UNIVERSIDADE ESTADUAL PAULISTA – Unesp

CÂMPUS DE JABOTICABAL

IMPACTO AMBIENTAL DE SISTEMAS PRODUTIVOS INTENSIFICADOS SOBRE O CRESCIMENTO E QUALIDADE DA CARNE DE TOURINHOS

Erick Escobar Dallantonia

Zootecnista

2020

UNIVERSIDADE ESTADUAL PAULISTA – Unesp

CÂMPUS DE JABOTICABAL

IMPACTO AMBIENTAL DE SISTEMAS PRODUTIVOS INTENSIFICADOS SOBRE O CRESCIMENTO E QUALIDADE DA CARNE DE TOURINHOS

Erick Escobar Dallantonia

Orientador: Prof. Dr. Ricardo Andrade Reis

Coorientadora: Drª. Márcia H. M. da Rocha Fernandes

Tese apresentada à Faculdade de Ciências Agrárias e Veterinárias – Unesp, Câmpus de Jaboticabal, como parte das exigências para a obtenção do título de Doutor em Zootecnia.

2020

D144i

Dallantonia, Erick Escobar

Impacto ambiental de sistemas produtivos intensificados sobre o crescimento e qualidade da carne de tourinhos / Erick Escobar Dallantonia. -- Jaboticabal, 2020

101 p.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal

Orientador: Ricardo Andrade Reis

Coorientadora: Márcia Helena Machado da Rocha Fernandes

1. Intensificação. 2. Adubação. 3. Pegada de carbono. 4. F1 Angus x Nelore. 5. Qualidadade de carne. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca da Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal. Dados fornecidos pelo autor(a).

Essa ficha não pode ser modificada.

UNIVERSIDADE ESTADUAL PAULISTA

Câmpus de Jaboticabal

CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: IMPACTO AMBIENTAL DE SISTEMAS PRODUTIVOS INTENSIFICADOS SOBRE O CRESCIMENTO E QUALIDADE DA CARNE DE TOURINHOS

AUTOR: ERICK ESCOBAR DALLANTONIA
ORIENTADOR: RICARDO ANDRADE REIS

Aprovado como parte das exigências para obtenção do Título de Doutor em ZOOTECNIA, pela Comissão Examinadora:

Prof. Dr. RICARDO ANDRADE REIS (Participaçao Virtual)
Departamento de Zootecnia / FCAV / UNESP - Jaboticabal

Pesquisador Dr. FLÁVIO DUTRA DE RESENDE (Participaçao Virtual)
Departamento de Descentralização do Desenvolvimento / APTA - Colina/SP

Dra. MÁRCIA HELENA MACHADO DA ROCHA FERNANDES (Participaçao Virtual)
Departamento de Zootecnia / FCAV / UNESP - Jaboticabal

Prof. Dr. RONDINELI PAVEZZI BARBERO (Participaçao Virtual)
Departamento de Produção Animal / Universidade Federal Rural - Rio de Janeiro/RJ

Prof. Dr. ELIAS SAN VITO (Participaçao Virtual)
Universidade Federal de Mato Grosso - UFMT / Sinop / MT

Jaboticabal, 29 de outubro de 2020

DADOS CURRICULARES DO AUTOR

ERICK ESCOBAR DALLANTONIA – filho de Ailton Aparecido Dallantonia e Leila Silva Escobar Dallantonia, nascido em São Carlos- SP, no dia 24 de setembro de 1990.

Em fevereiro de 2010 ingressou no curso de graduação em Zootecnia, na Universidade Estadual Paulista "Júlio de Mesquita Filho" – Faculdade de Ciências Agrárias e Veterinárias, campus de Jaboticabal, sendo estagiário e bolsista FAPESP sob orientação da profª. Drª. Telma Teresinha Berchielli, graduando-se em fevereiro de 2015.

