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FACULDADE DE MEDICINA VETERINÁRIA E ZOOTECNIA

Effects of intensification and pasture integration on carcass traits and meat quality in *Nellore* cattle

Pirassununga, SP
2023

GABRIELE VOLTARELI DA SILVA

Effects of intensification and pasture integration on carcass traits and meat quality in *Nellore* cattle

VERSÃO CORRIGIDA

Thesis presented to the College of Veterinary and Animal Sciences of the University of São Paulo, as a part of the requirements for obtaining the Doctorate degree in Science from the graduate program in Production and Animal Nutrition

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Dr. Paulo Henrique Mazza Rodrigues

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CERTIFICADO

Certificamos que a proposta intitulada "Efeitos da intensificação e integração da pastagem sobre características de carcaça e qualidade de carne em bovinos da raça Nelore", protocolada sob o CEUA nº 2609290120 (ID 007756), sob a responsabilidade de **Paulo Henrique Mazza Rodrigues** *e equipe; Gabriele Voltareli da Silva* - 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 - está de acordo com os preceitos da Lei 11.794 de 8 de outubro de 2008, com o Decreto 6.899 de 15 de julho de 2009, bem como com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi **aprovada** pela Comissão de Ética no Uso de Animais da Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo (CEUA/FMVZ) na reunião de 29/04/2020.

We certify that the proposal "Grazing intensification and integration effects on carcass characteristics and meat quality in Nellore cattle ", utilizing 30 Bovines (30 males), protocol number CEUA 2609290120 (ID 007756), under the responsibility of **Paulo Henrique Mazza Rodrigues** *and team; Gabriele Voltareli da Silva* - which involves the production, maintenance and/or use of animals belonging to the phylum Chordata, subphylum Vertebrata (except human beings), for scientific research purposes or teaching - is in accordance with Law 11.794 of October 8, 2008, Decree 6899 of July 15, 2009, as well as with the rules issued by the National Council for Control of Animal Experimentation (CONCEA), and was **approved** by the Ethic Committee on Animal Use of the School of Veterinary Medicine and Animal Science (University of São Paulo) (CEUA/FMVZ) in the meeting of 04/29/2020.

Finalidade da Proposta: Pesquisa

Vigência da Proposta: de 07/2020 a 07/2021 Área: Nutrição E Produção Animal

Origem:	Prefeitura do Campus da USP de Pirassununga						
Espécie:	Bovinos	sexo:	Machos	idade:	12 a 14 meses	N:	30
Linhagem:	Nelore			Peso:	300 a 400 kg		

Local do experimento: EMBRAPA - Pecuária Sudeste - São Carlos/SP

São Paulo, 06 de maio de 2020

Prof. Dr. Marcelo Bahia Labruna
Coordenador da Comissão de Ética no Uso de Animais
Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo

Camilla Mota Mendes
Vice-Coordenador
Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo

Embrapa
Pecuária Sudeste

CERTIFICADO
CEUA PRT Nº 04/2019

Certificamos que o projeto de Pesquisa intitulado: "Práticas estratégicas para a mitigação da emissão de gases de efeito estufa em sistemas pastoris da Região Sudeste brasileira", registrado com o número 20.19.00.047.00.00, sob responsabilidade do pesquisador científico Dra. Patrícia Perondi Anchão Oliveira, que envolve a produção, manutenção ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto humanos), para fins de pesquisa científica encontra-se de acordo com os preceitos da lei nº 11.794, de 8 de outubro de 2008, do Decreto nº 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 da Embrapa Pecuária Sudeste.

We hereby declare that the research project titled "Strategic practices for mitigating greenhouse gas emissions in grassland systems of the Brazilian Southeast" has been registered under the responsibility of Dra. Patricia Perondi Anchão Oliveira (number 20.19.00.047.00.00) involving production, management or utilization of animals from phylum Chordata, subphylum Vertebrata (except humans). The described experimental protocol is in accordance to the Brazilian Federal Law on Animal Experimentation (#11.794, enacted on 8th October 2008), to the Decree 6.899 (enacted on 15th July 2009) and the corresponding rules of National Council for Animal Experimentation Control (CONCEA), and it was approved by the Committee of Animal Experimentation of Embrapa Southeast Livestock.

São Carlos, 16 de Dezembro de 2019.

Dr Alexandre Rossetto Garcia
Presidente da Comissão de Ética no Uso de Animais
Embrapa Pecuária Sudeste

Finalidade	Pesquisa Científica
Vigência da Autorização	21/09/2019 a 31/12/2023
Espécie / Linhagem / Raça	Nelore (Bos Indicus)
Número de Animais	124
Peso / Idade	350 kg / 18-24 meses
Sexo	machos
Origem	Embrapa Pecuária Sudeste

Empresa Brasileira de Pesquisa Agropecuária
Ministério da Agricultura, Pecuária e Abastecimento
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Thesis presented to the College of Veterinary and Animal Sciences of the University of São Paulo as part of the requirements for obtaining the Doctorate degree in Science from the Graduate Program in Production and Animal Nutrition

Data:_______/_____/______

Committee member

Prof. Dr. ____

Institution:______________________________Result:_______________________________

Prof. Dr. ____

Institution:______________________________Result:_______________________________

Prof. Dr. ____

Institution:______________________________Result:_______________________________

Prof. Dr. ____

Institution:______________________________Result:_______________________________

Prof. Dr. ____

Institution:______________________________Result:_______________________________

DEDICATION

I dedicate this work to my parents, Sara and Edegar, my grandfather Dorival, my sister Ana Clara, my nephew Miguel and my grandmother Ivone (in memoriam) without them, my base, I would be nothing. They are with me in thought at all times.

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RESUMO

DA SILVA, G.V. **Efeitos da intensificação e integração de pastagens sobre características de carcaça e qualidade da carne de bovinos Nelore**. 2023. 65p. Tese (Doutorado em Ciências) – Faculdade de Medicina Veterinária e Zootecnia, Universidade de São Paulo, Pirassununga, 2023.

O setor pecuário mundial tem como um dos principais desafios adaptar-se às mudanças ambientais e econômicas, frente à crescente demanda de alimentos, melhorando cada vez mais a produtividade e qualidade de produtos de origem animal. O objetivo do projeto é identificar os sistemas de produção mais produtivos, aqueles com os maiores potenciais mitigadores de GEE e avaliar se houve alterações nas características de carcaça e na qualidade da carne desses animais. O trabalho foi realizado entre setembro de 2019 e setembro de 2021, na Embrapa Pecuária Sudeste, em São Carlos, SP. Foram utilizados 58 bovinos *Nellore* machos não castrados, com 280 ± 54.5 kg de peso vivo e 15 a 16 meses de idade. Cinco tratamentos com duas repetições foram avaliados: 1) pastagem de *Megathyrsus maximus* cv. Tanzânia sob manejo intensivo e irrigado com alta lotação e sobressemeado com aveia e azevém na época seca e fria (IAL); 2) pastagem de *Megathyrsus maximus* cv. Tanzânia sob manejo intensivo de sequeiro com alta lotação (SAL); 3) pastagem de sequeiro com mistura de *Urochloa decumbens* Stapf cv. Basilisk e *U. brizantha* (Hochst ex A. Rich) Stapf cv. Marandu, com taxa de lotação moderada (SML); 4) sistema silvipastoril com *U. decumbens* cv. Basilisk e árvores nativas brasileiras com taxa de lotação moderada (SSP) e 5) pastagem degradada de *U. decumbens* cv. Basilisk (DEG). A taxa de lotação foi ajustada pela técnica “put and take”, o desempenho animal foi acompanhado, a emissão de CH_4 foi estimada pela técnica do gás traçador hexafluoreto de enxofre (SF_6) e o consumo de matéria seca (CMS) determinado utilizando marcadores internos (FDNi - fração insolúvelda fibra em detergente neutro) e externos (TiO_2 - dióxido de titânio). Ao final do experimento os animais foram transportados até o abatedouro-escola da Universidade de São Paulo, em Pirassununga, SP, fiscalizado pelo Serviço de Inspeção Estadual. Antes do abate os animais foram mantidos em jejum sólido por 16 horas, recebendo água *ad libitum*. Após o abate obteve-se o peso de carcaça quente (PCQ) que depois foram resfriadas à 1°C por 24 horas. As metades esquerdas das carcaças foram pesadas e desossadas, amostrando-se a carne entre a 12ª e a 13ª costela para medida da área de olho de lombo (AOL), espessura de gordura subcutânea (EGS), marmoreio (MS), porção comestível da carcaça (CEP) e análise sensorial. Os dados foram submetidos à análise de variância com o PROC MIXED do SAS e as médias comparadas pelo teste de Fisher a 5%. Os sistemas mais intensificados apresentaram maiores valores das características citadas, mostrando que os parâmetros de produtividade, características de carcaça, qualidade de carne, além de menor intensidade emissão de CH_4 de metano em bovinos Nelore a pasto melhoraram com a recuperação e intensificação dos sistemas pastoris de produção avaliados.

Palavras-chave: Análise sensorial. Bovinocultura de corte. Forragem. Sistemas de produção.

ABSTRACT

DA SILVA, G.V. **Effects of intensification and pasture integration on carcass traits and meat quality in *Nellore* cattle.** 2023. 65p. Thesis (Doctorate in Science) – College of Veterinary Medicine and Animal Science, University of São Paulo, Pirassununga, 2023.

The world livestock sector has the challenge to adapt to environmental and economic changes, facing the growing demand for food, improving productivity and quality of animal products. The aim of this study was to identify the most productive pasture-based production systems with GHG mitigating potentials and evaluate whether there were changes in carcass characteristics and meat quality of *Nellore* steers. The work was conducted between September 2019 and September 2021, at Embrapa Pecuária Sudeste, in São Carlos, SP. Fifty-eight uncastrated male *Nellore* steers with 280 ± 54.5 kg of live weight and 15 to 16 months of age were distributed in five treatments with two repetitions: 1) irrigated pasture of *Megathyrsus maximus* cv. Tanzania under intensive management with high stocking rate overseeded with oats and ryegrass in the dry and cool season (IHS); 2) rainfed pasture of *M. maximus* cv. Tanzania under intensive management with high stocking rate (RHS); 3) rainfed pasture with a mixture of *Urochloa decumbens* Stapf cv. Basilisk and *U. brizantha* (Hochst ex A. Rich) Stapf cv. Marandu, with moderate stocking rate (RMS); 4) livestock-forest system with *U. decumbens* cv. Basilisk and native Brazilian trees with moderate stocking rate (LFS) and 5) degraded pasture of *U. decumbens* cv. Basilisk (DP). The stocking rate was adjusted by the "put and take" technique, animal performance was monitored, CH_4 emission estimated by the sulfur hexafluoride (SF_6) tracer gas technique and dry matter intake (DMI) determined using internal (iNDF – indigestible neutral detergent fiber) and external (TiO_2 - titanium dioxide) markers. At the end of the experiment the animals were transported to the slaughterhouse-school of the University of São Paulo, in Pirassununga, SP. Before slaughter, the animals were kept in solid fasting for 16 hours, receiving water *ad libitum*. Hot carcass weight (HCW) were determined and then cooled at 1°C for 24 hours. The left halves of the carcasses were weighed and deboned, and the meat was sampled between the 12^{th} and 13^{th} ribs to measure the ribeye area (REA), backfat thickness (BFAT), marbling score (MS) and carcass edible portion (CEP), as well as sensory analysis. The data were submitted to variance analysis with PROC MIXED of SAS and the means were compared by Fisher's test at 5%. The more intensified systems presented higher values of performance variables, carcass characteristics, meat quality, and lower intensity of CH_4 emissions demonstrating the potential of recovering and intensifying pasture-based systems under tropical conditions.

Key words: Beef cattle. Forage. Production systems. Sensory panel.

FIGURE LIST

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SUMMARY

1. INTRODUCTION

Brazilian territory has some climatic characteristics such as level of precipitation and luminosity, associated with land availability, that favors the production of tropical pastures in which a major part of country' livestock production is based, especially beef cattle (NABINGER, 1997).

Livestock production plays a fundamental role in Brazilian's economy, where cattle production represents 83.9% of total production (89% beef cattle and 11% milk production; DE MARCHI et al., 2016). Brazil has one of the largest herds in the world (FAO, 2013), with approximately 224.60 million heads (IBGE, 2022), being the world's largest exporter of beef, with 2.48 million tons in 2021 (ABIEC, 2022). In addition, Brazil is the second largest producer of meat, with 9.7 million tons per year, representing 13.7% of the world production (ABIEC, 2022), while the dairy sector is the fourth largest producer of milk, with about 35 billion liters per year (FAOSTAT, 2017).

