise, we observed that greater CP intake resulted in higher ADG, but the protein requirements of our animals seemed to be higher than those reported by Rotta et al. (2016).

The intake of grazing animals is driven by nutritional aspects (related to the quality of the ingested forage, mainly fiber content and digestibility) and by non-nutritional aspects (related to sward structural composition, such as forage allowance, density, and proportion of leaves), which together favor the formation of bites (Poppi et al., 1987). Therefore, the adopted grazing management (put-and-take) might have contributed to the similarities in the intake and apparent digestibility of DM, OM, and NDF among treatments. In our put-and-take system, the stocking rate was adjusted to achieve 95% light interception (Carnevalli et al., 2006) and a canopy height of 25 cm (Santana et al., 2017). Hence, canopy leaf blades grew and were soon consumed, preventing stem elongation and senescence (Miqueloto et al., 2019), resulting in high-quality pastures, indicated by the similarities in NDF content (Table 1) and pasture digestibility (Table 2), regardless of N fertilization.

The DM and NDF digestibility were similar (average of 51.7 and 54%, respectively, Table 2) at all fertilization levels evaluated, due to low indigestible fractions of the NDF (average of 17.9 %, Table 1), and consequently high potentially digestible aNDF. Consistent with the present findings, previous studies have not observed the effect of nitrogen fertilization on DM digestibility (Delevatti et al., 2019a; Sales et al., 2019). Irrespective of N fertilization, the grazing management of palisadegrass pastures at 25 cm height has been demonstrated to provide forage with high nutritional value, with an average of 14.2% CP and 58.5% NDF (Barbero et al., 2015, Delevatti et al., 2019a, b; Ruggieri et al., 2020). The increase in N intake, digestibility, and the positive N balance of cattle grazing on pasture fertilized with varying N levels is likely to be related to the increasing CP levels in fertilized pastures, which were 11, 14.7, and 17.3% CP for 0, 75, and 150 kg N ha^{-1}, respectively (Table 1). This increase in CP content might be coupled with increases in the proportion of rapidly and highly digestible CP (A + B1 fractions) associated with cellular content (Johnson et al., 2001). This favors digestibility and positive N balance that contribute to ADG increase, without affecting N excretion via urine, the primary source of N_2O emissions by ruminants (Raposo et al., 2020).

Conversely, microbial N production was not improved irrespective of the increase in CP content of forage. According to Poppi and McLemann (1995), optimization of the net transfer of feed protein to the intestines, precluding losses, could be attained when CP content in forage ranges from 160 to 210 g CP kg^{-1} of OMD. Additionally, Detmann et al. (2014) stated that it is necessary to have at least 157 g CP kg OMD^{-1} in tropical forages to achieve the relative production of microbial nitrogen in the rumen, resulting in an efficiency of microbial crude protein close to 156 g microbial CP/OMD. However, when this ratio exceeds 210 g CP/kg OMD, losses of N and/or incomplete protein transfer may occur, resulting in low forage CP utilization during ruminal digestion and Pmic synthesis, i.e., RDP is lost due to a lack of energy for synchronism (Poppi and McLemann, 1995).

In the present study, CP content in forage ranged from 222 to 353 g CP kg^{-1} of OMD, resulting in 44.7, 55.8, and 31.3 g d^{-1} of microbial N production, thus indicating an imbalance between energy and protein sources inside the rumen, which caused no change or enhanced microbial N production. Additionally, Owens et al. (1986) and Rennó et al. (2008) reported that microbial N production increases with an increase in DM intake due to faster rate of passage of liquids and solids in animals under higher intakes, thus reducing the proportion of energy used by bacteria for maintenance. However, there were no significant differences in DMI among the treatments in this study.

The NUE was similar among the fertilization doses. According to Detmann et al. (2014), the NUE of cattle on tropical pastures is very low, approximately 11.6%. Even with advances in rumen fermentation studies, little has been achieved regarding N utilization. Studies with dairy cows in the 1960s in the USA reported an efficiency of N use of 23.7%, and after 48 years, even with the efforts of scholars, this efficiency has only increased to 24% (Calsamiglia et al., 2010). Accordingly, the absence of significant difference observed in this study is because the NUE is relatively constant regardless of the level of urea (non-protein nitrogen, fraction A) addition in the steers' diet (Kropp et al., 1977). Herein, a similar effect is observed with an increase in CP in fertilized pastures, mainly associated with an increase in fractions A1 + A2 (Delevatti et al., 2019b).

Nitrogen fertilization in pasture did not affect the daily emission of enteric CH_4 by the animals ($P > 0.05$), whose averages were 145.6, 178.8, and 179.6 g animal^{-1} day for the 0, 75, and 150 kg N ha^{-1} fertilization levels, respectively (Table 3). Furthermore, the lack of differences in methane emission intensity (g CH_4 kg^{-1} ADG) rebutted our second hypothesis. Likely, previous studies have also pointed out similarities in individual CH_4 production of animals under the same grazing conditions (Oliveira et al., 2016; San Vito et al., 2016). The primary factor driving individual CH_4 production in animals is feed intake. Once the animals' DM and NDF intakes are similar, CH_4 emission among treatments will be similar (Van Lingen et al., 2019). Otherwise, it is important to mention that methane conversion rates (Ym) observed in this study were in accordance to the range proposed by the IPCC (2006) between 6.5% and 7.5% for cattle under tropical conditions, and were very close to the USEPA (2000) values, ranging between 5.5% and 6.5% in North America and Eastern Europe.

However, N fertilization affects pasture production and quality, as well as the SR and ADG, as an increase of 114% in SR and 32.25% in ADG was observed between the 0 and 150 kg N ha^{-1} (Table 3), suggesting that N fertilization might contribute indirectly to reducing GHG emission intensity.

Taken together, these results suggest that the application of varying N doses results in the intensification of the system, by increasing the stocking rate (animals per unit area), in addition to promoting an increase in the nutritional value of palisadegrass, enabling greater gains and N intake without increasing N excretion via urine, consequently mitigating N_2O the emission. Although the application of N fertilizer has not shown a reduction in enteric CH_4, it appears that N fertilization indirectly reduces CH_4 emission intensity per hectare by increasing productivity and pasture stocking rate, presenting an opportunity to produce the same amount of meat with less area.

Conflict of interest

The authors declare that they have no conflicts of interest.

Data Availability

Data will be made available upon request for authors.

Author Contributions

Conceptualization, M. H. M. R. F. and R.A.R.; writing—original-draft preparation and review and editing, all authors equally contributed. All authors have read and agreed to the published version of the manuscript.

Statement on ethical standards and animal rights

The animals involved in the experiment were cared for according to the rules of the São Paulo State University Animal Ethics and Use Committee. The committee reviewed and approved the experiments and all procedures conducted in the study (protocol approval number 7979/18).