Em março de 2015 ingressou no PPG em Zootecnia, mestrado, na Universidade Estadual Paulista "Júlio de Mesquita Filho" – Faculdade de Ciências Agrárias e Veterinárias, campus de Jaboticabal, sendo bolsista FAPESP sob orientação da profª. Drª. Telma Teresinha Berchielli. De maio a novembro de 2015 realizou mestrado sanduíche no Department of Animal Science / Purdue University, West Lafayette, IN, USA, sob orientação do Prof. Dr. Jon Schonmaker, graduando-se em fevereiro de 2017.

Em março de 2017 ingressou no PPG em Zootecnia, doutorado, na mesma instituição, sendo bolsista CNPq, sob orientação do prof. Dr. Ricardo Andrade Reis, graduando-se em outubro de 2020.

Dedico

Á minha mãe Leila e meu pai Ailton, minha irmã Jaqueline e meu irmão Renan, por serem meus exemplos de luta e vitória, por todo amor, carinho, dedicação, apoio e por sempre acreditarem em mim e estarem presentes nas minhas conquistas e dificuldades.

Eu não tenho ídolos. Tenho admiração por trabalho, dedicação e competência.

Ayrton Senna

AGRADECIMENTOS

Agradeço a Deus e a Nossa Senhora Aparecida por todos esses momentos especiais que eu passei.

Aos meus avôs (Antônia, Bonifácio e Ivo) por muitos dos poucos conhecimentos que eu possuo.

Ao Prof. Dr. Ricardo Andrade Reis e a Dra. Márcia H. M. da Rocha Fernandes por toda a confiança, puxões de orelha e por todas as oportunidades a mim oferecidas.

À Marcella Borsonello da Costa por todo companheirismo e pelos momentos difíceis que me ajudou a passar.

Aos meus amigos da República 51 e agregados que por lá passaram, por todos os conhecimentos adquiridos e por todos os momentos especiais.

Agradeço imensamente o Rhaony Gonçalves Leite e a Adriana Cristina Ferrari, por todo auxílio durante a condução do trabalho.

A toda equipe do grupo de estudo UnespFor, sem a ajuda de todos vocês, tudo seria mais difícil.

Aos funcionários Ademir Servidone, Oswaldo Ferrari (Juninho) e Vladimir (Vlade) por toda a ajuda no decorrer do experimento e pelas boas conversas.

A todos os professores e funcionários da UNESP, campus de Jaboticabal que foram base para essa conquista.

Agradeço ao CNPq e a Trouw Nutrition por todo suporte financeiro para que o projeto fosse realizado e executado.

E como um grande amigo meu diz:

Um Forte abraço

SUMMARY

ENVIRONMENTAL IMPACT OF INTENSIFIED PRODUCTION SYSTEMS ON THE GROWTH AND QUALITY MEAT OF BULLS

ABSTRACT - The objective of this research was to determine the impact of the intensification of beef production system on the variables of nutrient intake, forage nutritive value, digestibility, enteric methane emission, animal performance, gene expression and meat quality of Nelore and F1 ½ Angus x ½ Nelore, in two production systems [lenient (S1) and intensified (S2)] during the rearing and finishing phases. System S1 was practiced in 18.6 ha of Marandu grass pasture, divided in eight paddocks, which were not fertilized and managed in continuous stocking and constant rate of two animals per hectare, during the rearing. Then, 20 Nelore youn bulls (initial body weight (BWi), 277 ± 13 kg; initial age, 15.2 ± 1.1 months) and 20 F1 Angus × Nelore (BWi, 304 ± 21 kg; initial age, 15.8 ± 0.44 months) were randomly allocated to four paddocks for each breed. During the finishing phase, the animals remained in the pasture and received supplementation. System S2 was practiced in 11.4 ha of Xaraés grass pasture, divided in six paddocks, which were fertilized (150 kg N ha^{-1} $year^{-1}$) and managed in continuous stocking with variable rate of stocking, during rearing. Then, 24 Nelore young bulls (BWi, 288 ± 16 kg; initial age, 15.6 ± 0.65 months) and 24 F1 Angus × Nelore (BWi, 325 ± 18 kg; initial age, 15.8 ± 0.42 months) were randomly allocated in three paddocks for each breed. During finishing phase, the animals were transferred to feedlot. During rearing, the F1 Angus × Nelore bulls from S2 reached the highest average daily gain (ADG) and final body weight (BWf), while the Nelore from S1 reached the lowest ADG and BWf. In the end, the ADG and BWf were larger in S2 than in S1, as well as in the F1 Angus × Nelore bulls, than Nellore. From the beginning of the rearing until the end of the feedlot, the loin eye area of the F1 Angus × Nelore of S2 was larger. The higher fat deposition occurred during the finishing, resulting in greater thickness of the animals of S2, than the S1. Carbon footprint of F1 Angus × Nelore in S2 (10.8 kg CO_2eq kg^{-1} carcass) was like that of Nelore bulls in S1, but was approximately 13% and 11.5% lower than Nelore in S2 and F1 Angus × Nelore in S1, respectively. Intensive system can improve meat quality by increasing tenderness and meat color. In addition, F1 Angus x Nelore have improved meat quality when in intensive system, which provides better feeding conditions for them to express the genetic potential and increase the intramuscular fat deposition. This study has shown that increasing productivity by improving genetic merit and pasture management is an appropriate strategy to reduce environmental impact and achieve environmental sustainability.