Differently from many other countries' production systems, most of the Brazilian cattle farming is based on extensive systems with low average stocking rates (1.06 animal units/ha) and slaughter age above two years or even more, which technically represents a potential loss in beef value. This unsustainable scenario deserves attention considering that there is a potential feeding rate of 2.0 animals per ha, which could be achieved for example with improvements in pasture management, and assuming that the increasing global population and improved standards of living provide a market for high-quality ruminant protein in meat and milk (McADAM et al., 2022).

In extensive pasture systems, with low or no use of fertilization nor nutritional energy-protein supplementation and low stocking rates, cattle production cycle takes a relatively long time, and consequently, old animals are sent to slaughter (ARAÚJO FILHO, et al. 2019). In addition, extensive pasture production systems can be associated with higher greenhouse gases (GHG) emissions (OLIVEIRA, 2015), especially when these areas are not well managed, and no technology is used. As an example, the Brazilian beef production sector is responsible for approximately 3.3% of the total CH_4 produced worldwide (BERCHIELLI et al., 2012). Although the concentration and lifetime (8 to 12 years) of CH_4 in the atmosphere are lower than that of CO_2, it has a warming potential of 27.2 times greater compared to CO_2 (IPCC, 2022). However, the adoption of some technologies that have been well studied by the scientific community can contribute to improve the sustainability and avoid unnecessary judgment of the Brazilian livestock production.

In recent decades, the intensification of pasture-based systems aiming the improvement of productivity in a more sustainable way rely on the efficient exploitation of the tropical pastures by means of fertilizers application, adoption of a proper soil and forage management, the use of irrigation systems, overseeding temperate species in the "dry" season of the year, and integrating pastures and trees species. All these technologies are gaining importance since it can directly affect the production of animal products per area while decreasing the intensity of enteric CH_4 emissions (HRISTOV et. al., 2013). In addition, specific feeding regimes based on good-quality pastures and adequate herd management are linked to superior organoleptic and nutritional quality attributes of dairy and meat products (CARTERSTGLITZ, et al. 2003).

However, studies are still needed for a better estimation of production, meat quality and CH_4 emission intensity comparing these different pasture-based production systems under tropical conditions.

2. OBJECTIVE AND HYPOTHESIS

The objective of this study was to investigate the effects of intensification and integration of pastures-based systems on performance, carcass characteristics and meat quality of *Nellore* steers.

The hypothesis was that intensification and integration of pasture-based systems can improve animal performance, productivity, carcass yield and meat quality. In addition, the intensification of pasture-based systems can lead to lower CH_4 emissions per kg of product, which directly contribute to the sustainability of livestock production on tropical pastures.

3. LITERATURE REVIEW

3.1. Greenhouse Gases (GHG) Emissions - Global and Brazilian Scenario

Greenhouse gases (GHG) are crucial to keep the Earth at a suitable temperature for life. These gases let the sun's light shine onto Earth's surface, but they trap part of the heat that reflects into the atmosphere. Without the natural greenhouse effect, the heat emitted by the Earth would simply pass outwards from the surface into space and the planet would have an average temperature of about -18°C and many life forms would freeze (RODRIGUES, 2020). However, each of the last four decades has been successively warmer than any decade that preceded it since 1850 (IPCC, 2022).

Changes in Earth's temperature and climate patterns may be natural, but according to the latest IPCC report (IPCC, 2022) it is unequivocal that human influence has warmed the atmosphere, ocean, and land at an unprecedented rate for at least the last 2,000 years. Changes in the atmosphere, ocean, cryosphere, and biosphere are happening at an unprecedented rate (IPCC, 2022), this mainly due to the emission of GHG which are at their highest levels in 2 million years with annual averages of 410 parts per million (ppm) of carbon dioxide (CO_2), 1866 parts per million (ppb) of methane (CH_4) and 332 ppb of nitrous oxide (N_2O) (IPCC, 2022). With varying degrees of reliability, it is estimated that human activities have increased the Earth's surface temperature by 1.07 °C (IPCC, 2022).

In the 2002 article "Geology of mankind", Paul Crutzen attributed the term "Anthropocene" to the present human-dominated geological era due to the rapid expansion of the World's population an exploitation of the Earth's resources: during the last three centuries the human population increased tenfold; the CH_4-producing cattle herd also increased; about 30-50% of the planet's land surface has been exploited; tropical forests have disappeared at an accelerated pace; energy use grew 16 times during the 20th century, more nitrogen in the form of fertilizers is applied in agriculture than is fixed naturally in all terrestrial ecosystems and fossil fuel burning and agriculture activities have caused substantial increases in GHG concentration in the atmosphere (CRUTZEN, 2002).

In Latin America and the Caribbean, the human activities that most emit GHGs are those related to agriculture, forestry, and land use change (IPCC, 2022). In this scenario, Brazil gains special attention due to the CH_4 and N_2O emissions from livestock production and agricultural soils, mainly from enteric fermentation, animal waste management, rice production and burning of sugarcane (MCTI, 2016).

The enteric fermentation is a natural part of the ruminant digestive process, in which microorganisms present in the digestive tract and rumen breakdown and ferment the food ingested by the animal. In ruminant animals, approximately 95% of the fermentation process occurs in the rumen and 5% in the intestine. So, the term “enteric” is adopted because it represents the whole system. The enteric emission of CH_4 is a natural and intrinsic process carried out by methanogenic Archaea, which are strictly anaerobic microorganisms. Its function is to regulate rumen pH by removing H_2 produced during the fermentation processes. However, CH_4 production represents an energy loss that can vary from 2 to 12% of the gross energy intake (JOHNSON, 1994). Within the fermentation process, CH_4 production varies between 30 and 40% of the total gases produced, varying according to the concentration and relative proportions of the short-chain fatty acids (OWENS & GOESTCH, 1993). The emission of CH_4 tends to follow the growth of the herd: the greater number of cattle heads, the more CH_4 will be emitted. This could be affected according to the nutritional value, chemical composition, and the level of feed intake of an individual animal (WARNER et al., 2017).

Methane has 11.8 years of lifetime in the atmosphere and a global warming potential 27.2 times greater than CO_2 (IPCC, 2022). During the COP26 in Glasgow, more than 100 countries committed to reduce in 30% the CH_4 emission levels by 2030 (globalmethanepledge.org) and it is estimated that this can prevent more than 0.2°C of rise in temperature, bringing the World closer to the goals of the Paris Agreement.

It is important to measure the gross enteric CH_4 emission from the animals, as well as the emission intensity, which is the amount of CH_4 emitted to produce 1 kg of animal product like 1 liter of milk or 1 kg of meat, making “methane intensity” the most used and accepted indicator of production efficiency. From 1997 to 2014, there was a decrease in CH_4 intensity in Brazil which could be attributed to an increased animal productivity, since during this period the herd and gross CH_4 emission increased by 32% and 29%, respectively, while carcass production increased by 142% (IBGE, 2018).

Despite having one of the highest emission intensities due most of the livestock production based on extensive pastures, it is important to highlight that Brazil has a great mitigation potential due the intensification and integration of grazing systems (OLIVEIRA, 2015).

3.2. Panorama of beef cattle production in Brazil

Detaining much of its territory located between the tropics causes Brazil to have some climatic "phenomena" such as precipitation and luminosity working in its favor, since the actions of both, associated with the availability of land favors the production and maintenance of pasture and consequently, favoring animal production as well, especially beef cattle.

It is important to emphasize that the production of beef cattle comes mainly from pasture production systems (ARAÚJO FILHO, et al. 2019). According to the Brazilian Association of Meat Exporting Industries (ABIEC, 2020), in 2019 approximately 90% of slaughtered cattle came from grazing systems. The entire beef cattle production chain accounted for 8.5% of the national gross domestic product (GDP), which in terms of values corresponds to R$ 618.5 billion. Therefore, it is clear the importance of beef cattle production for the Brazilian economy.

As already mentioned, the cattle production in Brazil occurs mostly in low intensified systems, in pastures with little or no adoption of fertilization, without the adoption of energy-protein supplementation for the animals and with relatively low stocking rates, which makes the production cycle since breeding, raising, and fattening take a relative long time, consequently slaughtering older animals (ARAÚJO FILHO, et al. 2019).

According to Briske et al. (2008) much of the forage production occurs during the rainy season and this affect the availability and supply of quality fodder throughout the year, impairing the pasture support capacity and requiring adjustments of stocking rates. Seasonality has a direct effect not only on availability, but also on the quality of the fodder that will be offered to animals. It is known that the contents of dry matter, crude protein, neutral detergent fiber and other digestible components tend to vary throughout the year, not only under the influence of climatic factors, but also due to its natural production cycle since growth, forage maturity and its senescence. Such variations in the composition and availability of the pastures directly affect the consumption pattern, which may reflect in gains or losses of animal weight (CAPSTAFF & MILLER, 2018) and consequently in carcass and meat quality characteristics.

More intensified grazing systems in which fertilization is used following adequate recommendations, use of nutritional supplements, use of irrigation or association of grazing systems with forests (silvipastoral) are alternatives that in certain situations can contribute to improve the productivity and sustainability of the livestock production under tropical conditions with potential to mitigate GHG emissions (CARVALHO et al., 2001).

3.3 GHG emissions by the beef production system

The extension of the Brazilian territory leads the country to have an important role and impact on agriculture and livestock production. However, it is noticeable that the side effect of being able to exploit the land and its potentialities with poor regulations, has led the agricultural sector to be one of the main GHG contributors, being responsible for 32% of the country's GHG emission and 1% of total global emissions (IPCC, 2022).

The main gases emitted to the atmosphere within the Brazilian agricultural sector are CH_4 and N_2O. These emissions come from two different subsectors that are directly responsible for the growth of the national GDP. In first place comes livestock (enteric fermentation), mainly cattle, representing 57.5% of the sector's emissions, followed by agriculture (agricultural soils) with 35.0%, management of animal waste with 4.1%, rice production with 2.5% and the burning of sugarcane and cotton with 1.3% (MCTIC, 2016).

Comparing the emission intensity of the main beef producers' countries in the world, from 1961 and 2016, India led the ranking, followed by Brazil and Argentina respectively (FAO, 2018). Over this period, China has been decreasing its emission intensity. The United States, as the largest producer of beef in the world, has the lowest emission intensity since they adopt the use of a feedlot system. Brazil has one of the highest emission intensities, mainly due to most of the meat coming from the pasture system; however, it is important to highlight the carbon sequestration capacity of tropical pastures, being a great differential in comparison with other countries. According to Oliveira (2015) 89% of the mitigation potential of GHG emissions is related to the sequestration of C from the soil.

Climate change caused by GHG emissions is a threat to the agricultural sector, and is already affecting animal production, the quality of pastures and grains, water availability, animal reproduction and even the incidence of diseases and pests (ROJAS – DOWNING et al., 2017). This reality shows the importance of searching for GHG mitigation strategies related to the livestock production such as an efficient animal management and sustainable production systems, manipulation of the ruminal ecosystem and nutritional adjustments. The use of good-quality forages, supplements and additives in the formulation of diets, as well as inclusion of grains and concentrated feeds, legumes, tannins saponins, oils, saturated and unsaturated fats, ionophores, nitrate, yeast, malate, fumarate, essential oils, and vegetable extracts have been tested and proved to be efficient (HRISTOV et al., 2013). In addition, we must consider the potential for mitigating CH_4 and N_2O emissions through the C fixation capacity of tropical soils, recovering degraded pasture areas with the use of adequate and intensive pasture management techniques (BERNDT & TOMKINS, 2013; OLIVEIRA, 2015). It is important to point out that the mitigation strategies aim to maintain or increase the productivity of the system, either through milk or meat production, since the emission intensity (kg of CH_4 per kg of product) will be lower.

3.4. Grazing and intensification systems in beef cattle

C4 type forage species express high productive potential in Brazil due to favorable climatic conditions. Genera such as *Panicum*, *Pennisetum*, *Brachiaria* and *Cynodon* are commonly used (EUCLIDES, 1995), and *U. brizantha* can reach up to 36 tons of dry mass per hectare/year (GHISI & PEDREIRA, 1987), highlighting the potential of tropical pastures for feeding grazing animals.

However, most of the country's pastures are established in degraded soils (BARCELLOS et al., 2001; KLUTHCOUSKI & ADAIR, 2003), and the main causes of degradation are inadequate management of the forage plants, lack of soil fertility and conservation (OLIVEIRA, 2007). Because of the inappropriate management of pastures, there is GHG emissions, especially due to the exhaustion of soil organic matter during the degradation process that emits CO_2 (LAL, 2001). In addition, the performance and age at slaughter of animals are also impaired.

The correct pasture management has as main purpose: the intensification and optimization of forage productivity. We can intensify the production of a pasture in several ways, such as performing an appropriate management according to each species and variety, fertilization and soil correction, division of areas, irrigation, pests and weed control, in addition to the use of more productive cultivars. By making better use of natural resources and financial planning, we can increase the productivity of the system (OLIVEIRA et al., 2007).