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CHAPTER 3 - CARBON FOOTPRINT AND NET PROTEIN CONTRIBUTION OF NELLORE YOUNG BULLS IN TROPICAL PRODUCTION SYSTEMS

Abstract: This study aimed to access the carbon footprint and net protein contribution of Nellore young bulls under three levels of beef cattle production system. During backgrounding, the animals were kept in pasture of palisadegrass (*Urochloa brizantha* cv. Marandu). Grazing method was continuous stocking and variable stocking rate. Were used 48 tester Nellore young bulls with an average initial body weight of 283 ± 15 and remaining 28 animals (put-and-take animals) were used to maintain canopy height in 25 cm. The treatments consisted of beef cattle production systems with different levels and strategies of intensification, as follow: System 1: P0N+PS; System 2: P75N+F; and System 3: P150N+F. During backgrounding, pastures from P0N+PS, P75N+F and P150N+F beef cattle production systems received 0, 75 and 150 kg nitrogen ha^{-1}, as ammonium nitrate (32% N). During finishing phase, the animals of the P0N+PS system remained in the pasture and were supplemented at rate of 20 g of concentrate per kg BW, while the animals of P75N+F and P150N+F systems were moved to a feedlot barn. Animals from all treatments received only human-inedible feed during the entire experimental period. Stocking rate (SR) and Average daily gain (ADG) increased with the intensification levels (P <0.05). Thus, live weight (LW) and carcass production increased with the intensification levels, however GHG emissions intensity (kg CO_2e kg $carcass^{-1}$) also increased with the intensification levels (P < 0.05). Enteric methane (CH_4) was the main contributor to total greenhouse gases (GHG) emissions in all systems in both phases. Conversion Efficiency of Beef Cattle (HePCE) was similar for all systems in all phases (P > 0.05). Net protein contribution (NPC) was above 1 for all systems and phases, indicating each system was positively contributing to supply human protein requirements. Improvements in grazing management is a most powerful tool to mitigate environmental impact of grazing systems and the beef production system is a net contributor to the human protein supply without competing for food.

Keywords: feed conversion, greenhouse gases, human-edible protein, sustainability

1. Introduction

Grasslands comprise around 26% earth's terrestrial and livestock take over two-third of global agricultural land. Much of this land is not suitable for growing crops and it is composed by rangeland that is too rock, steep, or arid to support cultivated agriculture, yet this land can support cattle and protein upcycling (Conant, 2010). Most grasslands are in tropical developing countries, where they are particularly important to the economic and social panorama and food supply of these regions (Boval and Dixon, 2012). However, tropical beef cattle production has lately been the target of a major negative impact by public opinion, due to the low technological inputs in the production systems, which can directly impact on the productive indexes, deforestation process, food competition and the emission of greenhouse gases.

In this sense, the intensification of tropical pastures presents itself as an important tool, which aims to increase the productivity of the beef production chain, and simultaneously contribute to the gradual and proportional reduction of environmental impact (Tedeschi et al., 2015). Technologies as grazing management combined with fertilization and supplementation are resourceful strategies to improve animal performance, increase stocking rates, meat production per unit area, improve carcass and meat quality, and finally, to reduce age at slaughter (Berndt and Tomkins 2013). The intensification of cattle-production systems can contribute to avoid further deforestation as a result of lower land occupation factors in these systems. Associated with decreased deforestation, studies have shown that the GHG emissions intensity ($CO_2e \cdot kg^{-1}$ LW) decreased in 49.6 and 59.3% with increasing animal productivity (Cardoso et al., 2016; Dick et al., 2015).

There is also a lack of studies regarding the ruminant's ability to upcycle low-quality protein from by-products into high quality. In view of this, the environmental impact of beef production can be assessed using other approaches. For instance, understanding the protein quality of beef relative to other protein sources in human diets is essential to understand the impacts of the beef value chain on human food supply. Beef products provide a more complete source of dietary protein (i.e., greater biological value) than plant sources, which contain insufficient levels of indispensable aminoacids (Young and Pellett, 1994).

The dilemma in hand is how to meet the challenge of providing high-quality food to a growing human population while reducing the environmental footprint in an effective, economical, and timely fashion (Tedeschi et al., 2015). In order to properly evaluate animal production, humanly consumable energy and protein intake should also be used for efficiency comparisons. Thus, developing methods of accurately accounting the GHG emission using experimental field data and estimate the beef's contribution to human nutrient supplies in tropical conditions is essential for addressing societal concerns and optimizing sustainability.

Therefore, we investigate the carbon footprint and net protein contribution of Nellore young bulls grazing palisadegrass (*Urochloabrizantha* cv. Marandu) under three levels of beef cattle ranching intensification system during the background and finishing phases. We hypothesised that livestock intensification, achieved by fertilization of pastures combined with grazing management and supplementation, is a viable strategy for decreasing the carbon footprint of the activity, and the use of by-products for animal feed enhances the net protein contribution of the beef cattle chain to meet human protein requirement, in addition reducing competition of livestock feed with human food.

The objectives are: (1) to compare animal performance; (2) to evaluate the GHG emissions from the P0N+PS to the intensive system, based on the combined measured and estimated carbon footprint using field experimental data; (3) to estimate the contribution of beef from our systems to meet human protein requirement using a summation model of net protein contribution.

2. Material and Methods

a) System boundaries

The boundaries of this study consider backgrounding and finishing phases of beef cattle production system, using field experimental data, aiming for more accurate results. A life cycle inventory of GHG emissions resulting from on-farm activities, such as animal activities (enteric CH_4, N_2O, and CH_4 from manure), nitrogen fertilization of the grassland, use of diesel fuel, and CO_2 emission from fuel and machinery, was modelled to calculate carbon footprint. The functional unit was kilogram of CO_2

equivalents per kilogram of carcass (kg·CO_2e·kg^{-1} carcass). The net protein contribution to the human food supply from beef cattle production was assessed by using methodology of Barber er al. (2018).

Primary data from a field experiment were used to assess the effects of GHG emissions and net protein contribution. Primary data included forage and animal production, intake, diet digestibility, nitrogen balance, carcass production, and enteric CH_4 emission during the backgrounding and finishing phases, and secondary data were used to calculate GHG emission.

b) Experimental site and beef cattle production systems (treatments)

The experiment was carried out in the Beef Cattle Center of São Paulo State University "Julio de Mesquita Filho", Jaboticabal, SP, Brazil (21°15′22″S 48°18′08″W, 595 m altitude). The typical climate is humid subtropical, with semi, dry winters, and hot, wet summers. The experimental period involved two phases: backgrounding (rainy season [December 2018 to May 2019]) and finishing (dry season [June to September 2019]). During the entire experimental period, average temperature was 22.4±2.5°C and total rainfall was 927.4 mm (Table 1).

Table 1. Weather data from December 2019 to May 2020, from the city of Jaboticabal - SP.

Monthly weather data for year 2018 in Jaboticabal.					
Month	Tmax (ºC)	Tmin (ºC)	Tmed (ºC)	Precipitation (mm)	ND
Dec/19	32	20.2	25.2	88.2	16
Jan/20	32.7	20.9	26.1	148.1	11
Feb/20	30.9	20.4	24.4	282.6	17
Mar/20	31	20.1	24.5	115.2	12
Apr/20	30.6	19.0	23.9	97.6	6
May/20	29.1	16.4	21.9	24.2	4
Jun/20	27.5	14.0	20.7	11.5	2
Jul/20	27.2	12.2	19.7	9.3	2
Aug/20	29.2	14.1	21.7	12.8	3
Sep/20	33.1	18.0	25.5	79.8	6

Pressure: atmospheric pressure; Tmax: maximum temperature; Tmin: minimum temperature; Tmed: average temperature; ND: number of rainy days.
Data obtained from the agroclimatological station of the Faculty of Agricultural and Veterinary Sciences, Unesp, Jaboticabal campus (https://www.fcav.unesp.br/#!/estacao).