Key Words: Intensification, fertilization, carbon footprint, F1 Angus x Nelore, meat quality

IMPACTO AMBIENTAL DE SISTEMAS PRODUTIVOS INTENSIFICADOS SOBRE O CRESCIMENTO E QUALIDADE DA CARNE DE TOURINHOS

RESUMO - O objetivo dessa pesquisa foi determinar o impacto da intensificação do sistema produtivo de bovinos de corte nas variáveis de consumo, valor nutritivo da forragem, digestibilidade de nutrientes, emissão metano entérico, desempenho e crescimento animal, expressão gênica e qualidade da carne de tourinhos Nelore e F1 ½ Angus x ½ Nelore, em dois sistemas de produção [leniente (S1) e intensificado (S2)] durante as fases de recria e terminação. O S1 foi praticado em pastagem de capim Marandu de 18,6 hectares (ha), dividida em oito piquetes, que não foram fertilizados e manejados com lotação contínua e taxa constante de lotação com dois bovinos por hectare, durante a recria. Assim, 20 tourinhos Nelore [peso corporal inicial (PCi), 277 ± 13 kg; idade inicial, 15,2 ± 1,1 meses] e 20 tourinhos F1 Angus × Nelore (PCi, 304 ± 21 kg; idade inicial, 15,8 ± 0,44 meses) de sobreano, foram alocados aleatoriamente em quatro piquetes para cada raça. Durante a terminação, os bovinos permaneceram na pastagem e receberam suplementação. O S2 foi praticado em pastagem de 11,4 ha de capim-Xaraés, dividida em seis piquetes, que foram fertilizados (150 kg N ha^{-1} ano^{-1}) e manejados com lotação contínua com taxa variável de lotação, durante a recria. Em seguida, 24 tourinhos Nelore (PCi, 288 ± 16 kg; idade inicial, 15,6 ± 0,65 meses) e 24 tourinhos F1 Angus × Nelore (PCi, 325 ± 18 kg; idade inicial, 15,8 ± 0,42 meses) de sobreano foram alocados, aleatoriamente, em três piquetes para cada raça. Durante a terminação, os bovinos foram transferidos para o confinamento. Durante a recria, os tourinhos F1 Angus × Nelore do S2 alcançaram o maior ganho médio diário (GMD) e peso corporal final (PCf), enquanto os Nelore do S1 alcançaram os menores GMD e PCf. O GMD final e o PCf foram maiores no S2 do que no S1, assim como nos tourinhos F1 Angus × Nelore, do que os Nelore. Do início da recria até o final do confinamento, a área de olho de lombo dos F1 Angus × Nelore do S2 foi maior. A maior deposição de gordura ocorreu durante a terminação, resultando em maior espessura nos bovinos do S2, do que nos do S1. A pegada de carbono dos F1 Angus × Nelore em S2 (10,8 kg CO_{2eq} kg^{-1} carcaça) foi semelhante à dos touros Nelore em S1, mas foi aproximadamente 13% e 11,5% menor do que a dos Nelore em S2 e F1 Angus × Nelore em S1, respectivamente. O sistema intensivo pode melhorar a qualidade da carne por meio do aumento da maciez e da cor da carne. Além disso, os F1 Angus x Nelore apresentam a melhora da qualidade da carne quando em sistema intensivo, devido a melhor condição alimentar para estes expressarem o potencial genético e o aumenta da deposição de gordura intramuscular. Este estudo demonstrou que o aumento da produtividade por meio da melhoria do mérito genético e do manejo de pastagens é uma estratégia adequada para reduzir o impacto ambiental e alcançar a sustentabilidade ambiental.