Oliveira et al. (2018) demonstrated that the intensification adopted in beef cattle production system is extremely valuable for the increase of productivity. The authors evaluated the performance of *Nellore* cattle in degraded pasture (DP), irrigated pasture with high stocking rate (IHS), dryland pasture with high stocking rate (DHS) and dryland pasture with moderate stocking rate (DMS) grazing systems. The authors found that the higher the level of intensification adopted, the more satisfactory were the results of average daily gain and carcass yield.

Oliveira et al. (2018) also emphasized that it is important to compare the one with greater or lesser intensification, considering factors such as: carcass productivity, annual GHG emissions and the system's ability to act as C sink. The adoption of an intensified system, both in an environmental and economic perspective, presents a wide advantage since the intensity of emission per kg of meat ha/year is lower when compared to less intensified systems (OLIVEIRA et al., 2018). In fact, the increase in the level of intensification in the production system when well adopted represents improvements in productivity by area, increasing the animal performance and mitigating GHG emissions, contributing to a more sustainable livestock production.

3.5. Meat quality

Consumers are increasingly searching for healthy foods, including meat that is considered an important element in the human diet (RAMOS & GOMIDE, 2007). At the time of purchase of the product, several attributes are evaluated by the consumer such as meat color and fat, distribution and amount of fat, and the decision to re-consume it is due to the taste, succulence and softness that are characteristics that define the quality of meat (SILVA SOBRINHO, 2001), and these quality characteristics are influenced by the breed, age at slaughter, feeding and production system in which the animal was raised (SILVA SOBRINHO & SILVA, 2000). In addition, factors such as nutritional and grazing management can be controlled in the various stages of production, interfering in the quality of products of animal origin and to meet the demands of the consumer market, the effect of diet on the quality of beef should be investigated (BRIDI et al., 2015).

The strong relationship between beef quality and production system was observed by French et al. (2000). The authors evaluated the meat quality of crossbreed steers by consuming increasing levels of concentrate and decreasing levels of forage in the diet. The yellow fat content was increased by the inclusion of forage in the diet, and the animals finished in pasture with low concentrate level produced meat with better softness evaluated at 2 days postmortem. Meat from beef produced on pasture has desirable nutritional characteristics such as higher levels of polyunsaturated fatty acids, a lower ratio of omega-6:omega-3 fatty acids, in addition to higher amounts of conjugated linoleic acid when compared to those produced in confinement (WOOD et al., 2003).

Although the pasture-based system is the most common way of raising cattle, pastures systems can be strongly affected by forage production and quality due to seasonality, which directly increases the time needed to send cattle to slaughter (REALINI et al., 2004), which might not be the most appealing decision to take. However, the adoption of technologies that were extensively cited in this thesis can lead to pasture-based production systems that can reduce the time until the animal reaches the slaughter weight.

Cattle slaughtered at early age have a carcass composition with desirable characteristics to the consumer market, such as adequate amount of fat, parts of constant size, color, tenderness, and flavor. Consumers, especially those in the international market, look for meat with proven quality even at high prices (BARCELLOS, 2007). Moreover, if the cattle are raised and finished in pasture, we also have a more appealing product not only because the meat has higher levels of polyunsaturated fatty acids, greater amount of conjugated linoleic acid, but also by the fact that the animal was raised in a system that meets important requirements of the welfare in livestock production (BALBINO et al., 2011).

4. MATERIAL AND METHODS

4.1. Location and animals

The experiment was carried out at Embrapa Southeast Livestock in São Carlos - SP, Brazil (21º 57'S, 47º 50'W, 860 m) for two consecutive years (2019 to 2021), during two periods: September 2019 to September 2020 (1st period) and September 2020 to September 2021 (2nd period). Climate is classified as subtropical humid (Köppen: Cwa), with two well-defined seasons: dry (from May to September) and rainy (from October to April), presenting during the experimental period an annual average temperature of 21.7 ºC, with a maximum of 28.2 ºC and a minimum of 16.7 ºC, annual average relative humidity of 67.8% and average cumulative annual rainfall of around 1110.5 mm (PASQUINI NETO, 2022).

A total of 58 *Nellore* steers (*Bos taurus indicus*), 28 steers during the period 1 and 30 steers during the period 2, were used as experimental animals. Non-castrated males with approximately 280 ±54.5 kg of live weight and between 15 and 16 months old were used as experimental animals. The animals came from the University of São Paulo (PUSP – C/USP), Pirassununga - SP, Brazil, and were managed in accordance with the "Guidelines of the Institutional Committee for the Care and Use of Animals" – CEUA (No. 20.19.00.047.00.00) of Embrapa. The animals were selected within a homogeneous (body weight, age and genetic composition) group and randomly assigned to 5 different pasture-based treatments.

Six experimental animals per treatment were used each year for measurements of enteric methane (CH_4) production using the sulfur hexafluoride (SF_6) tracer gas technique (n=4) and dry matter intake (n=2). A variable number of non-experimental "regulator animals" were used to adjust the animal stocking rate following the "put and take" technique (MOTT & LUCAS, 1952) in order to maintain a grazing pressure, close to the carrying capacity of the pastures, based on the specific residue heights, as recommended by COSTA & QUEIROZ (2013). Throughout the entire experimental period the animals were pasture-fed with *ad libitum* protein mineral supplementation formulated with ammonium nitrate (non-protein nitrogen) as ingredient (Table 1).

Table 1 - Proportion and bromatological composition of the mineral-protein supplement

Ingredients	Proportion (%)
Ground Corn	45.0
Sodium Chloride	10.0
Mineral Core [1]	15.0
Ammonium nitrate [2]	30.0
Bromatological Composition	
Crude Protein (% DM)	46.1
Total Digestible Nutrients (%DM)	60.7
Non-Fiber Carbohydrates (% DM)	21.5
Neutral Detergent Fiber (%DM)	6.1
Acid Detergent Fiber (%DM)	2.3
Lignin (% DM)	0.7
Mineral Matter (% DM)	25.3
Ethereal Extract (%DM)	1.2
Gross Energy (MJ/ kg)	8.8
Calcium (g/ kg)	11.0
Phosphor (g/ kg)	11.3
Magnesium (g/kg)	0.7
Sulfur (g/kg)	12.3
Potassium (g/kg)	4.3
Copper (mg/ kg)	124.7
Manganese (mg/ kg)	84.9
Iron (mg/ kg)	321.4
Zinc (mg/ kg)	426.0

Adapted from Pasquini Neto (2022). [1]Mineral core, quantity per kg of product: 240.0 g of Calcium (maximum), 160.0 g of Phosphorus, 60.0 g of Sulfur, 200.0 mg of Cobalt, 2500.0 mg of Copper, 125.0 mg of Iodine, 2250.0 mg of Manganese, 50.0 mg of Selenium, 7500.0 mg of Zinc, 1600.0 mg of Fluorine; [2]Fertilizer containing the source of N (33.5 a 34.5%), quantity per kg of product: 340.0 mg of Calcium, 20.0 mg of Phosphorus, 22.7 g of Sulfur, 3.2 mg of Copper, 2.4 g of Manganese, 2.9 mg of Zinc, 2.2 mg of Manganese, 40.5 mg of Iron, 140.0 mg of Potassium.

4.2. Pastures and production systems treatments

The treatments consisted of five different types of grazing systems with two replications per treatment (Figure 1), as follows: *i)* degraded mixture pasture of *U. brizantha* cv. Marandu and *U. decumbens* cv. Basilisk under extensive management (DP) *ii)*intensively managed silvopastoral system with rainfed *U. decumbens* cv. Basilisk intercropped with native Brazilian trees using high tree density (LFS); *iii)* intensively managed rainfed mixture pasture of *Urochloa* (syn. *Brachiaria*) *brizantha* (Hochst ex A. Rich) Stapf cv. Marandu and *U. decumbens* Stapf cv. Basilisk (RMS); *iv) M. maximus* Jacques cv. Tanzania pasture, rainfed, intensively managed (RHS); and *v)Megathyrsus maximus* (syn. *Panicum*) Jacques cv. Tanzania pasture, irrigated, intensively managed (IHS).

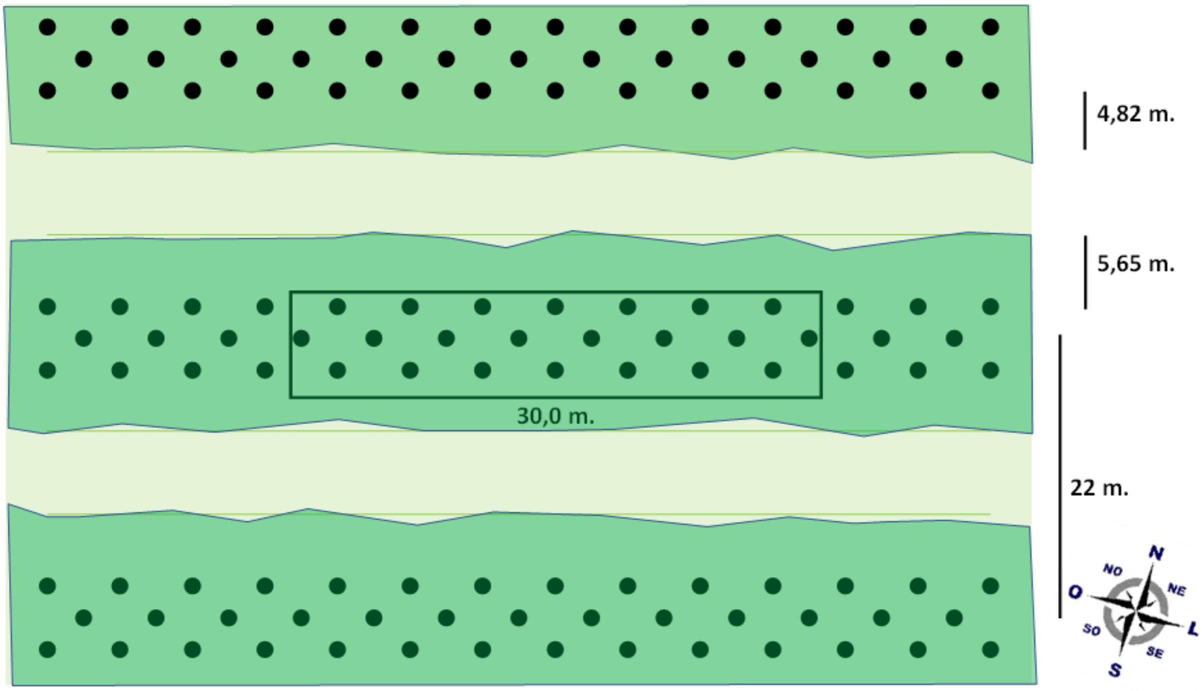
Figure 1 - Aerial view of the experimental area

Source: Adapted from Google Earth.

Before the beginning of the experimental period, soil analysis was performed, and the intensively managed treatments (IHS, RHS and RMS) received application of lime and fertility correction with superphosphate (SFS) and potassium chloride (KCl) to achieve 20 mg $P.dm^{-3}$ and 4% K in cation exchange capacity (CEC). The DP treatment did not receive any type of liming nor fertilization.

The IHS and RHS pasture systems were established in 2002 while pastures in the RMS and DP systems were established in 1996 with *U. brizantha* cv. Marandu but were later compound by *U. decumbens* cv. Basilisk. The pasture in the LFS system was established and afforested in 2008 with native species in sets of three lines spaced 17 m following the terrain and with a 2.5 × 2.5 m, resulting in about 545 trees/ha, distance between trees composed of the following species: *Anadenanthera colubrina* (Angico branco), *Peltophorum dubium* (Canafístula), *Zeyheria tuberculosa* (Ipê felpudo), *Cariniana estrellensis* (Jequitibá branco) and *Croton floribundus* (Capixingui). In 2016, 50% of the trees on the marginal lines were thinned, resulting in a total amount of 350 trees per hectare in this system.

In the months of March to May 2020 a characterization of the experimental area was performed with respect to the tree component. In the tree rows, 8 plots of 30 m linear were allocated where the tree count and measurements of diameter at breast height (DBH) and tree height were taken. The average number of trees per plot was 23, totaling an average of 350 trees ha^{-1}. The average DBH was 24.77 cm, with wide variation among individuals, characterizing a basal area of 16.46 m2 ha^{-1}. The average height was 10.85 m. The average projection of the crowns on the north side of the branch was 5.65 m and on the south side, 4.82 m. In the figure below is a sketch of the projection of the crowns of the trees with emphasis on an experimental plot.