Animals involved in this study were cared for according to the guidelines of the São Paulo State University Animal Care and Use Committee and the National Council of Animal Experimentation Control (protocol approval number 7979/18).

The treatments consisted of beef cattle production systems with different levels and strategies of intensification, as follow: System 1: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation (P0N+PS); System 2: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot (P75N+F); and System 3: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot (P150N+F); which were designed to support stocking rates of 1.5, 3.0 and 4.5 livestock units (LU, 450 kg BW) ha^{-1}, respectively.

The experimental site consisted of 24 hectares of palisadegrass (*Brachiaria brizantha* Hochst ex A. Rich Stapf cv. Marandu) pastures divided into 12 paddocks of approximately 2 hectares each, in a completely randomized design with four replicates (paddocks). During backgrounding, pastures from P0N+PS, P75N+F and P150N+F production systems received 0, 75 and 150 kg nitrogen ha^{-1}, as ammonium nitrate (32% N), which was divided into three doses of the same amount. The overall grazing method was continuous stocking and variable stocking rate, to keep the canopy height at 25 cm, considering the 95% light interception (IL) (Santana et al., 2017). Seventy-six young Nellore bulls (*Bos taurus indicus*) were used due to the continuous stocking grazing method and variable stocking rate, of which 48 (initial body weight 283 ± 15 kg) animals were used as tester animals and the remaining 28 animals (put-and-take animals) were used to maintain canopy height at 25 cm (Santana et al., 2017), whereby the grazing cycles lasted 28 days. At backgrounding, all animals received a supplement consisting exclusively of *ad libitum* mineral mixture from December to March. Between April and June 2019 (transition) animals of all treatments were supplemented at rate of 1 g of per kg BW from a single supplement (Table 2).

Table 2. Chemical composition of the mineral mix offered from December to March, and the supplement supplied from April and June, during backgrounding phase.

Variable	Mineral Mix	Supplement
Ingredients, % of DM		

Cotton seed meal	-	37
Defated corn germ	-	21.9
Urea	-	4.6
Mineral mix	100	36.5
Chemical composition, % of DM		
Calcium	14.5	13
Phosphorus	8	2
Magnesium	1	0.2
Sulfer	4	2
Sodium	13	3
Crude Protein	-	32.4
aNDF	-	14.5

DM = dry matter; aNDF =ash free neutral detergent fiber

In the finishing phase, the animals of P0N+PS production system remained in the pasture and were supplemented at rate of 20 g of concentrate per kg BW (Table 3); while the animals of P75N+Fand P150N+F were moved to a feedlot barn. During feedlot the animals were kept in 10 × 6 m pens (4 tester animals per pen, the same four animals previously grouped from paddocks) and the diet was formulated with a roughage: concentrate ratio of 20:80, for daily gains of 1.2 kg d^{-1}, based on human inedible ingredients (Table 3).

Table 3. Ingredients and chemical composition of the supplement, forage and total mixed ration (TMR; based on DM) of Nellore cattle during the finishing phase under different cattle ranching intensification systems.

	Production Systems[1]			
Variable	P0N+PS		P75N+F[3]	P150N+F[3]
	Supplement	Pasture[2]		
Ingredients, % of DM				
Sorghum silage	-	-	20.0	20.0
Defated corn germ	94.4	-	75.5	75.5
Urea	1.8	-	1.5	1.5
Mineral mix	3.8	-	3.0	3.0
Chemical composition[4]				

DM, % as fed	85.5	40.8	74.1	74.1
OM, % of DM	93.4	92.6	90.5	90.5
CP, % of DM	17.0	7.3	15.8	15.8
NDF, % of DM	25.7	57.5	32.1	32.1

[1]P0+PS: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation; P75N+F: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot; and P150N+F: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot.
[2]Hand plucked forage samples in August 2019.
[3]Composition of Total mixed ration.
[4]DM = dry matter; OM = organic matter, CP= crude protein; NDF= neutral detergent fiber;

c) Field measurements

c.1) Forage mass and morphological composition

Forage samples were collected every 28 days, during the entire period of grazing, in each paddock. The average canopy height was assessed every 7 days, based on the measurement of 80 random points per paddock using a graduated ruler, to maintain the canopy height at 25 cm. Forage mass was estimated at four average sward height sites per paddock, after clipping at soil level, of all plants included within the perimeter of a circular rim (0.25 m^2) representing mean forage mass of paddocks. Samples were then separated into dead material, stem + sheath, and green leaves and dried at 55°C to a constant weight to estimate forage DM per hectare. In March 2019 (backgrounding phase) and August 2019 (finishing phase), additional forage samples were hand plucked (Bonnet et al., 2011) to estimate chemical composition. Data of canopy characteristics and chemical composition of the hand-plucked forage samples during backgrounding phase were in Table 4. Data of chemical composition of the hand-plucked forage samples during finishing phase from P0N+PS production system was depicted in Table 3.

Table 4. Characteristics of Marandu palisadegrass *Urochloa brizantha* Hochst ex A. Rich Stapf cv. Marandu pastures at different intensification systems during backgrounding (wet season).

	Production System[1]		
Pasture	P0N+PS	P75N+F	P150N+F
Characteristics[1]			
Herbage mass (10^3 kg DM ha^{-1})	4.6 ± 1.2	5.3 ± 1.58	5.0 ± 1.1
Green leaves (%)	24.5 ± 3.8	30 ± 6.2	33.1 ± 5.8

Stem + sheath (%)	16.2 ± 6.0	25.1 ± 8.9	28.6 ± 5.5
Dead material (%)	59.3 ± 7.5	44.9 ± 13.4	38.3 ± 7.6
Forage allowance (kg DM kg^{-1} BW)	3.0 ± 0.9	1.9 ± 0.74	1.6 ± 0.4
Leaf allowance (kg DM kg^{-1} BW)	0.78 ± 0.2	0.59 ± 0.25	0.54 ± 0.1
Chemical composition[3]			
OM (% of DM)	91.4 ± 0.4	91.8 ± 0.3	92.4 ± 0.5
CP (% of DM)	11.0 ± 0.3	14.7 ± 0.4	17.3 ± 0.5
aNDF (% of DM)	47.8 ± 8.9	48.9 ± 4.3	47.5 ± 1.6
ADF (% of DM)	21.5 ± 4.7	19.9 ± 3.6	21.6 ± 2.6
iNDF (% of DM)	19.5 ± 2.2	17.2 ± 0.7	16.9 ± 2.6
GE (MJ kg^{-1} DM)	17.0 ± 0.1	17.3 ± 0.1	17.6 ± 0.1