Palavras-chave: Intensificação, adubação, pegada de carbono, F1 Angus x Nelore, qualidadade de carne

CAPÍTULO 1 – CONSIDERAÇÕES GERAIS

1. Introdução

A produção de bovinos de corte no Brasil é baseada em sistemas pastoris, dos quais 87% dos bovinos abatidos no país são provenientes desses sistemas (ABIEC, 2020). Deste modo, o entendimento das limitações do ecossistema pastoril permite o estabelecimento de metas e estratégias para obter aumentos na produtividade da pecuária. As condições de clima tropical propiciam dois grandes momentos na produção a pasto, o primeiro é a estação das águas caracterizada por grande acúmulo de matéria seca e o segundo pela estação das secas, caracaterizado pela paralização da produção vegetal. Esse fato afeta a disponibilidade e o valor nutritivo da forragem, dificultando o equilíbrio entre oferta e demanda (REIS et. al., 2009).

Em termos ambientais a agropecuária tem sido criticada pela mídia como poluidora do meio ambiente, entretanto, o setor foi responsável por menos de ¼ das emissões nacionais de gases de efeito estufa (22%), emitindo em 2016, aproximadamente 485 MtCO_2eq (SEEG, 2018). Além disso, a produção de bovinos a pasto atende ao conceito de “human-inedible food” (TEDESCHI et al., 2015) e a sua intensificação gera o efeito “poupa terra” (WEDEKIN et al., 2017), evitando o desmatamento. A intensificação do sistema produtivo de bovinos de corte pode ocorrer de várias maneiras: ajuste da taxa de lotação para manutenção da altura alvo de manejo, adubação nitrogenada e a exploração da heterose em cruzamentos, todas elas visando o menor tempo de recria e a terminação de bovinos jovens.

Delevatti et al., (2019) ao recriarem tourinhos Nelore e adubar o capim Marandu com diferentes doses de nitrogênio, utilizando ureia e mantendo os pastos na altura de dossel a 25 cm, observaram aumentos lineares no acúmulo e na massa de forragem, o que permitiu aumentar de 3.3 UA (unidade animal = 450 kg ha^{-1}) onde não foi adubado, para 6.5 UA/ha na dose de 270 kg de N ha^{-1} ano^{-1}. Aliado ao aumento da taxa de lotação também podemos melhorar a qualidade da carne com o cruzamento industrial, utilizando raças bovinos européias (especialmente as britânicas), onde o teor de gordura intramuscular é uma característica importante para o consumidor e a indústria de carne bovina (BAZILE et al., 2019). O maior teor de gordura intramuscular em bovinos F1 Aberdeen Angus é esperado, uma vez que os tourinhos atingem a maturidade e começam a deposição de gordura mais cedo, quando comparados a raças zebuínas, que são de porte maior e menor porcentagem de carne marmorizada (RODRIGUES et al., 2017).