The IHS and RHS areas (1.83 and 1.80 hectares, respectively) were divided into 12 paddocks each treatment and managed as a rotational grazing system (3 days of occupation followed by 33 days of rest). RMS and LFS treatments (3.10 and 3.71 hectares, respectively) were divided into 6 paddocks and managed in a rotational grazing system with 6 days of occupation and 30 days of rest. In the DP treatment (2.01 hectares) the animal were extensively managed with continuously occupation regardless the height of the pasture residue throughout the entire experimental period. To meet the water demand, reduce the effects of seasonality and provide adequate conditions to increase forage production and nutritional quality, the IHS treatment was irrigated using a Fixed Center Pivot (Carborundum model PC 08-636/L3/G2S, Lindsay Corporation, Omaha, Nebraska, EUA) and overseeded with pure and viable seeds of the temperate species *Avena byzantina* (60 kg ha^{-1}) and ryegrass (*Lolium multiflorum*, 30 kg ha^{-1}) that develop best in autumn and winter (OLIVEIRA et al., 2005).

4.3. Forage samplings

In each season of year, samples of pasture were collected by hand-plucking simulating the forage consumed by the animals. Sampling was carried out for 3 days and for this the steers were observed for a few minutes and followed during grazing. The material was collected in places close to those selected by the animal, and for greater similarity some requirements were followed: the quantity sampled in each point was similar to the quantity harvested by the animal; the proportion of leaves, stem and dead material in the sample was visually similar to the proportion harvested by the animal; the length of the leaves removed by sampling was similar to that removed by grazing. Each experimental unit had a sample composed of 3 days of sampling that were dried in forced air circulation oven at 65°C for 72 hours and ground into a Willey type mill using 1- and 2-mm mesh screen for further chemical composition and indigestible neutral detergent fiber (iNDF) analysis, respectively.

4.4. Dry matter intake and animal performance

The total DMI (kg DM/day) was estimated by the sum of forage and supplement consumed by the animals:

$$DMI = DMI_s + DMI_f$$

Where: DMI = total dry matter intake (kg DM/ day); DMI_f = forage dry matter intake (kgDM/ day); DMI_s = mineral supplement intake (kg).

The mineral supplement intake was estimated by the difference between the amount provided and the amount of supplement leftovers in the trough after five days. For this measurement a digital scale (1-10000g) was used, and the calculation followed the equation:

$$DMIs = \frac{[(DMIsSupplied - DMIsLeftovers)]/5(days)}{Total\ Weight}$$

Where: DMIs = mineral supplement intake (kg); DMIsSupplied = total supplement provided (kg); DMIsLeftovers = mineral supplement leftovers after 5 days (days); Total Weight = total weight of animals with access to that trough (kg).

To determine the forage DMI (DMIf) indirect methods with external (titanium -TiO_2) and internal (iNDF) markers were used to estimate dry matter intake (DMI). TiO_2 (15g) was administrated directly into the esophagus with the aid of a metal applicator for 10 days in each of the four seasons of the year. 5th day onwards feces samples were collected after spontaneous defecation and/or directly from the rectum of the animals in a containment trunk in the handling corral, frozen (-20°C) in properly identified plastic bags, then thawed, homogenized and dried at 65 °C in a forced ventilation oven for 72h and ground into Willey type mill using 2 mm mesh screen, to determine the concentration of TiO_2, through atomic absorption spectrophotometry technique described by Myers et al. (2004). To determine the concentration of the internal marker (iNDF), samples of forage, feces and supplements were placed in 100 g.m^2 TNT filter bags and incubated for 288 hours in rumen of cannulated animals consuming pasture. After removing from the rumen, the TNT filter bags were rinsed in water and dried in a forced air circulation oven at 65°C for 72 hours. The method described by Van Soest et al. (1991) was used to determine the content of neutral detergent fiber (NDF) and the remaining residue was considered as the iNDF content.

Using the external marker, it was possible to calculate fecal excretion by estimating the ratio of the amount of the external marker administered (kg/day) and the amount recovered in the feces (kg):

$$\text{Fecal excretion (kg/day)} = TiO_2 \text{ diet (kg/day)} / TiO_2 \text{ feces (kg)}$$

Where: TiO_2 diet = Titanium dioxide administered (kg/day); TiO_2 feces: Titanium dioxide recovered in feces (kg).

Subsequently, the forage DM intake (DMI) was calculated considering the internal marker concentration found in the pastures and feces according to the equation:

$$\text{Forage DMI (kg/day)} = [(\text{Fecal excretion}) \times (\%\text{ iNDF on feces})] / (\%\text{ iNDF on forage})$$

Where: Fecal excretion = expressed as kg/day estimated by using the external marker.

The individual average daily gain (ADG) of the animals was obtained dividing the body weight difference between two successive weighing by the interval of days between measurements. The animals were weighed in a fasted state at the beginning of the experiment and subsequently at 28 days intervals, and the following equation was used:

$$ADG = (BW_F – BW_I)/IW$$

Where: ADG = Average daily gain (kg); BW_F = Final BW, most current weight (kg); BW_I = initial BW, weight from previous weighing (kg); IW = Interval between weighing (days).

By following the weighing protocol, the final live weight of the animals in each season (LWfs) was also determined.

The stocking rate expressed in animal unit (AU) was calculated as the total weight of the lot divided by AU (450 kg of live weight) and by the area of the paddocks (in hectares). The stocking rate expressed in animal equivalent (AE) was obtained by dividing the total weight of the lot by the AE (equivalent to the average weight of the animals in the lot) and by the area of the paddock (in hectares).

$$SR = \left(\frac{BWTOTAL}{AU}\right)/Area$$

Where: SR= Stocking rate (AU ha^{-1}); BWtotal = Total body weight of tracers and regulators animals present in the experimental area (kg); AU = Animal unit (450 kg); Area = Experimental unit area (ha^{-1}).

4.5. Enteric CH_4 emission

Sulfur hexafluoride (SF_6) tracer gas was used as the method for measuring eructated CH_4 (JOHNSON et al., 1994; adapted to Brazil by PRIMAVESI et al., 2004). A small brass permeation tube, with a known SF_6 permeation rate, was placed in the reticulum, orally at the beginning of the experiment, to allow the tracer gas to equilibrate in the rumen. The CH_4 expelled through the animal's nostrils and mouth was captured by means of a silicone tube, transported by a capillary tube, and deposited in a storage-collector, called canister (PVC tube, closed and molded to fit the neck of the animal), coupled to a halter. For each experimental unit (paddock), 2 steers were monitored and each animal went through a 5-day adaptation period before the sampling procedure.

Each animal was sampled daily (24h) for five consecutive days in each season of the experimental period: spring, summer, autumn and winter. If the canister of any animal was broken or there was a problem with the capillary gas collector, it was replaced and the collection was extended for one more day, until reaching the recommended 5 effective collection days.

Additional PVC canisters were placed near the experimental pastures to monitor the ambient daily concentration of CH_4 and SF_6 during each sampling period. Sampling was performed daily at 07:00 h when the animals were removed from the paddocks and transferred to the working facilities of Embrapa Pecuária Sudeste. After the gas sampling, pure nitrogen was added to the canisters and then CH_4 and SF_6 were measured using gas chromatographs (Agilent HP-6890, Delaware, USA; and Shimadzu GC-2014, Columbia, MD, USA).

The CH_4 flux was calculated according to Westberg et al. (1998), using the following equation:

$$QCH_4 = QSF_6 \, [(CH_4)y - (CH_4)b] \, / \, [(SF_6)y - (SF_6)b]$$

Where: QCH_4= CH_4 emission rate per animal; QSF_6 = known SF_6 emission rate from the capsule in the rumen; $(CH_4)y$ = CH_4 concentration in the collection device; $(CH_4)b$ = basal concentration of CH_4; $(SF_6)y$ = SF_6 concentration in the collection device and $(SF_6)b$= basal SF_6 concentration in the ambient.

The gross energy intake (GEI) was calculated by multiplying DMI (kg) and diet GE (MJ/kg), and the CH_4 conversion rate (Ym, the percentage of GEI converted to CH_4) was calculated using the following equation, considering the heat value of CH_4 as 55.6 MJ/kg:

$$Ym\ (\%) = \frac{(CH4 \times 55.6)}{GEI} \text{ x } 100$$

4.6. Carcass and non-carcass characteristics

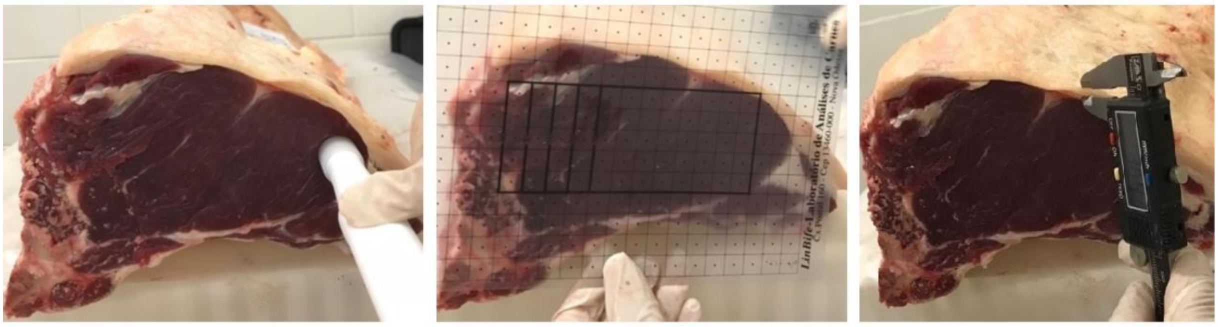
At the end of each period, the animals were slaughtered at the School Slaughterhouse of the University of São Paulo, Pirassununga, São Paulo, Brazil to evaluate carcass and non-carcass characteristics. Before slaughter, the animals were fasted for 16h and weighed to determine the fasting body weight (FBW). The slaughter was performed according to the current Brazilian law on the Regulation of Industrial and Sanitary Inspection of Animal Products (RIISPOA, 1952), through stunning by cerebral concussion using a pneumatic pistol and then bleeding out via sectioning of the jugular veins. After bleeding, skinning and evisceration, the hot carcass was weighted (HCW) and hot carcass yield (HCY) was determined using the equation:

$$HCY = HCW/FBW \times 100$$

Subsequently, the carcasses were carried to the cold room at 0 to 2 °C for 24 hours. Half-carcasses were divided into forequarters (with five ribs), hindquarters and spareribs (BARROS & VIANNI, 1979). After chilling, the carcass halves were weighed to obtain the cold carcass weight (CCW). After this period measurements and sampling were made on the left half of each carcass: approximately 2.5 cm thick samples were excised from the ribeye at the height of the 12th rib through a perpendicular cut to the *longissimus* muscles located between the 12th and 13th ribs.

The pH was measured using a digital pH meter (Hanna Instruments Inc®, Model HI 99163), ribeye area (cm^2) was determined using a plastic grid (resolution = 1cm^2), while fat thickness (mm) was measured using a digital caliper (Amatools®, model ZAAS Precision) (Figure 2), and a visual evaluation of the degree of marbling was performed according to the methodology proposed by the American Meat Science Association (AMSA, 2001). Four samples of *longissimus thoracis* muscle (2.5 cm thick) were collected, individually vacuum packed and frozen at - 2 °C for further qualitative analysis.

Figure 2 - Analysis of pH, backfat thickness and ribeye area



Source: personal collection.

Half-carcasses were divided into forequarters, hindquarters and spareribs, and the carcass edible portion (CEP) was expressed in kilograms and as a percentage of CCW (CEP%).

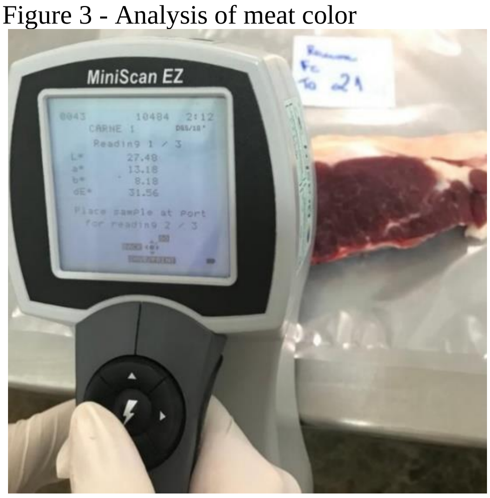
The CEP was calculated as the sum of edible portions of the Brazilian primal cuts (Yokoo et al., 2003): hindquarter (HEP), forequarter (FEP) and spareribs. The HEP and FEP were calculated as the sum of the edible portions of retail cuts: HEP – sirloin, tenderloin, rump, knuckle, topside, flat, eye of round, cap and tail and shank; FEP – shoulder clod, hump, chuck, and brisket. Hindquarter fat trimmings (HFT) and forequarter fat trimmings (HFT) with the standardization of about 3 mm of fat on the retail beefs are expressed in kilograms and as a percentage of CCW – HFT%. These traits were considered representative of carcass fat content. Bones and non-edible components and were also expressed in kilograms and as a percentage of CCW.