[1]P0+PS: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation; P75N+F: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot; and P150N+F: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot.
[2]Means from January to May 2019, ± standard deviation.
[3]Hand plucked forage samples on March 2019. BW = body weight; OM= organic matter; DM = dry matter; CP= crude protein; aNDF= neutral detergent fiber exclusive of ash; iNDF = indigestible aNDF; GE = gross energy

c.2) Animal performance

Average daily gain was measured in 48 tester animals (16 animals per treatment; 4 animals per paddock) by the difference between weight at the beginning and at the end of each phase, after a 14-h feed and water withdraw. In addition, animals were weighted every 28 days (without previous fasting) to calculate stocking rate, total herbage allowance and the gain per hectare (GPH). Stocking rate was calculated based on the number of bulls in each paddock (sum of the bulls used in the animal-performance evaluation and put-and-take bulls) and the weight of those bulls. The LU was used in this evaluation to represent 450 kg BW.

c.3) Intake, digestibility, nitrogen balance and enteric methane

Intake, digestibility, nitrogen balance, and enteric methane measurements were performed in eight tester animals per treatment (two per paddock). Two evaluations were performed in the same animal: one during the backgrounding phase (March 2019) and the other during the finishing phase (August 2019). Intake and digestibility of forage or TMR diet were estimated based on data of faecal production and the indigestible neutral detergent insoluble fiber (iNDF) as an internal marker for estimating pasture DM intake. For the estimation of faecal production, chromium oxide (Cr_2O_3)

was supplied orally at a dose of 10 g (packaged in paper cartridges) for 10 days, of which the first seven for adaptation and the final three for the collection of feces, with two collections per day. To represent the diet (forage) consumed by grazing animals in each paddock, forage samples were hand plucked (Bonnet et al., 2011) during each phase. Chemical composition of the hand-plucked forage is depicted in Table 3 and 4. The iNDF content of forage and fecal samples were estimated according to Valente et al. (2011). Forage intake was estimated as described by San Vito et al. (2016). For feedlot animals, the offered feed and orts were recorded daily for individual pens, sampled twice a week.

Urine collections were performed in the form a spot sample during spontaneous urination in the morning during three consecutive days. Daily urinary volume was estimated based on creatinine excretion, as described previously (Santos et al., 2016). Approximately 40 mL of pure urine was separated for analysis of total nitrogen.

To evaluate of enteric methane emissions, the sulphur hexafluoride (SF_6) marker technique was adopted, in which a permeation capsule containing SF_6 with known release rate was inserted into the animal rumen (adapted from Primavesi et al., 2004). A halter equipped with a capillary tube was fitted to the animal's head, with prior adaptation, and connected to a PVC (polyvinyl chloride) chamber equipped with a valve and register, previously subjected to vacuum. After sampling, the yoke is pressurized with N and the concentrations of CH_4 and SF_6 were determined by gas chromatography (Shimadzu GC2014 Gas Chromatograph, Kyoto, Japan). The measurements were performed on five consecutive days in each phase (backgrounding and finishing). Daily enteric CH_4 emission was calculated as described previously (Berça et al., 2019).

c.4) Chemical analyses

Samples of hand-plucked forage, feed ingredients, orts and feces were dried at 55 °C for 72 h in a forced-air oven for dry matter (DM) determination and ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) through a 1-mm and 2-mm screen. Dried and 1-mm ground samples were analysed for DM (method 934.01; AOAC, 1990), ash (method 942.05; AOAC, 1990), total N content (FP, Leco Instruments Inc., St. Joseph, Michigan, USA) and neutral detergent fiber exclusive of ash (aNDF) (Ankon

200 fiber analyser, Ankom Technologies, Fairport, NY, USA). Dried and 2-mm ground samples of forage and feces were analysed for iNDF content according to Valente et al. (2011). Urine was analyzed for DM and N content (method 978.02; AOAC, 1990).

c.5) Slaughter and carcass evaluation

At the end of the finishing phase, all animals were slaughtered. The carcass of each animal was divided into two half-carcasses, which were weighed to determine the weight of the hot carcass and then chilled in a cold chamber at 0ºC for 24 h. After cooling, the carcasses were weighed again to obtain the cold carcass weight. The cold carcass yield was calculated as the cold carcass weight divided by the final weight of the empty body, with the result multiplied by 100.

d) GHG emission and carbon footprint

To assess the environmental impact, we adopted a CF approach in which only GHG emission was taken into account. System boundaries were limited to the backgrounding and finishing phases, with a timeline of 264 days. GHG emission was calculated as CH_4 production from enteric fermentation and cattle dung; N_2O emission from dung and urine deposited in the pasture or in pens; N_2O emission from fertilizer applications in the field; and fossil CO_2 emission from the production, manufacture, and transport of animal feeds and fertilizers, from the use of diesel for on-farm operations, and from the production of electricity. Emissions associated with buildings and machinery or with veterinary product and pesticide production as well as emissions generated beyond the farm gate (transport for slaughter and carcass processing, among others) were omitted from the analysis. Soil organic carbon was assumed to be at equilibrium across all production systems. The GHG emission from each treatment was calculated using Tier 2 methodologies of Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2019).

In this study, we used local emission factors (EFs) when available. Enteric CH_4 emission was modelled using Tier 2 refinement methods of IPCC (IPCC, 2019). Average daily CH_4 emission measured using the SF_6 tracer gas was considered. The CH_4 emission from pastorally deposited excreta is 0.54 kg $CH_4 \cdot head^{-1} \cdot year^{-1}$, according to a Brazilian study performed at same location (Cardoso et al., 2019). In the feedlot, CH_4 emission from feces was determined based on total fecal production from the measured intake and digestibility. We used equation 10.23 from the methodology to estimate CH_4 EFs (IPCC, 2019).

Nitrogen excreted through feces and urine during backgrounding and finishing was measured in the field. During backgrounding, direct N_2O emission from feces and urine excreted on the pasture was estimated separately using N_2O–N EFs (EF_{3PRP}) for grazing beef cattle (0.36% and 1.02%, respectively) derived from a Brazilian study (Cardoso et al., 2019). During finishing, direct N_2O emission from manure in P0N+PS cattle ranching intensification system (EF_{3PRP}) was 0.34%, according to a Brazilian study (Cardoso et al., 2019). For feedlot animals (P75N+F and P150N+F production systems), direct N_2O emission from a dry lot was estimated using the default EF recommended in chapter 10 of IPCC (Table 10.21 of IPCC, 2019). For both phases and systems, indirect N_2O emission was estimated based on EFs recommended in chapter 11 (Table 11.3 of IPCC, 2019), except the fractions of total nitrogen from animal manure and urine emitted as NH_3 (FracGASM) in the pasture during backgrounding and finishing (6.4% and 11.5%, respectively) (Cardoso et al., 2019).

The GHG emissions from fuel, energy, fertilizers, and feeds used in the production systems were accounted for using the IPCC factors and other sources identified and cited in the literature (Cardoso et al., 2016; Vellinga et al., 2013). The assumptions and EFs used for each source and input are described in Table 5. The fossil fuel requirements from the sorghum silage were taken from an update version of Cardoso´s spreadsheet (Cardoso et al., 2016) using inputs and yields from actual management in the field. The sorghum was sown on 2018 November in a 2-ha area under no-till. On 2019 February, whole-crop sorghum was harvested with yields of 41.88 tons of fresh silage ha^{-1}.