O desenvolvimento desta pesquisa propiciou a avaliação de sistemas de produção de bovinos de corte, nos quais foram determinadoso desempenho animal, a emissão de gases do efeito estufa e a qualidade da carne os quais são alterados por diferentes sistemas de produção e pelos grupamentos genéticos de bovinos de corte. O objetivo desse estudo foi avaliar o impacto da intensificação de um sistema produtivo sobre o consumo, valor nutritivo da forragem, digestibilidade de nutrientes, emissão de metano entérico, desempenho animal, crescimento animal, produção e expressão gênica e qualidade da carne de tourinhos Nelore e F1 ½ Angus x ½ Nelore, em dois sistemas de produção (leniente e intensificado) durante a recria e a terminação.

2. Revisão de Literatura

2.1. Sistemas de produção de bovinos em regiões tropicais

A denominação de sistema de produção de bovinos de corte intensivo ou extensivo é bastante complexa, depende de fatores como as condições locais de clima, solo e relevo, as tecnologias de processos adotadas (ajuste de taxa de lotação, diferimento de pastagens), tecnologias de insumos (adubação, suplementação, irrigação) e claro o objetivo que se quer atender. Duas formas já conhecidas de se intensificar o sistema de produção de bovinos de corte são a adubação nitrogenada dos pastos e a heterose com raças especializadas na produção de carne (Matrizes Nelore x touros Aberden Angus, Hereford, Charolês etc.). O conceito de intensificação sustentável da pecuária está baseado na necessidade de aumentar a produção animal por unidade de área, considerando alternativas de produção que contemplem integralmente os três pilares da sustentabilidade, ou seja os aspectos sociais, ambientais e económicos (TEDESCHI et al., 2015).

2.1.1. Sistemas extensivos

Os sistemas extensivos de produção de bovinos de corte são caracterizados pela utilização de grandes áreas, sendo que as pastagens são a única fonte de alimento para o desenvolvimento dos bovinos. Esse sistema representa aproximadamente 87% da produção de carne brasileira, sendo utilizada praticamente por todo setor produtivo. Nesse caso as pastagens, em sua maioria, são compostas por forrageiras nativas ou de forrageiras cultivadas sem o correto manejo, assim, esse sistema propicia uma grande variação de desempenho dos bovinos (CEZAR et al., 2005), além de problemas econômicos de produtividade. Esse somatório de fatores converge para aumento de áreas degradadas, deste modo, aumenta-se a necessidade de abertura de novas áreas, resultando em desmatamento além dos limites da fronteira agrícola.

2.1.2. Sistemas semi-intensivos

Como no sistema anterior a base alimentar dos bovinos são as pastagens, podendo estas serem nativas ou cultivadas. Neste sistema são adotadas algumas ferramentas tecnológicas, como manejo de pastagens e o uso de suplementos minerais, proteicos, proteicos-energéticos e energéticos. A soma dessas tecnologias permite encurtar o ciclo pecuário, podendo deste modo, estabelecer metas de ganhos ao longo das fases de vida dos animais, além de poder explorar fases em que se tem maiores eficiências biológicas (cria e recria). Em sua maioria a suplementação praticada no Brasil é a mineral, entretanto, o uso de outros suplementos concentrados vem sendo utilizado no País. Usualmente, os suplementos são compostos por fontes energéticas (milho e sorgo), e as proteicas (farelos de soja, farelos de algodão, farelos de caroço de algodão, farelos de glúten de milho, grão de soja e ureia; CEZAR et al., 2005).

2.1.3. Sistemas intensivos

A diferença entre o sistema semi-intensivo e o intensivo é o fato desse ter o uso estratégico do confinamento dos bovinos, principalmente na fase de terminação (CEZAR et al., 2005). O uso do confinamento tem como restrição o maior custo na produção da arroba dos bovinos. Essa ferramenta permite o uso intensivo das pastagens na época das águas, onde se utiliza uma elevada taxa de lotação, o que se tornaria um problema no período seco, onde se tem uma elevada carga animal e uma menor disponibilidade de forragem. Neste sistema uma parte dos bovinos é confinada e outra parte permanece nas áreas de pastagens, recebendo elevadas quantidades de concentrado (± 2% do peso vivo), caracterizando um semi-confinamento. Em geral, nos confinamentos são utilizadas as seguintes fontes de volumosos: silagem de milho, sorgo, cana *in natura* picada e outras gramíneas; e em algumas regiões do país utiliza-se bagaço de cana resultante da produção de açúcar e de álcool.