4.7. Meat quality

Steaks measuring 2.5 cm thick from the *Longissimus* muscle were individually vacuum packed in polyethylene bags (Cryovac®, Charlotte, NC, EUA) and aged between 0 and 2ºC for measuring cooking losses (CL), shear force (SF) and sensory analysis.

The determination of meat color was performed, as described by Houben et al. (2000), in three locations of each steak sample after a 30 min bloom time at 4ºC, for oxygenation of myoglobin to occur. For this a Minolta colorimeter (Model CM2500d, Minolta Camera Co. Ltd., Osaka, Japan) was used, evaluating the lightness (L*), redness (a*), and yellowness (b*) (Figure 3). The color aspects were assessed by the CIE L*a*b color system using 0º/45º and the unit calibrated using a black and white standard plate.

Figure 3 - Analysis of meat color



Source: personal collection.

For the analyses for cooking loss and shear force, the meat samples were cooked in a gas oven at 175ºC until they reach 72ºC at their geometric centers. The weights of the steaks before and after cooking were measured to calculate the cooking losses (CL), according to Honikel (1998). After 24 h cooling, six cores were removed from the steaks using a 2.5 cm diameter drawn punch. A Brookfield® CT-3 Texture Analyser (Brookfield, USA) were used to measure the force necessary to transversally cut each core. The average cutting force were calculated, representing the shear force of each sample as described by Wheeler et al. (2001).

4.8. Sensory panel

The sensory panel of meat aims to determine whether the samples analyzed differ with respect to sensory attributes, such as aroma, tenderness, flavor, juiciness, and global acceptability (GA) be evaluated through taster feedback. To do this, people are recruited to taste the meat and characterize it as to their perception of these characteristics (HOLMAN et al., 2020). The participants of the sensory analysis are called tasters, and can be trained or untrained, in the case of untrained tasters they are considered as consumer tasters. Thus, when the objective of the study is to know the perception and acceptance of the population in relation to meat, untrained tasters are recommended (AMSA, 2015).

For the sensory panel, a sample steak was taken from the LT muscle (13th rib and 2.54 cm thick). Five LT muscle samples were offered to each taster, referring to the five treatments of the experiment (DP, LFS, RMS, RHS and IHS), all matured for 14 days.

The samples were coded with a three-digit number and given one at a time to the tasters (FERREIRA et al., 2000). To minimize the effect of presentation on the tasters' judgments, the order of presentation of the samples was balanced and randomized among the tasters (AMSA, 2015).

For sensory evaluation of fresh meat, the samples were kept in a domestic refrigerator (7°C) for 24 hours for defrosting and cut in a standard size. The steaks were roasted in an oven at 175°C until reaching a temperature of 75°C in the geometric center, which was monitored by individual thermocouples. After this procedure, the meat was cut into cubes, packed in foil paper and served in a panel of untrained consumers in individual cabins, using a quantitative affective acceptability test (*n* = 130 tasters) (MEILGAARD et al., 1999).

The samples were offered sequentially to each taster in coded plastic coffee cups, accompanied by a salt and water biscuit for residual taste removal and a cup of water to wash the palate (Figure 4). The attributes aroma, tenderness, juiciness, flavor, and global acceptability were evaluated according to the methodology described by AMSA (2015). The evaluation of the samples was made by hedonic scale scores ranging from 1 to 9, with 1 being the minimum score and 9 being the maximum score (MEILGAARD et al., 1999).

Figure 4 - A cup of water, biscuit and the meat sample offered to the tasters

Source: personal collection.

5. STATISTICAL ANALYSIS

The grazing units were considered the experimental units for the data obtained by area and the steers were the experimental units for the data obtained per animal. Data was statistically analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Before analysis, outliers were identified, and the residuals normality tested (Shapiro-Wilk). When the normality assumption was not accepted, the logarithmic or square root transformation was applied. Then the data were analyzed using the mixed procedure (PROC MIXED) testing different covariance structures and chosen the best fitting model based on the lowest value of the Corrected Akaike Information Criterion (AICC) (WANG and GOONEWARDENE, 2004). For performance, dry matter intake and CH_4 emissions data, season was considered as a repeated variable (split-plot in time), the model included treatment (five different systems) and season (spring, summer, autumn, and winter) effects and the interaction systems × season was tested, except for the data after the slaughter as well as sensory data, in the case, the tasters were considered the experimental units. For the sensory panel analysis, effect of treatment and tasters were considered as random. The means were presented as least square means and effects considered significant at 5%.

6. RESULTS

6.1. Dry Matter Intake and Animal Performance

Significant effects of season and treatment were found for forage and supplement DMI (Table 2) (P < 0.05). Also, effect of season was found for Total DMI (Table 2) (P < 0.05). Animals kept in the DP system presented the highest intake of supplement, while higher intake of forage was found for IHS when compared to DP and LFS systems (P < 0.05). Numerically, the supplement DMI from animals in the IHS treatment was 20.3, 39.6, 38.9 and 60.7% lower than RHS, RMS, LFS and DP, respectively. Forage and total DMI followed the same trend considering the seasons of the experimental period in which higher values were found for the summer and autumn when compared to spring and winter (P < 0.05), and the lowest intake of supplement was found during the spring (P < 0.05).

Table 2 - Forage, supplement, and total dry matter intake of *Nellore* steers in the different pasture-based production systems during the different seasons of the experimental period

Fixed effects		**Variables**					
Systems[2]	Seasons	Forage DMI[1]		Supplement DMI		Total DMI	
		(kg day^{-1})	(% LW[3])	(kg day^{-1})	(% LW)	(kg day^{-1})	(% LW)
DP		6.89^{b}	1.44	0.599^{a}	0.13	7.46	1.55
LFS		6.80^{b}	1.40	0.385^{b}	0.08	7.15	1.47
RMS		7.50^{ab}	1.54	0.389^{b}	0.08	7.93	1.63
RHS		7.72^{ab}	1.71	0.295^{c}	0.06	8.01	1.78
IHS		9.09^{a}	1.83	0.235^{c}	0.05	9.34	1.89
	Spring	6.57^{B}	1.65	0.228^{B}	0.06	6.81^{B}	1.71
	Summer	9.37^{A}	1.94	0.489^{A}	0.10	9.84^{A}	2.04
	Autumn	8.81^{A}	1.69	0.408^{A}	0.09	9.23^{A}	1.77
	Winter	5.64^{B}	1.06	0.397^{A}	0.08	6.04^{B}	1.14
Average		7.45	1.56	0.381	0.08	7.81	1.64
SEM[4]		0.286	0.052	0.028	0.004	0.294	0.053
Statistics Probabilities							
Systems		**0.0419**	**0.0127**	**<.0001**	**0.0083**	0.1004	**0.0310**
Season		**<.0001**	**<.0001**	**0.0080**	**0.0276**	**<.0001**	**<.0001**
Systems × Seasons		0.4602	**0.0346**	0.8990	**0.0049**	0.4932	**0.0359**

Source: Pasquini Neto (2022).
[A,B,C] Capital letters differ within season (P<0.05); [a,b,c] lowercase letters differ within systems (P<0.05).
[1]DMI: Dry matter intake. [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]LW: Live weight. [4]SEM: Standard error of mean.

The variables used to assess animal performance were average daily gain (kg.day^{-1}), final live body weight (kg) and stocking rate (AU ha^{-1}) (Table 3). Season and pasture-based production systems effects were found for all variables (P < 0.05). In addition, significant interactions between systems×seasons were found for these variables and are presented in Figures 5, 6 and 7.

Table 3 - Performance of *Nellore* steers in different production systems of the experimental period

Systems[1]	$_{I}$LBW[2]	$_{F}$LBW[3]	LWG annual per Hectare[4]	YGC annual per Hectare[5]
	(kg)	(kg)	(kg ha year^{-1})	(kg carcass ha year^{-1})
DP	334.9	441.1^{c}	241.4^{d}	125.6^{d}
LFS	337.1	457.9^{c}	231.6^{d}	119.1^{d}
RMS	331.3	564.3^{b}	791.7^{c}	425.9^{c}
RHS	341.4	561.9^{b}	1162.2^{b}	620.5^{b}
IHS	333.4	620.6^{a}	1808.4^{a}	1018.1^{a}
Average	334.5	531.1	847.1	461.8
SEM[6]	7.45	11.82	138.69	78.63
P Value	0.6949	**<.0001**	**<.0001**	**<.0001**

[1]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate.[2]$_{I}$LBW: Initial live body weight; [3]$_{F}$LBW: Final live body weight; [4]LWG: Live weight gain;[5]YGC: Yield gained per carcass; [6]SEM: Standard error of mean.

Table 4 - Performance of *Nellore* steers in different production systems in different seasons of the experimental period

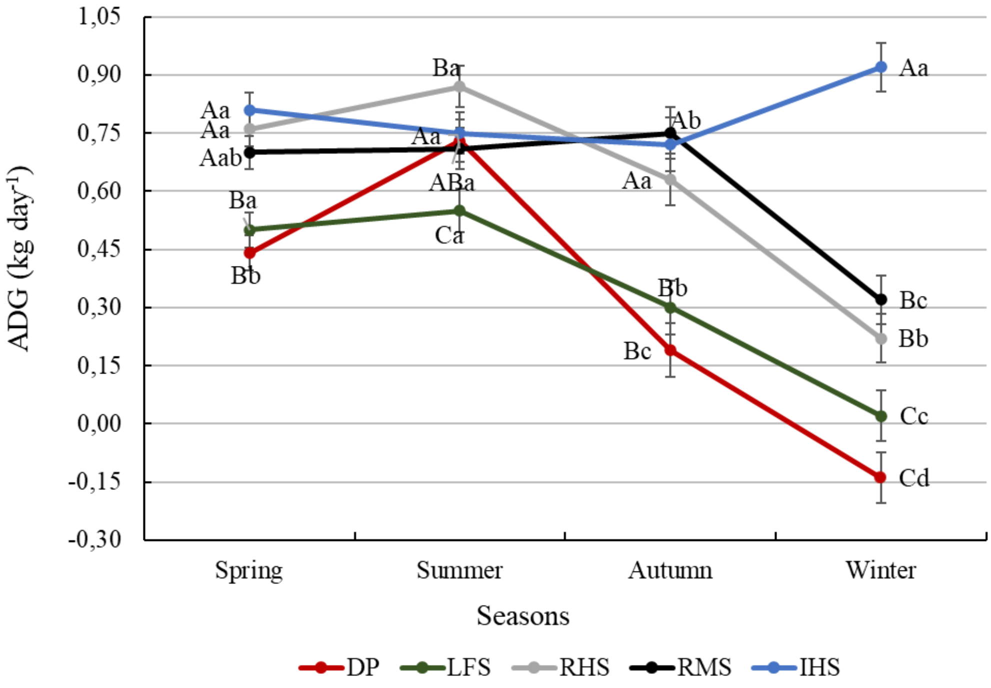
Fixed effects		**Variables**		
Systems[1]	Season	ADG[2]	LWfs[3]	SR[4]
		(kg day^{-1})	(kg)	(AU[5] ha^{-1})
DP		0.303	426.8	1.89
LFS		0.344	432.8	1.24
RMS		0.621	490.6	2.56
RHS		0.619	497.7	3.90
IHS		0.800	503.8	5.68
	Spring	0.642	391.0	1.69
	Summer	0.724	455.5	4.63
	Autumn	0.518	504.7	3.90
	Winter	0.267	530.0	1.99
Average		0.543	469.9	3.05
SEM[6]		0.022	5.702	0.253
		Statistics Probabilities		
Systems		**<.0001**	**<.0001**	**<.0001**
Season		**<.0001**	**<.0001**	**<.0001**
Systems × Seasons		**<.0001**	**<.0001**	**<.0001**

[1]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [2]ADG: average daily gain;[3]LWfs: Final live weight in each season; [4]SR: stocking rate; [5]AU: Animal Unit; [6]SEM: Standard error of mean. [A,B,C]Capital letters differ within treatments (P<0.05); [a,b,c,]low case letters differ within seasons (P<0.05).

When interaction was unfolded, it was possible to visualize that during the spring the animals kept in IHS, RHS and RMS presented higher ADG when compared to DP and LFS (P

< 0.05) (Figure 5). In this season, the IHS system presented 38.27 and 45.68 % higher ADG when compared to LFS and DP, respectively (Appendix A). During the summer, the lowest ADG was found for the LFS treatment (P < 0.05). The same differences among treatments during the spring were found during the autumn, with animals from IHS, RHS and RMS presenting higher ADG when compared to DP and LFS (P< 0.05). During the winter, the season in which the rain is scarce and the seasonality play an important role in forage mass production, the highest ADG was found for the IHS system (P < 0.05), being 97.8 and 115% higher than those found for LFS and DP systems, respectively (Appendix B).