Table 5. Emission factors for production of purchased resources and feeds.

Source	unit	Value	Reference
Diesel fuel use	kg $CO_2e \cdot L^{-1}$	3.53	Cardoso et al. (2016)
Eletricity	kg $CO_2e \cdot MWh^{-1}$	115	EPE (2015)
Lime	$kg \cdot CO_2e \cdot kg^{-1}$	0.48	Cardoso et al. (2016)
Fertilizer			
Nitrogen (ammonium nitrate)	$kg \cdot CO_2e \cdot kg^{-1}$	5.50	Ledgard et al. (2011)
Purchased feed			

Mixed mineral	$kg \cdot CO_2e \cdot kg^{-1}$	0.16	Cardoso et al. (2016)
Cottonseed meal	$kg \cdot CO_2e \cdot kg^{-1}$	0.91	Feedprint[1]
Deffated corn germ meal	$kg \cdot CO_2e \cdot kg^{-1}$	0.27	Feedprint[1]

[1] Vellinga et al. (2013). http://webapplicaties.wur.nl/software/feedprintNL/

CF was assessed according to the model and methodology developed by IPCC (IPCC, 2013). Emissions were allocated as a function of carcass weight ($kg \cdot CO_2e \cdot kg^{-1}$ carcass). All data were converted to their 100-year global warming potential in CO_2e; CO_2e values for CH_4 and N_2O are 28 and 265, respectively (Myhre et al., 2013).

e) Beef's Contribution to Meeting Human Protein Requirements

A summative model of NPC was used to estimate beef's contribution to meeting human protein requirements. System boundaries were limited to the backgrounding and finishing phases of this study, with a timeline of 264 days.

The methodology presented by Baber et al. (2018) was used to estimate the NPC to the human food supply.

e.1) Conversion Efficiency of Beef Cattle

The human-edible protein produced (HeP_p) was calculated for each production phase (backgrounding and finishing) and for the entire production system. To predict HeP_p for each size of animal, body protein (BP) was estimated using EBW. Empty body weigh was the weight of an animal with the gastrointestinal tract emptied of digesta, and included inedible byproducts (IBP), which represent 25.0% of EBW in steers (Terry et al., 1990; Apple et al., 1999). Body weigh was estimated from an equation presented in Simpfendorfer (1974) and NASEM (2016)

$$BP, kg = (0.235EBW - 0.00013EBW^2 - 2.418)$$

To estimate the HeP_p, the inedible fraction of EBW was removed after calculation of BP as follows:

$$HePp, kg = BP\ x\ (1 - IBP)$$

The amount of HeP_p in the backgrouding and finishing phases was the difference in the calculated beginning and ending HeP_p.

The human-edible protein of feed was used to represent the HeP removed from human food supply by the beef value chain. Intakes of beef cattle were estimated using actual field measurements. Feedstuffs were classified as edible, partially edible, or inedible using criteria according to Wilkinson (2011) and Ertl et al. (2016b).

Calculations of HeP_f were conducted according to Ertl et al. (2016b). For feedstuffs considered partially edible (e.g., defatted corn germ meal) a fraction of the feedstuff was estimated to be potentially edible by humans based on previous data (Wilkinson, 2011; Ertl et al., 2016a). HePf was summed across production phases to calculate total HePf for the value chain.

The HeP conversion efficiency (HePCE; Ertl et al., 2016) is a metric of comparison indicating the conversion of HeP_f into beef. HePCE was calculated using the equation:

$$HePCE = \frac{HePp}{HePf}$$

The entire production system's HePCE was calculated as the sum of HeP_p from all phases divided by the sum of HeP_f from all phases.

e.2) Assessing Protein Quality Using Digestible Indispensable Amino Acid Score

The digestible indispensable amino acid score, % (DIAAS) determines amino acid (AA) digestibility, at the end of the small intestine, providing accurate measure of the amounts of amino acids absorbed by the body and the protein's contribution to human amino acid and nitrogen requirements. To calculate the DIAAS, the method proposed by FAO (2011) was used:

$$DIAAS = \frac{mg\ of\ indispensable\ amino\ acid\ in\ 1\ g\ of\ dietary\ protein}{mg\ of\ same\ digestible\ indispensable\ amino\ acid\ in\ 1\ g\ of\ reference\ protein}\ x\ 100$$

The method is based on AA digestibility determined for each AA at the distal ileum, and the pig has been accepted as an appropriate animal model for estimating AA digestibility if values cannot be determined in humans (FAO, 2013 and Shivakumar et al., 2019). The reference protein used in this model was the requirement published by the FAO (2011) for children between the ages of 0.5 and 3 yr. When formulating diets for cattle, a weighted average of the DIAAS for human-edible feed ingredients was calculated for each amino acid.

A DIAAS was also estimated for the human-edible portion of the output product, beef, and it has a DIAAS of 112, indicating that it has an amino acid profile superior to the requirements of a child (reference protein). To capture the change in biological value of HeP that occurs when plant-derived HeP is converted to beef, PQR was calculated as follows:

$$PQR = \frac{DIAAS\ of\ beef}{DIAAS\ of\ diet}$$

A PQR was calculated for each phase of the beef production chain. To calculate the PQR regarding the entire period, the PQR was weighted based on the proportion of total HeP_f in each production phase.

e.3) Net Protein Contribution

The NPC was calculated by multiplying the ratio of HeP in beef to the HeP in feedstuffs by the PQR:

$$NPC = PQR\ x\ HePCE$$

An NPC greater than 1 indicates that the value chain is positively contributing to meeting human requirements, whereas an NPC less than 1 indicates the beef value chain is competing with humans for protein.

f) Statistical analyses

The experimental design was completely randomized with three treatments and four replicates (paddocks). The results were evaluated for homoscedasticity of variances and normality of errors. Treatment means were compared using the Tukey test and adopting $P < 0.05$. The standard errors of the mean derived from the model are reported in the tables. Statistical analysis was conducted using the MIXED procedure of SAS (version 9.4; SAS Institute, Cary, NC, USA)

3. Results

a) Individual performance

As initially proposed, the increase in stocking rate (SR) supported the settlement of cattle ranching intensification levels, in which (SR) of P75N+F and P150N+F systems were in average 78 and 118% greater, respectively, than P0N+PS system (Table 6). Considering actual SR and mean shrunk body weight (SBW), the average number of animals per hectare has increased from 2, 4 and 5 young bulls for P0N+PS, P75N+F and P150N+F beef cattle production systems.

During backgrounding, ADG of animals from P75N+F and P150N+F systems were in average 30 and 35% greater, respectively, greater than P0N+PS system (Table 6). Moreover, dry matter (DM) intake (DMI), DM digestibility and individual enteric methane emission did not differ among systems, whereas crude protein digestibility of animals from P75N+F and P150N+F systems were in average 25% greater than P0N+PS system (Table 6).

Table 6. Individual performance of Nellore yearling bulls at different production systems, during backgrounding, finishing and entire period.