2.2. Impacto do manejo da pastagem sobre o sistema de produção: mitigação de carbono e adubação nitrogenada

Os ecossistemas pastoris no Brasil somam em torno de 162 milhões de hectares de pastagens (nativas e cultivadas; ABIEC, 2020). De acordo com Cardoso et al., (2016), a intensificação do uso das pastagens através de sistemas de manejo que propiciam manter a persistência dos pastos, resultam em aumento linear nos estoques de CO_2. Diante disso, o manejo adequado das pastagens, no qual se busca o equilíbrio entre a oferta de pasto de qualidade, que atenda a demanda dos bovinos em pastejo e que respeite os mecanismos de rebrota das plantas forrageiras, pode resultar em sistemas estáveis que propiciam alta eficiência zootécnica, econômica e ambiental devido a mitigação dos gases efeito estufa (BARBERO et al., 2015, 2017; DE FIGUEIREDO et al., 2016; CARDOSO et al., 2016, 2017, TSUTSUMI et al., 2018).

No Brasil estima-se que entre 27% e 42%, do total de pastagens, estão degradadas ou em algum estado de degradação, sendo que uma das principais causas é o esgotamento da fertilidade do solo, principalmente pela baixa disponibilidade de fósforo e nitrogênio (COSTA et al., 2010; SILVA et al., 2017). A degradação de pastagens reduz a oferta e qualidade da forragem, comprometendo a produtividade dos sistemas, em termos zootécnicos e econômicos, mas também resulta em efeito no ambiente, pois sistemas de exploração extensiva de pastagens aumentam a degradação da matéria orgânica do solo, resultando em maior emissão de gás carbônico (CO_2) para atmosfera e redução no sequestro do carbono.

Adicionalmente a adoção de práticas agrícolas ligadas à fertilidade do solo de pastagens pode aumentar de 50 a 150 kg de carbono sequestrado por hectare, já a falta de nitrogênio e a degradação da pastagem podem resultar em perda de carbono de 57 g/m^2 por ano para a atmosfera (PAULINO & TEIXEIRA, 2010).

Diante desses cenários a adoção de tecnologias para intensificar o sistema produtivo de bovinos de corte propicia vantagens como o aumento de mitigação de carbono, de produtividade e de ganhos econômicos (MACEDO et al., 2013; ASSAD & MARTINS, 2015; BARBOSA, et al., 2015, BARBERO et al., 2015, 2017). De acordo com o relatório completo da FGV-EESP (2016), a intensificação do uso de pastagens degradadas (com até 0,75 cabeças/hectare) para áreas adubadas e bem manejadas, possibilitaria uma maior taxa de lotação, até 1,5 cabeças/hectare. Deste modo, observa-se que a intensificação da pecuária resulta em um aumento no armazenamento de carbono no sistema produtivo de 634 milhões de t CO_2eq (BRAZ et al., 2013; SILVA et al., 2017, CARDOSO et al., 2020).

Além desse importante fato, ocorre um aumento significativo na produtividade do sistema, uma vez que o rebanho bovino nacional poderia ser alojado em metade da área de pastagens brasileiras, destinando áreas para a produção de grãos ou ainda; portanto, aumentar a taxa de lotação sem nenhum desmatamento, chamado efeito “poupa terra” (WEDEKIN et al., 2017).

Dentre as formas de adubação, a utilização de adubos nitrogenados tem o intuito aumentar a produção de matéria seca e a disponibilidade de forragem (GASTAL & LEMAIRE, 2015). Segundo Fagundes et al, (2006), o uso de nitrogênio permite aumentar a densidade volumétrica da forragem e sobretudo a produção de folhas, pois o nitrogênio tem efeito positivo sobre a taxa de aparecimento e alongamento de foliar nas gramíneas (CAMPOS et al., 2020). Além desses benefícios, a adubação nitrogenada garante uma melhor qualidade do pasto, o que permite aumentar a taxa de lotação sem prejudicar o desempenho individual dos bovinos.