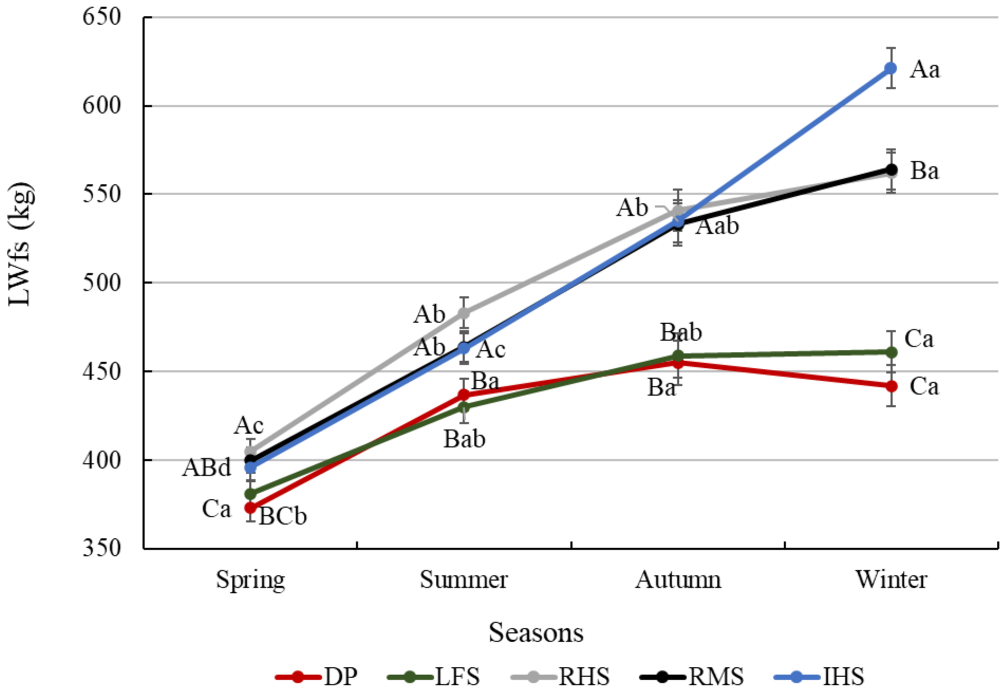
Figure 5 - Interaction between treatment and season for average daily gain of *Nellore* steers in different grazing systems and seasons



A, B, C Capital letters differ within treatments (P<0.05); a,b,c, lowercase letters differ within seasons (P<0.05). Vertical bars are standard error of the mean.

The LWfs showed a patter in which the more intensified systems (IHS and RMS) had similar results during the spring, summer and autumn and were higher than DP e LFS (P < 0.05) (Figure 6). In the winter season, the highest LWfs was found for the IHS system, followed by RHS and RMS that were higher than DP and LFS ($P < 0.05$). During this season, the animals kept in the IHS system presented on average 10% higher LWFs when compared to RHS and RMS (Appendix B).

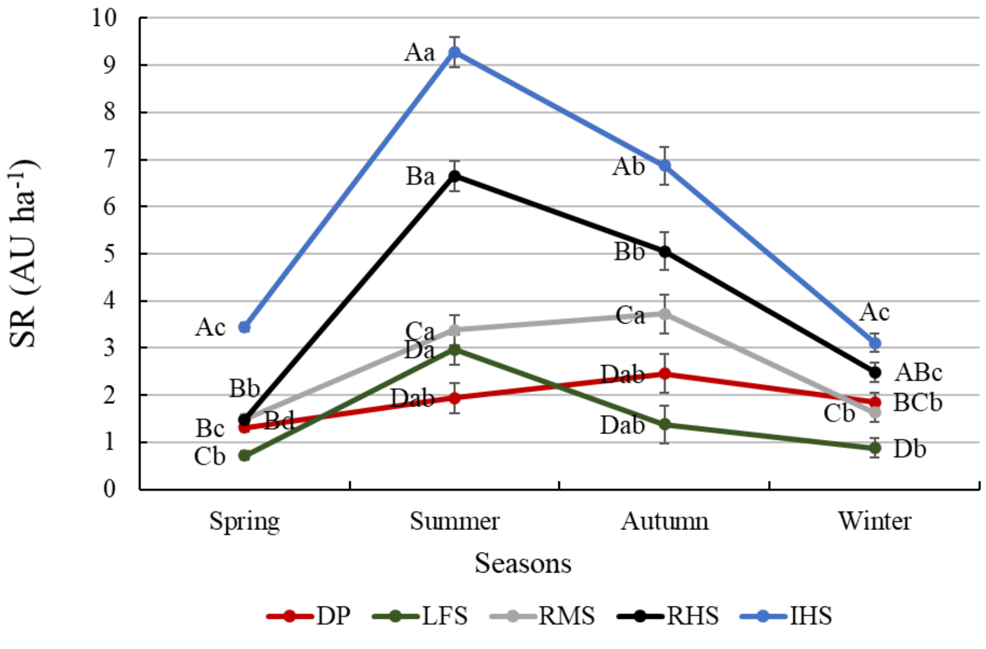
Figure 6 - Interaction between treatment and season for live body at the end of each season of *Nellore* steers in different grazing systems and seasons



A,B,C Capital letters differ within treatments ($P<0.05$); a,b,c, lowercase letters differ within seasons ($P<0.05$). Vertical bars are standard error of the mean.

Another pattern found in our results was that the more intensified systems allowed the use of higher SR (Figure 7). During the summer season, IHS had on average a 28% higher SR when compared to RHS and 79% higher than DP (Appendix B). During the winter season, RHS system had a similar SR when compared to IHS, and in all seasons lower SR values were found in DP an LFS systems (Figure 7).

Figure 7 - Interaction between treatment and season for stocking rate of *Nellore* steers in different grazing systems and seasons



A,B,C Capital letters differ within treatments (P<0.05); a,b,c, lowercase letters differ within seasons (P<0.05). Vertical bars are standard error of the mean.

6.2. Carcass and non-carcass characteristics

Significant differences among treatments were found for the carcass characteristics variables (P < 0.05; Table 4). The final body weight (FBW); shrunk body weight (SBW) and HCW variables showed the same pattern in which higher values were found for the IHS system, followed by RMS and RHS, and finally LFS and DP. The IHS system also presented higher values of HDP and BFAT when compared to the other systems. Higher values of REA and MS were found for RMS and IHS, while lower values were found for LFS and DP systems.

Table 5 - Carcass characteristics of *Nellore* steers in the different production systems

Variables[1]	Systems[2]					SEM[3]	*P Value*
	DP	LFS	RHS	RMS	IHS		
SBW (kg)	414.9[c]	432.2[c]	532.8[b]	539.6[b]	590.5[a]	11.5	**<0.0001**
HCW (kg)	219.1[c]	228.1[c]	290.1[b]	299.3[b]	339.9[a]	7.37	**<0.0001**
HDP (%)	53.8[c]	52.8[c]	54.5[bc]	55.3[b]	58.5[a]	0.35	**<0.0001**
REA (cm^2)	66.2[c]	69.9[c]	79.2[b]	86.1[a]	85.7[ab]	1.47	**<0.0001**
BFAT (mm)	1.38[b]	1.48[b]	1.92[b]	2.17[b]	3.02[a]	0.14	**<0.0001**
MS	4.05[bc]	4.00[c]	4.08[b]	4.20[a]	4.17[ab]	0.03	**0.0002**

SBW: shrunk body weight; HCW: hot carcass weight; HDP: hot dressing percentage; REA: ribeye area; BFAT: backfat thickness; MS: marbling score. [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]SEM: standard error of mean. [a,b,c] Means followed by different letters within a row differ at $P \leq 0.05$.

All carcass and no-carcass component variables showed significant differences among treatments when expressed in kilograms ($P < 0.05$; Table 5). LCCW, CEP, HEP and FEP presented the same pattern in which higher values were found for the IHS system, while lower values were found for DP and LFS. Higher SR values were found for RHS, RMS and IHS. For the HFT variable, the only difference was found between IHS and RMS, in which higher values were found for IHS. Higher values of FFT were found for RMS and IHS when compared to the other systems. Concerning the weight of bones, higher value was found IHS, followed by RHS, RMS, LFS and finally DP.

Table 6 - Carcass and no-carcass components of *Nellore* steers finished on different pasture-based production systems expressed in kilograms

Variables[1]	Systems[2]					SEM[3]	*P Value*
	DP	LFS	RHS	RMS	IHS		
LCCW (kg)	101.7[c]	106.3[c]	136.6[b]	141.0[b]	161.7[a]	4.30	**<0.0001**
CEP (kg)	75.6[c]	79.7[c]	106.7[b]	111.1[b]	128.2[a]	4.00	**<0.0001**
HEP (kg)	35.5[c]	36.6[c]	47.1[b]	49.2[b]	55.8[a]	1.45	**<0.0001**
FEP (kg)	32.2[c]	34.2[c]	47.0[b]	48.1[b]	56.4[a]	1.76	**<0.0001**
SR (kg)	12.2[c]	12.8[c]	18.3[a]	18.9[a]	23.0[a]	0.66	**<0.0001**
HFT (kg)	2.3[ab]	2.4[ab]	3.2[ab]	3.1[b]	4.3[a]	1.30	**<0.0001**
FFT (kg)	1.3[b]	1.2[b]	1.5[b]	2.4[a]	2.3[a]	0.18	**0.0013**
Bones (kg)	22.5[d]	23.0[cd]	25.5[ab]	24.4[bc]	27.0[a]	0.33	**<0.0001**

[1]LCCW: Left cold carcass weight; CEP: carcass edible portion; HEP: hindquarter edible portion; FEP: forequarter edible portion; SR: spareribs; HFT: hindquarter fat trimmings; FFT: forequarter fat trimmings; [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]SEM: standard error of mean. [a,b,c]Means followed by different letters within a row differ at $P \leq 0.05$.

When expressed as percentage, significant differences among treatments were found for CEP, FEP, SR and bones weight variables ($P < 0.05$; Table 6). The CEP values were lower on DP and LFS systems when compared to RHS, RMS and IHS. Higher values of FEP were found for RHS, RMS and IHS when compared to DP and LFS. The highest value of SR was found for the IHS system, while higher values of bones weight were found for DP and LFS systems.

Table 7 - Carcass and no-carcass components of *Nellore* steers finished on different pasture-based production systems expressed as percentage

Variables[1]	Systems[2]					SEM[3]	*P Value*
	DP	LFS	RHS	RMS	IHS		
CEP (%)	73.9[c]	74.6[c]	77.3[b]	77.9[ab]	78.7[a]	0.58	**<0.0001**
HEP (%)	34.8	34.5	34.6	35.0	34.6	0.15	0.7634
FEP (%)	31.3[b]	32.1[b]	33.9[a]	33.7[a]	34.4[a]	0.27	**0.0001**
SR (%)	12.1[c]	12.1[c]	13.5[b]	13.5[b]	14.3[a]	0.15	**<0.0001**
HFT (%)	2.3	2.3	2.4	2.3	2.7	0.07	0.2103
FFT (%)	1.4	1.2	1.3	1.8	1.6	0.15	0.0974
Bones (%)	22.4[a]	21.9[a]	19.1[b]	18.1[bc]	17.1[c]	0.47	**<0.0001**

[1]CEP: carcass edible portion; HEP: hindquarter edible portion; FEP: forequarter edible portion; SR: Spareribs; HFT: hindquarter fat trimmings; FFT: forequarter fat trimmings; [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]SEM: standard error of mean. [a,b,c]Means followed by different letters within a row differ at $P \leq 0.05$.

6.3. Meat quality

No significant difference among treatments were found for pH, shear force and cooking losses variables ($P > 0.05$; Table 7). On the other hand, differences on meat color variables of luminosity (L*) and yellow (b*) intensities were found in which higher values were found for IHS, followed by DP, LFS, RHS and RMS ($P < 0.05$; Table 7).