	Production Systems[1]				
Variable[2]	P0N+PS	P75N+F	P150N+F	SEM	P
Backgrounding					
Days, d	172	172	172	-	-
Avg. initial SBW, kg	273	282	294	15.60	0.650
Avg. SBW at end, kg	385	423	437	20.00	0.210
Avg. daily gain, kg d^{-1}	0.62[b]	0.81[a]	0.84[a]	0.030	0.001
Stocking rate, LU ha^{-1}	1.76[b]	3.14[a]	3.84[a]	0.220	<0,001
Dry matter intake, %BW	2.4	2.5	2.5	0.230	0.970
Dry matter digestibility, %	50.5	55.3	50.1	2.910	0.410
Crude Protein digestibility, %	45.2[b]	57.3[a]	55.9[a]	2.870	0.028
Individual enteric methane, g d^{-1}	141.2	173.3	179.6	16.360	0.260
Finishing					
Avg. daily gain, kg d^{-1}	0.92	1.01	1	0.074	0.640
Dry matter intake, %BW	2.8[a]	2.4[ab]	2.3[b]	0.130	0.046
Dry matter digestibility, %	58.7	61.9	60.2	1.820	0.450
Protein digestibility, %	61	63.8	60.7	4.250	0.820
Individual enteric methane, g d^{-1}	135.0[b]	218.6[a]	224.5[a]	22.20	0.033
Avg. slaughter SBW, kg	460	504	510	17.10	0.130
Carcass weight, kg	265[b]	300[a]	304[a]	10.80	0.055
Dressing percentage, %	59.9	59.3	59.4	0.600	0.750

[1]P0+PS: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation; P75N+F: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot; and P150N+F: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot.

Avg. = average; BW = body weight; SBW = shrunk body weight; LU = livestock unit, 450 kg BW.

During finishing, DM and crude protein digestibility, ADG and slaughter weight did not differ among systems, but carcass weight of animals from P150N+F and P150N+F systems were in average 25% greater than P0N+PS system (Table 6). Although DMI of animals from P0N+PS systems (pasture finished) was greater, their individual enteric methane emission was lower than animals from P75N+F and P150N+F systems (Table 6).

b) GHG emission and carbon footprint

During the backgrounding of each herd, carcass production from bulls of the more intensified systems was higher compared to the P0N+PS system (Table 7). Likely, total GHG emissions of the more intensified systems were higher than the P0N+PS (Tabel 7). There was not observed differences for the GHG intensity, CO_2e kg carcass^{-1} between the P75N+F system and the other systems, however the P150N+F system presented the greatest GHG intensity (Table 7).

During the finishing phase, carcass production from bulls of the intensified systems remained higher than the P0N+PS system. Total GHG emissions and GHG intensity were also greater for the P150N+F system but did not vary between P75N+F system and the other systems.

Regarding the entire period, accounting the backgrounding up to the finishing phase, the environmental impact of the tested systems, represented by the total GHG emissions of each herd as the sum of direct (field emissions) and indirect emissions (upstream emissions), was greater for the intensified systems (Table 7). Although carcass production from bulls of the intensified systems were higher compared to the P0N+PS system, the gain was not enough to offset the GHG emissions intensity, since the emissions of CO_2e kg carcass^{-1} of the more intensified systems were higher than the P0N+PS.

The emissions of CH_4 converted in CO_2e emissions was similar among the systems, while manure emissions, which was the sum of CH_4 emission from feces and N_2O emission from dung and urine deposited, were higher in the intensified systems where animals were finished in feedlot. Feed emissions were similar among the systems, while the emissions of fertilizer were not expressed for the P0N+PS system and increased over the intensified systems (Table 7). The emissions of other sources were greater for the intensified systems (Table 7).

Table 7. Greenhouse gas emission of Nellore yearling bulls at different production systems, during period of backgrounding, finishing and entire period.

	Production Systems[1]				
Variable[2]	P0N+PS	P75N+F	P150N+F	SEM	P
Backgrounding					
GHG total, kg CO_2e ha^{-1}.	1994[b]	4634[a]	6134[a]	397	0.001
Carcass production, kg ha^{-1}	134[b]	272[a]	311[a]	21.1	0.001
GHG intensity, kg CO_2e kg $carcass^{-1}$	5.87[b]	7.32[ab]	8.35[a]	0.522	0.025
Finishing					
GHG total, kg CO_2e ha^{-1}.	1580[b]	4429[a]	5363[a]	582	0.0034
Carcass production, kg ha^{-1}	203[b]	366[a]	423[a]	35.8	0.005
GHG intensity, kg CO_2e kg $carcass^{-1}$	4.65[b]	6.80[ab]	7.40[a]	0.652	0.036
Entire period					
GHG total, kg CO_2e ha^{-1}.	3574[b]	9063[a]	11498[a]	838	0.0003
Carcass production, kg ha^{-1}	337[b]	637[a]	734[a]	45.8	0.0004
GHG intensity, kg CO_2e kg $carcass^{-1}$	10.53[b]	14.13[a]	15.76[a]	0.915	0.008
Enteric CH_4 kg CO_2e kg $carcass^{-1}$	7.42	8.90	9.27	0.702	0.19
Manure kg CO_2e kg $carcass^{-1}$	1.09[b]	1.86[a]	1.93[a]	0.149	0.005
Feed kg CO_2e kg $carcass^{-1}$	1.76	1.60	1.61	0.202	0.82
Fertilizer kg CO_2e kg $carcass^{-1}$	0[c]	1.64[b]	2.81[a]	0.131	<0.001
Other kg CO_2e kg $carcass^{-1}$	0.26[a]	0.14[b]	0.12[b]	0,014	<0.001

[1]P0+PS: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation; P75N+F: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot; and P150N+F: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} $year^{-1}$ during backgrounding and finishing on feedlot.
[2]GHG= greenhouse gases; CO_2e= CO_2 equivalent, CH_4= methane.

c) Beef's Contribution to Meeting Human Protein Requirements

A DIAAS was estimated for the diets provided and for human-edible protein from beef produced. The DIAAS (%) represents the human-edible protein quality of a food and its ability to meet the protein requirements of a child 0.5 to 3 yr of age. The only human partially edible feedstuffs (defatted corn germ) used in beef cattle diets of this study have low DIAAS (34.8) while beef presents a much higher value (DIAAS of

112.00). Furthermore, with the DIAAS of beef fixed at 112.00, all beef cattle intensification systems in all phases, had a PQR of 3.22 (Table 8).

For all production phases, HePCE (conversion of HePf into beef) was calculate as a metric of comparison. During backgrounding HePCE were similar among the systems, since animals from all systems received the same diet (Table 8). The NPC was also similar among the three systems, positively contributing to meet human protein requirements as indicated by NPC > 1 (Table 8).

The same pattern was observed in the finishing phase. However, the values of HePCE and NPC were lower compared with the values observed during the backgrounding (Table 8).

Considering the entire period, HePCE was similar for all beef cattle production systems, with average value of 1.19. Net protein contribution for the entire period evaluated was above 1 for all systems, indicating each system was positively contributing to human protein requirements and were not competing with humans for HeP (Table 8).

Table 8. Net protein contribution of Nellore yearling bulls at different production systems, during period of backgrounding, finishing and entire period.