O uso de adubos nitrogenados possibilita o aumento no teor de matéria orgânica do solo, ao longo do acumulado de adubação (SANTOS, 2009). Segundo Coan & Reis (2011), adubações com 50 kg/ha/ano evitam a degradação das pastagens, pois aumentam o teor de matéria orgânica e previnem a perda de produtividade das forrageiras. Desta forma, a adubação nitrogenada, associada ao manejo do pastejo tem a capacidade de mitigar a emissão de gases de efeito estufa, devido ao maior armazenamento de carbono (BARBERO et al., 2015; CARDOSO et al., 2016) e forrageiras adubadas possuem melhor eficiência de uso da água e da radiação solar (LEMAIRE & CHAPMAN, 1996).

Outro benefício do uso da adubação nitrogenada é o aumento na quantidade de proteína bruta da forragem, principalmente as frações solúveis (A, B1, B2). De acordo com Sniffen et al, (1992), as formas de nitrogênio para ruminantes podem ser classificadas em cinco frações, dentre essas: A, B1, B2, B3 e C. Delevatti et al., (2019) observaram que a aplicação de adubação nitrogenada resultou em aumento nos valores de proteína bruta da forragem, devido à elevação nos teores de aminoácidos e da síntese proteica, aumentando as frações A, B1 e B2 do dossel.

O sucesso da adubação nitrogenada depende de alguns fatores, como estratégias de aplicação, quantidade aplicada, fonte e forma de dividi-lá (MARTHA JÚNIOR et al., 2004), visando achatar a curva de produção de matéria seca, com vistas a promover a maior produção de folhas ao longo da estação, associada a eficiência do pastejo, e consequentemente a colheita pelos animais em pastejo. A somatória desses fatores são os principais determinantes da eficiência biológica e econômica da adubação nitrogenada de pastagens, o que permite desenhar estratégias para aumentar a eficiência de uso e minimizar o impacto ambiental.

Trabalhos conduzidos na Faculdade de Ciências Agrárias e Veterinárias (UNESP - Jaboticabal) evidenciaram que a associação do manejo da adubação com nitrogênio e suplementação propiciou melhora no valor nutritivo do dossel e, por conseguinte, diminuição na emissão de metano de tourinhos Nelore em pastejo: Barbero et al., (2015), José Neto et al., (2015), San Vito et al., (2016), Dallantonia (2017) observaram que a emissão média por animal foi de 46, 43, 48, e 41 kg de CH_4/ano, respectivamente. Vale ressaltar que esses valores são bem menores que o valor estabelecido pelo IPCC (2006), que foram de 55 kg e 58 kg de CH_4/ano, em sistemas de alta e baixa produtividade respectivamente.

2.3. Uso de cruzamento industrial como método de intensificação de sistemas de produção de bovinos de corte

Aliado a melhoria no manejo de pastagens (adubação nitrogenada) e diminuição da pegada de carbono, a genética dos bovinos contribui de maneira expressiva para o desenvolvimento da pecuária nacional. Sua contribuição com o cruzamento entre raças zebuínas (*Bos taurus indicus*) e taurinas (*Bos taurus taurus*), chamado cruzamento industrial, aproveita a complementariedade entre raças, explorando a heterose (PEREIRA, 2008).