Table 8 - Meat quality of *Nellore* steers in different pasture-based production systems

Variables[1]	Systems[2]					SEM[3]	*P Value*
	DP	LFS	RHS	RMS	IHS		
pH	5.81	5.92	5.92	5.87	5.86	0.03	0.8159
SF_0 (N)	108.46	123.47	112.09	116.31	110.72	0.28	0.2948
SF_{14} (N)	73.84	87.87	72.37	73.06	77.47	0.26	0.2175
CL_0 (%)	28.52	29.12	27.50	29.76	28.62	0.42	0.4818
CL14 (%)	27.23	28.33	25.63	27.15	29.71	0.51	0.1060
Meat color							
L*	34.45[ab]	33.84[ab]	32.98[bc]	31.90[c]	35.21[a]	0.34	**0.0060**
a*	14.16	14.03	14.27	13.39	14.75	0.18	0.1318
b*	10.35[ab]	10.12[b]	10.08[b]	9.27[b]	11.37[a]	0.21	**0.0062**

[1]SF_0: initial shear force; SF_{14}: shear force after 14 days of maturation; CL_0: initial cooking losses; CL_{14}: cooking losses after 14 days of maturation; L*= luminosity intensity; a*= red intensity; b*= yellow intensity. [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]SEM: standard error of mean. [a,b,c] Means followed by different letters within a row differ at $P \leq 0.05$.

6.4. Sensory panel

All the sensory panel variables showed significant differences among treatments ($P < 0.05$; Table 8). Lower values of aroma were found for DP, LFS and RMS systems when compared to RHS. Higher value of tenderness was found for RHS when compared to LFS and RMS systems, while the highest value of juiciness was found in the RHS system. IHS presented higher value of flavor when compared to LFS. Considering the GA, higher values were found for RHS and IHS when compared to LFS.

Table 9 - Characteristics evaluated in the sensory panel of *Nellore* meat from different pasture-based production systems

Variables[1]	Systems[2]					SEM[3]	*P* Value
	DP	LFS	RHS	RMS	IHS		
Aroma	6.79[b]	6.82[b]	7.06[a]	6.92[b]	6.94[ab]	0.04	**<0.0001**
Tenderness	6.60[ab]	6.36[bc]	6.76[a]	6.27[c]	6.64[ab]	0.05	**<0.0001**
Juiciness	6.86[b]	6.81[b]	6.93[a]	6.74[c]	6.74[c]	0.04	**<0.0001**
Flavor	6.88[ab]	6.83[b]	6.97[ab]	6.89[ab]	7.02[a]	0.04	**<0.0001**
GA	7.01[ab]	6.80[c]	7.13[a]	6.89[bc]	7.07[a]	0.04	**<0.0001**

[1]GA: global acceptability. [2]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [3]SEM: standard error of mean. [a,b,c] Means followed by different letters within a row differ at $P \leq 0.05$.

6.5. Intensity of CH_4 emissions

Significant systems×seasons interaction was found for enteric CH_4 production per ADG ($P < 0.05$; Table 9; Figure 7), significant season effects were found for daily CH_4 production (kg/d) and CH_4 production per ADG ($P < 0.05$; Table 9). When expressed as kilograms per day, lower CH_4 production was found during the spring, while when expressed per ADG higher CH_4 production was found during the winter ($P < 0.05$; Table 9). System effect was found for CH_4 per HCW and CEP, in which higher emissions were found for the DP and LFS systems when compared to RHS, RMS and IHS ($P < 0.05$). When expressed per HCW, the CH_4 intensity of the IHS system was 62.8 and 67.9% lower than those found for LFS and DP, respectively ($P < 0.05$). Considering CH_4 per CEP, IHS showed emissions 36.05 and 36.2% lower than LFS and DP ($P < 0.05$).

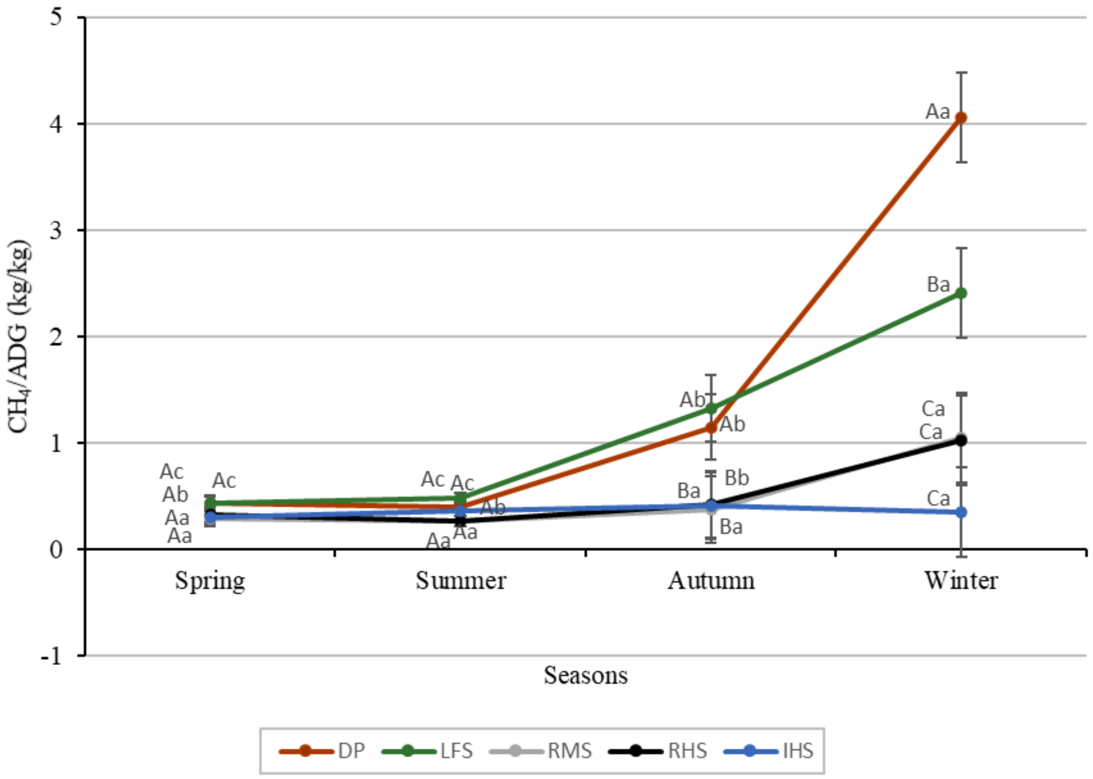
Table 10 - Enteric CH4 production of *Nellore* steers in different pasture-based production systems during different seasons of the experimental period

Fixed effects		Variables[2]					
Systems[1]	Season	CH_4 (kg day^{-1})	CH_4/ADG (kg kg^{-1})	CH_4/LBW (g kg^{-1})	CH_4/HCW (kg kg^{-1})	CH_4/CEP (kg kg^{-1})	Ym (%)
DP		0.229	1.506	0.535	1.706[A]	1.855[A]	15.60
LFS		0.232	1.160	0.553	1.473[A]	1.850[A]	14.09
RHS		0.230	0.505	0.470	0.727[B]	1.463[B]	12.88
RMS		0.239	0.492	0.481	0.635[BC]	1.270[C]	11.68
IHS		0.277	0.352	0.537	0.547[C]	1.183[C]	13.88
	Spring	0.208[b]	0.353	0.523	-	-	12.45
	Summer	0.238[a]	0.350	0.523	-	-	12.35
	Autumn	0.258[a]	0.732	0.514	-	-	12.26
	Winter	0.261[a]	1.776	0.500	-	-	17.46
Average Data							
Average		0.241	0.803	0.515	0.881	1.514	13.90
SEM[3]		0.011	0.088	0.024	0.109	0.043	0.725
Statistics Probabilities							
Systems		0.4103	**0.002**	0.1777	**<.0001**	**<.0001**	0.5539
Season		**0.0256**	**<.0001**	0.8932	**-**	**-**	**0.0036**
Systems × Seasons		0.2169	**<.0001**	0.0669	**-**	**-**	**0.0197**

[1]DP: degraded pasture; LFS: livestock-forest system; RHS: rainfed pasture with high stocking rate; RMS: rainfed pasture with moderate stocking rate; IHS: irrigated pasture with high stocking rate. [2]ADG: average daily gain; LBW: live body weight; DMI_T: total dry matter intake; HCW: hot carcass weight; CEP: carcass edible portion; Ym: percentage of gross energy ingested converted to methane. [3]SEM: Standard error of mean. [A,B,C]Capital letters differ within treatments (P<0.05); [a,b,c,]lowercase letters differ within seasons (P<0.05).

No statistical difference among systems was found during the spring and summer seasons for CH_4 per ADG (Figure 8) (P > 0.05). However, during the winter LFS and DP systems presented higher emissions when compared to the more intensified systems (RMS, RHS and IHS) (P < 0.05). Also, during the winter, the CH_4 intensity of the IHS system was 85.6 and 91.4 % lower than LFS and DP, respectively (P < 0.05).

Figure 8 - Interaction between treatment and season for enteric CH4 production per average daily gain of *Nellore* steers in different grazing systems and seasons



[A,B,C] Capital letters differ within treatments (P<0.05); [a,b,c,] lowercase letters differ within seasons (P<0.05). Vertical bars are standard error of the mean.

7. DISCUSSION

7.1. Dry matter intake and animal Performance

The higher forage DMI intake from animals in the IHS system can be explained by the higher availability and better quality of forage in this system. In the same area, Pasquini Neto (2022) found that the IHS system reached 9882.2 kg DM ha^{-1} of forage mass with a 12.5% and 4.3% content of crude protein (CP) and lignin (Lig), respectively. On the other hand, the degraded system (DP) presented 1639.3 kg DM ha^{-1} with 5.8% CP and 6% Lig (PASQUINI NETO, 2022). These results could also be related to the supplement DMI, since higher intake was found in the less intensified systems (especially DP), and lower in the systems with higher forage mass availability and quality (IHS) where animals can fully exercise their forage preference (TAMBARA et al., 2021). Usually, under tropical grazing conditions the intake of mineral supplement is inversely proportional to the forage nutritional quality.

In general, considering that the performance of beef cattle under grazing systems is heavily influenced by environmental issues, we understand that management strategies on pastures (OLIVEIRA SILVA et al., 2017) and the adoption of mineral-protein supplementation (DIXON et. al., 2011) might help the production system based on pastures to be more intensive, with greater forage availability, and thus we can expect a higher animal performance (PASQUINI NETO, 2022).

In fact, during the winter season, the IHS system was the only one able to improve ADG considering the previous season. The average ADG values found in this study are in line with those reported by De Marchi et al. (2016) and Nascimento et al. (2016) evaluating *Nellore* cattle in grazing systems with energy supplementation. At the rumen level, low CP content limits the microbial activities, negatively affecting fiber digestion, short-chain fatty acids production and therefore reducing animal performance (DETMANN et al., 2014), which could be the reason for the results found in the less intensified systems with lower forage quality (PASQUINI NETO, 2022). Another limiting factor that could be related to lower gains during the dry seasons and higher supplement intake is the low availability of dietary energy (PASQUINI NETO, 2022) because possibly the animals were using the protein source in the supplement to meet their energy maintenance requirements.

The results of this study showed that more intensified pasture-based systems were able to improve some of the most important metrics for livestock production such as SR, ADG and FBW, corroborating the results of Cardoso et al. (2016). The irrigated system (IHS) was able to support a greater AU per hectare (5.68 AU ha^{-1}) when compared to the DP system (1.89 AU ha^{-1}). This might be explained by the overall greater forage mass availability, which was 85% higher in IHS when compared to DP (PASQUINI NETO, 2022).

In addition to relating more intensified systems with higher productive parameters, we also assessed the CH_4 emissions per amount of produced meat, highlighting the advantages of more intensified pasture-based systems. A clear example was that, especially in the dry seasons with relatively low ADG, the less intensified system (DP) showed higher intensity of CH_4, while this intensity was attenuated considering the more intensified systems.

7.2. Carcass and non-carcass characteristics

Oliveira et al. (2018) evaluated carcass characteristics and meat quality parameters of *Nellore* steers with similar live body weight (271 ± 2.2 kg) and age (15 months old) on pasture-based systems (irrigated pasture with high stocking rate, rainfed pasture with high stocking rate, rainfed pasture with moderate stocking rate and degraded pasture). Our results of higher values of FBW, HCW and HDP for the IHS system when compared to less intensified systems was found by Oliveira et al. (2018) when comparing intensified systems and a degraded pasture. These results may be attributed to a higher performance of the animals grazing a better nutritional quality pasture available when intensifying pasture-based systems (PASQUINI NETO, 2022).

Parameters like HDP and REA are positively correlated to the total muscle content in the carcass, and values between 50.3-56.8% for HDP (RAZOOK et al., 1998) and a minimum REA of 29 cm^2 for every 100 kg of body weight (LUCHIARI FILHO, 2000) are expected for finishing animals. For all treatments, our results were above the expected by these authors and, once again, higher values were found in the more intensified pasture-based systems. The same pattern was found by Oliveira et al. (2018), in which lower values of HDP and REA were found in the degraded pasture system.