	Production Systems[1]				
Variable[2]	P0N+PS	P75N+F	P150N+F	SEM	P
Backgrounding					
Diet DIAAS	34.8	34.8	34.8		
PQR	3.2	3.22	3.22		
Total HePf, kg paddock^{-1}	0.6[b]	1.16[a]	1.31[a]	0.110	0.004
Total HePp, kg paddock^{-1}	55.2[b]	118.3[a]	129.4[a]	8.530	<0.001
HePCE	90.8	103.7	99.4	5.060	0.240
NPC	212.7	242.7	232.7	11.84	0.240
Finishing					
Diet DIAAS	34.8	34.8	34.8		
PQR	3.2	3.22	3.22		
Total HePf, kg paddock^{-1}	98.9	162.1	162.9	23.58	0.140
Total HePp, kg paddock^{-1}	36.7[b]	68.6[a]	70.2[a]	7.470	0.019
HePCE	0.4	0.5	0.5	0.059	0.510
NPC	1.1	1.4	1.4	0.180	0.510
Entire period					
Diet DIAAS	34.8	34.8	34.8		

PQR	3.22	3.22	3.22		
Total HePf, kg paddock^{-1}	99.5	163.2	164.2	23.60	0.140
Total HePp, kg paddock^{-1}	91.9^{b}	186.9^{a}	199.6^{a}	12.80	<0.001
HePCE	0.92	1.31	1.34	0.240	0.450
NPC	2.79	3.95	4.04	0.740	0.440

[1]P0+PS: managed pasture without fertilization during backgrounding and finishing on pasture with high supplementation; P75N+F: managed pasture with fertilization of 75 kg nitrogen(N) ha^{-1} year^{-1} during backgrounding and finishing on feedlot; and P150N+F: managed pasture with fertilization of 150 kg nitrogen(N) ha^{-1} year^{-1} during backgrounding and finishing on feedlot.
[2]DIAAS = digestible indispensable amino acid score (%), PQR = protein quality ratio, HePf = human-edible protein consumed, HePp = human-edible protein produced, HePCE = human-edible protein conversion efficiency, NPC = net protein contribution

4. Discussion

a) Performance and GHG emission

With regards to livestock context, the sustainable intensification of livestock can be an alternative to reduce the environmental impacts caused by the activity (Cardoso et al., 2020; Delevatti et al., 2019).Thus, it is possible to increase livestock efficiency and mitigate GHG emissions through the adoption of technologies, because intensified pastoral systems, with the use of fertilizers and adequate grazing management, result in high forage production, with increasing stocking rates per hectare and gain per animal, consequently reducing the need for deforestation (Dumortier et al., 2010). In the present study, intensification of beef cattle production accounts for the increase of animal production per area. Thus, based on the sustainable intensification concept, this study evaluated the effect of intensification strategies on performance, GHG emissions and net protein contribution of Nellore cattle grazing palisade grass pasture under continuous stocking during backgrounding and finished on pasture or feedlot.

The greater carcass production of more intensified systems (P75N+F and P150N+F), mainly during the backgrounding phase, was a consequence of the combination of the increase of animals per area with greater gain per animal. In this case, the intensification was achievable due to previous fertilization and management of pastures. Those intensification strategies have the principle of manipulating soil-plant-animal factors, seeking a balance between supply and demand for food. It results in greater forage mass production and nutritional value, which led to an increase in the stocking rate and gain per animal, since the animals harvest the high-quality leaf tissue before the forage enters senescence (Ruggieri et al., 2020). The largest number of animals per area resulted in more GHG production. However, the gains achieved in the P150+F system could not offset its GHG emissions due to the system's low productivity and high amount of fertilizer used (source of N_2O emissions). On the other hand, the GHG emission intensity (kg CO_2e kg carcass^{-1}) was similar between the P75N+F system and the other systems, elucidating that this intermediate system improved short carrying capacity and the ADG of animals, especially during the backgrounding, without affecting GHG emissions (Cardoso et al., 2020).

Regarding the entire period, from backgrounding to farm gate, the environmental impact of the cattle ranching intensification systems, represented by the total GHG emissions, increased in the P75N+F and P150N+F systems. Although carcass production of the more intensified systems was higher compared to the P0N+PS system, during the finishing phase the differences in gain between P0N+PS the P75N+F and P150N+F system were shortened. In this phase, animals from all systems received the same concentrated diet, which provided a similar live weight gain among them and reduced the differences in gain reached during backgrounding. In view of this, the gain augment of P75N+F and P150N+F systems was not enough to offset the augment in GHG emissions, resulting in emissions of kg CO_2e kg carcass^{-1} of these systems 42% higher than the P0N+PS. Conversely, studies have shown that the GHG emissions intensity (kg CO_2e kg carcass^{-1}) decreased with increasing animal productivity (Cardoso et al., 2016; Dick et al., 2015; Weiss and Leip, 2012). Nonetheless, even the P0N+PS beef cattle production system of the present study was somehow intensified by improvements in grazing management during backgrounding and by high concentrate supplementation during finishing (pasture-finished animals).

For the purpose of comparison with studies that assess the entire livestock live cycle carbon footprint, we consider that the cow-calf phase represents 50% of the total emission intensity of the beef cattle chain, so the values in this study for the entire cattle ranching life cycle would be 21.06, 28.26 and 31,52. kg CO_2e kg carcass^{-1} for P0N+PS, P75N+F and P150N+F systems, respectively. Although the intensity of emissions has increased with the intensification levels, these values are in accordance with the most intensified systems evaluated by Cardoso et al (2016). Evaluating five different scenarios, with increasing intensification levels, total emissions were estimated in 58.3, 40.9, 29.6, 32.4, 29.4 kg CO_2e kg carcass^{-1}. Considering that the first two scenarios cover less intensified systems than those evaluated in our study, this implies that improvements in intensification realized in the present study had a positive environmental impact. Another study simulated different beef production systems and estimated CO_2e emissions in 30.8, 34.4, 34.4 and 36.6 kg CO_2e kg carcass^{-1} for pasture fertilized, pasture re-seeded, pasture with grain supplementation and extensive pasture, respectively. Simulated pasture improvements resulted in lower GHG footprints compared to extensive, although, they emitted more GHG from land management (fertilization) and production of external resources (feed and fertilizer) compared to extensive (Molossi et al., 2020). Dick et al., 2015 observed even lower livestock emission for intensified systems (18.32 kg CO_2e kg carcass^{-1}), while for the extensive system, were found values of 45 kg CO_2e kg carcass^{-1}. However, in Dick's study the grazing systems were not fertilized with N, and the animals did not receive concentrate diets in any phase of their life cycle.

The SR of the P0N+PS system of our study was on average 1.76 LU ha^{-1} that is 66% greater than Brazilian national mean (1.06 LU; ABIEC, 2020), enhancing the idea that improvements in grazing management per se, is the most powerful tool to mitigate environmental impact of grazing systems.

Additionally, greater animal productivity and lesser emissions are more difficult to be realized, as the most used breed in the Brazilian systems is Nellore cattle, which presents natural resistance to the high temperatures, the humidity of the wet season and the parasites common in national conditions, generally do not have the potential to transform the improved forage quality into much higher LWGs (Cardoso et al., 2016).

Our results indicate that CH_4 from enteric fermentation is the largest proportion of total GHG emissions in contrasting beef cattle production systems, corroborating with previous studies with ruminants (de Figueiredo et al., 2016; Ripple et al., 2014). In our study, enteric fermentation makes up in average 64% of total CO_2e emissions, value higher than those found in studies conducted in Europe and Canada, where enteric CH_4 emissions corresponded for 32 to 42% (Weiss and Leip, 2012) and 48% (Mc Geough et al., 2012) of total CO_2e emissions. The lower contribution of enteric emissions obtained by these authors is consequence of the greater contribution of emissions from manure management and animal production with large amounts of concentrates.

There was not observed differences in enteric CH_4 emissions among the systems, however the P0N+PS system presented an enteric CH_4 contribution 15,8% higher than the intensified systems, once the latter had greater contribution of other sources, related to fertilization [P75N+F (75 kg of N ha^{-1}) and P150N+F (150 kg of N ha^{-1})]. The crucial issue regarding chemical fertilizers refers to their potential to harm the environment. In tropical pastures, ammonia (NH_3) volatilization is one of the main loss pathways, (Martha Jr., 2004; Zaman et al., 2012). When applied to the soil, the nitrogen fertilizer rapidly undergoes hydrolysis by the action of the enzyme urease, releasing ammonia (NH_3) and carbon dioxide (CO_2) into the atmosphere (Jenkinson, 2001). In this study, N fertilizer was ammonium nitrate, which contributed to approximately 11.6 and 18% of the total CO_2e emissions in the entire period for P75N+F and P150N+F systems.

Manure emissions were higher in the more intensified systems where animals were finished in feedlot. The manure produced by cattle can be sources for both CH_4 and N_2O emissions. Under grazing conditions, the excretions have little impact since the soil-plant system is able to use most of the nutrients present in the manure. In feedlots, due to the high concentration of animals, the large volume of feces and urine accumulated on the floor of the pens can cause contamination by superficial carrying, leaching in the soil or volatilization of gases (BR Corte, 2016)

In the present study, the CF estimate was related only to emissions from farm inputs and activities and did not consider the effect of carbon sequestration on reducing the associated CO_2 emission. Some authors have been giving attention to the potential of *Urochloa* pastures to accumulate soil C (Bustamante et al., 2012; Assad et al., 2013), because C sequestration can alter the GHG balance from liquid sources to carbon sinks, especially when pastures are better fertilized (Picasso et al., 2014). A study comparing three contrasting production scenarios (degraded pasture, managed pasture, and integrated crop-livestock-forest system) in brachiaria pasture in Brazil, found that managed pastures fertilized with NPK are able to decrease the intensity of GHG emissions, due to C sequestration in the soil, in over 20% (de Figueiredo et al., 2016). However, the sink for atmospheric CO_2 does not increase indefinitely and it is dependent of the input of organic material and its rate of oxidation, the rate at which existing soil organic matter decomposes, soil texture and climate (Johnston et al., 2009). As we feel that there is not enough data available at the moment to use carbon sequestration as a CO_2 mitigation strategy in different systems, this is not considered in this study.

b) Beef's Contribution to Meeting Human Protein Requirements

The HePf and HePp of the P0N+PS system was lower than the HePf of the other systems both in the growing and finishing phases. This difference occurred because the HeP consumption and production calculations were per paddock considering their respective stocking rates. As the paddocks stocking rates increased with the intensification levels, the consumption and production of HeP increased concomitantly. Thus, HePCE was adopted as a comparison metric. Since both in the backgrounding and finishing phase, the animals from the different systems received the same diet (pasture-based backgrounding diet and concentrate-based finishing diet), HePCE did not differ among the systems.

During the backgrounding, the three systems had a similar NPC and positively contributed to meeting human protein requirements as indicated by NPC > 1. During this phase, all the animals received a pasture-based diet, and was incorporated a small amount of HeP (low intake supplement) offered during the last 3 months of this phase, over the transition of the wet season to the dry season, when pasture suffers quantitative and qualitative losses. Around 90% of supply for animal feed for total national meat produced is pasture (ABIEC, 2020), a product that is human-inedible. However, ruminants are efficient in upcycling and converting pasture with low quality proteins, into beef, a high-quality protein source for humans (Ertl et al., 2015).

During the finishing phase, the HePCE of all systems were below 1 (meaning during this phase more HeP was being consumed than produced). However, the cattle's ability to upcycle protein from low quality to high quality allowed a NPC greater than 1. This way, the quality of the protein produced by the animals was superior to the protein consumed leading to a positive contribution to meet human protein requirements. In this study a DIAAS was estimated for the diets fed and the human-edible portion of a beef carcass. The DIAAS (%) represents the ability of a human-edible feedstuff to meet the protein requirements of a child 0.5 to 3 years of age. The feedstuff offered for animal feed was considered partially edible and presented DIAAS of 34, while the DIAAS of the animal protein produced was estimated at 112, proving much greater capacity of beef products to meet the human protein requirement.

A previous study carried by Baber et al., 2018, comparing 4 different scenarios, embracing possible production parameters and industry diets used in the United States, found NPC values for the finishing phase much lower (0.30, 0.38, 0.84 and 1.07) than in the current study. Considering that ruminants are efficient in converting vast renewable resources, including by-products, into high quality food edible for humans (Mottet et al., 2017), we aimed to explore the use of by-products, with low nutritional value for humans, into the cattle's diet, which led to a small HePf when compared to conventional systems. In American conventional systems, large amounts of human-edible grains, such as corn, are fed to the animals decreasing the NPC.

Considering the entire period, HePCE was similar for all beef cattle production systems, with average value of 1.19. Although in the finishing phase more HeP were being consumed than produced, it was outweighed by the backgrounding ability to positively contribute to the human food supply by using less HeP and improving the protein quality. When Molossi et al., 2020 simulated different cattle grazing scenarios in Brazil, was observed that the grazing system with grain supplementation (cows, heifers, and stockers fed with corn and soybean at a supplementation level to meet 45% of recommended protein requirements) presented HePCE below 1, indicating a net reduction in potential human food driven by greater use of human edible feed to produce animal products. These results reinforce the importance of using by-products as a viable strategy for future human food availability.

NPC for the entire period evaluated was above 1 for all systems, indicating each system was positively contributing to human protein requirements and were not competing with humans for HeP. Overall, the backgrounding had the greatest NPC when compared with the finishing phase, since during the backgrounding the main feed consumed by the animals was pasture, while in the finishing phase a concentrated supplementation was included.

5. Conclusion

The results suggest that the increase in SR supported the settlement of cattle ranching intensification, since with intensification strategies it is possible to produce more meet using less area, decreasing the need of deforestation for increases in beef production. The P0N+PS beef cattle production system presented the lowest environmental impact when considering the total GHG emissions intensity (CO_2e kg carcass^{-1}), implying that improvements in grazing management per se, is the most powerful tool to mitigate environmental impact of grazing systems. The beef value chain is a net contributor to the HeP available for human consumption. Furthermore, the quality of the HeP produced was enhanced throughout the beef value chain due to the ability of cattle to upcycle protein from low quality to high quality. Thus, it allowed for all systems in both phases to have an NPC greater than 1, positively contributing to the human protein requirements without competing with human for food.

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