The BFAT protects meat against the stiffening caused by dehydration and cooling, and as well as MS are indicatives of edible parts composition and fat percentage of the carcass (MCINTYRE, 1994). Oliveira et al. (2018) found no significant differences among the pasture-based systems for BFAT, while our results indicate that IHS system was able to improve this parameter, since the highest value was found in the carcasses of this treatment. According to the Brazilian industry, values from 3 to 6 mm of BFAT, with a minimum fat thickness of 3 mm (RIBEIRO et al., 2004) are recommend for uncastrated young animals and only the IHS treatment met this criterion. It is important to notice that a medium and uniform fat thickness is the desirable score, and this parameter is important for the beef production sector due to its direct relation to meat quality, which, despite the need for higher investment, can bring financial benefits to the producer (MCINTYRE, 1994). The MS parameter followed the pattern of higher values in more intensified systems, as higher and similar results were found between IHS and RMS when compared to LFS. This characteristic is responsible for the texture, flavor and also influences the tenderness, which are the main characteristics sought by the consumer.

7.3. Meat quality

Many factors can affect the meat quality of ruminant animals and they can be divided into two categories: those ones directly related to the animal (*e.g.* breed, age, sex, etc.) and factors external to the animal (*e.g.* diet, weather, slaughtering procedures, etc.) also known as "environmental factors". Among the environmental factors, nutrition and feeding regime plays the most important role in the determination of quality (PRIOLO et al., 2001).

Usually, at the time of slaughter, the muscle pH value is between 6.9 to 7.2 and stabilizes around 5.8 to 5.5 after 24 hours of the slaughter (SILVA et al., 2021). Our results are in line Silva et al. (2021) but slightly higher than the normal range of 5.4 to 5.6 typical for beef cattle, without significant difference among treatments. In addition, shear force (SF_0 and SF_{14}) and cooking loss (CL_0 and CL_{14}) parameters were also similar among the treatments, which are in line with Oliveira et al. (2018).

Shear force values equal or lower than 43.1 N can indicate if the meat can be classified as tender (PLATTER et al., 2005) and our results are well above this. According to Del Campo et al. (2010), there are many factors such as diet, growth rate, and animal age that may affect tenderness. Other authors evaluating grass-fed beef cattle found that decreasing tenderness is related to the length of finishing period (FRENCH et al., 2000). Our results indicating less tender meat than the values found in the literature may be explained by use of *Nellore* breed animals and the relatively long period they remained in the pasture to achieve slaughter weight (OLIVEIRA et al., 2018). It is also important to consider that meat tenderness can be improved through electrical stimulation of carcass (HOPKINS, D. L., 2012), which was not performed in the slaughter of our animals.

Color is a very important aspect to be evaluated because it greatly determines the consumers' choice. According to Priolo et al. (2001), diet components and, particularly, pasture-based diets can affect cattle meat color. Meat from cattle raised on pasture is reported to be darker than meat from animals fed concentrate diets. Several factors, not a specific one, are responsible for this difference, but variations in the final pH and in the intramuscular fat content between animals finished at pasture and those finished feds concentrate diets seem to play a major role.

Despite other authors reporting no differences in meat color of beef cattle finished on different grazing systems (DUCKETT et al., 2013), luminosity (L*) and yellow (b*) intensities were affected by the different pasture-based systems. Higher luminosity intensity was found for the IHS system when compared to both RMS and RHS, while lower yellow intensity was found for RMS, RHS and LFS when compared to the more intensified system (IHS). All these color intensities are within the expected pattern for beef indicated by Muchenjea et al. (2009) (L*: 33.2 to 41, a*: 11.1 to 23.6, and b*: 6.1 to 11.3).

7.4. Sensory panel

Beef is characterized as a food with excellent nutritional value and to be attractive to the consumer it must present desirable organoleptic aspects. According to Andrighetto (2010) the sensory attributes of meat are tenderness, color, juiciness, flavor, and aroma. Tenderness and color are relevant attributes in the consumer's decision to buy meat, followed by juiciness, which is defined as the sensation of moisture observed in the first chewing movements; and the flavor and aroma that are related to the volatile compounds produced in the preparation of the meat.

The testers' scores for meat tenderness showed that there was a preference for meat from the RHS treatment. The GA refers to how much the consumers liked or disliked the meat overall. The results obtained for the consumers' GA behaved in the same way as the results obtained for tenderness, reinforcing the fact that tenderness is the determining attribute in consumer acceptability, as described above. Regarding the juiciness, an aspect considered decisive for preferring different kind of meat products, most tasters considered RHS meat as succulence (6.93) and described RMS and IHS meat as little succulence with equal averages of (6.74). This demonstrated a certain preference among tasters for RHS meat.

In addition, among the evaluated attributes, aroma was the one that stood out the most for the testers, with RHS samples being the best evaluated, while no perception of difference was found when comparing DP, LFS and RMS meat samples. The best values for flavor were found for IHS meat samples, but in general, all samples from the different systems were well accepted by the testers and gain satisfactory scores in terms of the evaluated sensory aspects.

All these sensory characteristics related to the consumer's perception of meat attributes determine purchase decisions (MERLINO et al., 2018) but it is important to keep in mind that the process of perceiving a product quality is also determined by objective and subjective aspects inherent in human nature, allowing consumers to form a holistic view (ABOAH and LESS, 2020) considering the sustainability of the production system from which a meat came from.

7.5. Intensity of CH_4 emissions

Integrated and/or intensified pasture-based production systems can lead to greater forage mass availability and quality if compared to extensive systems (MEO-FILHO et al., 2022), being this directly related to higher SR and ADG of a cattle herd. A system with high forage availability with high support capacity allows the use of high socking rate and may produce more animal product per hectare and thus reduce its CH_4 intensity. With that in mind we can say that the intensity of CH_4 emission can vary according to the available forage mass and its quality, the average daily gain of the herd, and consequently the production of its meat products. In more intensified systems we expect to achieve a more constant forage availability, with high quality, more palatable leaves, and soluble compounds, while degraded pastures are usually related to high lignified compounds, reducing the digestibility and passage rate of the diet, resulting in higher CH_4 emissions.

When expressed per ADG, the highest CH_4 intensity was found for DP during the dry season of the year, which can be explained by the reduced performance results of this treatment (Table 3, Figure 5). When analyzing only CH_4 per animal (kg/d) it is possible to not found statistical differences among treatments with levels of pasture intensification (MEO-FILHO et al., 2022; PONTES et al.,2018; SAKAMOTO et al., 2018). However, for this CH_4 emission variable the same authors found a significant effect of season during the experimental period.

When considering the CH_4 intensity expressed per ADG, the authors found results in line with our study, with higher intensity in the less intensified systems (DP) (MEO-FILHO et al., 2022; PONTES et al.,2018; SAKAMOTO et al., 2018).

The same pattern of higher values in the less intensified/degraded systems was found when expressing the CH_4 intensity per HCW and CEP. These variables have been shown to be a useful measure portraying the emissions in relation to the gain efficiency pear area of each pasture-based system (MEO-FILHO et al., 2022), showing that pasture intensification methods contributed to greater performance and production of animal products, while also reducing the emissions of enteric CH_4 per area.

8. CONCLUSIONS

The results of this study confirmed the hypothesis that intensification of pasture-based systems improve the productivity and meat quality of *Nellore* cattle since better results were found for the more intensified systems when compared to DP. In addition, these intensified systems showed lower CH_4 intensity when expressing the emissions per average daily gain and kg of animal product, highlighting the potential of adopting these strategies to contribute to the sustainability of livestock production based on tropical pastures.

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APPENDIX A

Unfolding of the interactions of intake variables of male *Nellore* cattle as a function of different intensification levels in pastoral beef cattle production systems.

Systems[1]	Seasons			
	Spring	Summer	Autumn	Winter
Forage Dry Matter Intake (kg Animal day^{-1})				
DP	6.08	9.41	8.60	3.48
LFS	5.80	8.65	6.93	5.80
RMS	6.07	9.63	8.49	5.81
RHS	5.94	8.77	10.65	5.52
IHS	8.98	10.38	9.41	7.60
Forage Dry Matter Intake (% Live Weight)				
DP	1.59^{ABa}	1.76^{Aa}	1.66^{Ba}	0.74^{Bb}
LFS	1.43^{Ba}	1.56^{Aa}	1.38^{Ba}	1.23^{Aa}
RMS	1.51^{Ba}	2.10^{Aa}	1.53^{Ba}	1.01^{ABb}
RHS	1.58^{ABb}	2.07^{Aab}	2.13^{Aa}	1.07^{ABc}
IHS	2.15^{Aa}	2.21^{Aa}	1.75^{ABa}	1.24^{Ab}
Supplement Dry Matter Intake (kg Animal day^{-1})				
DP	0.289	0.806	0.671	0.631
LFS	0.202	0.484	0.395	0.457
RMS	0.279	0.445	0.395	0.436
RHS	0.157	0.374	0.314	0.335
IHS	0.214	0.335	0.265	0.124
Supplement Dry Matter Intake (% Live Weight)				
DP	0.07^{Ab}	0.16^{Aa}	0.14^{Aa}	0.13^{Aa}
LFS	0.05^{Ab}	0.09^{ABa}	0.08^{ABa}	0.09^{Ba}
RMS	0.07^{Aa}	0.09^{ABa}	0.09^{ABa}	0.08^{Ba}
RHS	0.04^{Aa}	0.08^{ABa}	0.07^{Ba}	0.06^{Ba}
IHS	0.05^{Aab}	0.07^{Ba}	0.06^{Bab}	0.02^{Cb}
Total Dry Matter Intake (kg Animal day^{-1})				
DP	6.37	10.08	9.26	4.11
LFS	6.00	9.03	7.32	6.26
RMS	6.35	10.22	8.90	6.25
RHS	6.10	9.15	10.95	5.86
IHS	9.21	10.72	9.70	7.73
Total Dry Matter Intake (% Live Weight)				
DP	1.66^{ABa}	1.89^{Aa}	1.79^{ABa}	0.87^{Bb}
LFS	1.48^{Ba}	1.63^{Aa}	1.46^{Ba}	1.33^{Aa}
RMS	1.58^{Ba}	2.23^{Aa}	1.61^{Ba}	1.09^{ABb}
RHS	1.62^{ABb}	2.16^{Aab}	2.19^{Aa}	1.13^{ABc}
IHS	2.20^{Aa}	2.29^{Aa}	1.80^{ABa}	1.26^{Ab}

Source: Pasquini Neto (2022). [a, b, c, d] Different capital letters in the same column and different lowercase letters in the same row differ ($P \leq 0.05$) by Fisher's test.

APPENDIX B

Unfolding of the interactions of the performance variables of male *Nellore* cattle as a function of different intensification levels in pastoral beef cattle production systems.

Systems	Season			
	Spring	Summer	Autumn	Winter
	Average Daily Weight Gain (kg day^{-1})			
DP	0.435^{Bb}	0.733^{ABa}	0.189^{Bc}	-0.144^{Cd}
LFS	0.500^{Ba}	0.552^{Ca}	0.304^{Bb}	0.019^{Cc}
RMS	0.702^{Aa}	0.710^{Ba}	0.748^{Aa}	0.322^{Bb}
RHS	0.762^{Aab}	0.870^{Aa}	0.627^{Ab}	0.219^{Bc}
IHS	0.809^{Aa}	0.754^{ABa}	0.722^{Aa}	0.917^{Aa}
	Final Live Weight in Each Season (Kg)			
DP	372.7^{Cb}	437.2^{Bab}	455.1^{Ba}	442.0^{Ca}
LFS	380.7^{BCb}	430.1^{Bb}	458.8^{Bab}	461.4^{Ca}
RMS	400.4^{Ac}	464.1^{Ab}	533.4^{Aab}	564.3^{Ba}
RHS	405.1^{Ab}	482.8^{Aa}	541.1^{Aa}	561.9^{Ba}
IHS	396.1^{ABd}	463.4^{Ac}	535.1^{Ab}	620.6^{Aa}
	Stocking Rate (AU Ha^{-1})			
DP	1.31^{Bc}	1.94^{Dab}	2.46^{Da}	1.85^{Cb}
LFS	0.72^{Cb}	1.97^{Da}	1.38^{Dab}	0.88^{Db}
RMS	1.50^{Bb}	3.38^{Ca}	3.72^{Ca}	1.64^{Cb}
RHS	1.48^{Bd}	6.56^{Ba}	5.05^{Bb}	2.49^{Bc}
IHS	3.45^{Ac}	9.28^{Aa}	6.87^{Ab}	3.11^{Ac}

Source: Pasquini Neto (2022). [a, b, c, d] Different capital letters in the same column and different lowercase letters in the same row differ ($P \leq 0.05$) by Fisher's test.