Para utilizar-se do cruzamento industrial é necessário conhecer as características que se busca melhorar na progênie, diante disso, devemos buscar raças paternais que possuem características desejáveis para dado sistema (ELER, 2017). Assim a raça Nelore deve ser utilizada como base materna; essas matrizes possuem as características produtivas e reprodutivas ideais para o sucesso dessa ferramenta de melhoramento genético, além de altamente adaptdas as condições do Brasil tropical, sendo o binômio “vaca da Índia e capim da África” peças fundamentais para o sucesso da pecuária brasileira. As características de resistência, adaptabilidade e fertilidade são advindas da linha materna Nelore, já o ganho de peso, precocidade sexual e acabamento de carcaça são advindos da linha paterna Aberdeen Angus, aumentando a eficiência do sistema (GUERRA et al., 2016; AMARAL et al., 2018;). Deste modo, os parâmetros positivos de cada uma das raças se complementariam na progênie (LAZIA, 2017).

Essa estratégia de melhoramento genético permite que características de baixa herdabilidade e que ocorrem em indivíduos de outras raças, possam ser expressas nos bezerros oriundos desse cruzamento (PIZZOL, 2012; ROSA et al., 2013). Diversas pesquisas comprovam que os bezerros cruzados são superiores aos produtos "puro-sangue" em uma ou mais características (SANTIAGO, 1984; SANTOS, 1999; RESTLE et al., 2004).

Eler (2015) relata que a heterose é o quanto a geração F1 é superior em relação à média dos pais, sendo assim, quanto maior for a distância genética entre as duas raças, maior será a heterose (EUCLIDES et al., 2018). Além disso, quanto menor a herdabilidade maior será a heterose de determinada característica, como supracitado. Características de baixa herdabilidade como fertilidade, adaptabilidade e demais fatores relacionados a reprodução, possuem altos valores de heterose e baixa de herdabilidade. Já características de alta herdabilidade como crescimento pós-desmama, conversão alimentar e composição de carcaça, possuem baixo valor de heterose (ARTMANN et al., 2015).

Mais um benefício do uso do cruzamento industrial remete a produção de carne de qualidade, mercado este que está crescendo no País (RODRIGUES et al., 2017; BAZILE et al., 2019). A intensificação dos sistemas de produção, busca a redução da idade de abate, o aumento do ganho de peso, musculosidade das carcaças, com maior rendimento (PEREIRA et al., 2009) e com acabamento, maciez e marmoreio (ZAMBONI, 2010). Esse somatório de fatores tem permitido produzir carne de qualidade para atender os grandes centros urbanos, restaurantes e churrascarias, consumidores de alta renda.

Bovinos oriundos de sistemas extensivos (pasto) possuem uma vantagem frente aos consumidores, pois os produtos cárneos apresentam uma relação entre ω6:ω3 de 4:1, sendo considerada ideal quando comparando com animais confinados, os quais podem chegar a valores maiores que 20:1 (DALEY et al., 2010). Além disso, bovinos criados a pasto apresentam carne com menores quantidades de ácido graxo monoinsaturado, quando comparamos novamente com animais terminados em confinamentos e suplementados com grãos (SMITH et al., 2006).

Diante disso, práticas de manejo envolvidas na produção de bovinos de corte têm um profundo impacto nas características da carcaça e qualidade da carne (BARKER et al., 1995). O principal empecilho de produzir indivíduos com maiores potenciais genéticos que as raças puras é em relação a maiores exigências nutricionais, sabe-se que existe uma influência notável do fator ambiental sobre as respostas dos bovinos F1 (CARVALHO et al., 2016; GUERRA et al., 2016).

2.4. Influência da intensificação sobre o crescimento muscular e deposição de gordura dos bovinos.

A intensificação de produção de bovinos permite obter animais pesados, isto é o somatório do aumento do peso de componentes não carcaça (trato digestivo, couro etc.) e de componentes carcaça (osso e músculo). De acordo com Owens et al., (1993) o crescimento ocorre pelo aumento do tamanho das células e/ou pelo aumento no número de células, sendo esses processos conhecidos como hipertrofia e hiperplasia, respectivamente. Sabe que a produção de bovinos a pasto apresenta maior necessidade de energia em relação ao sistema de confinamento (VALADARES FILHO et. al., 2016).

O processo de crescimento inicia no momento da concepção (a) até a maturidade do animal (d), descrita por Batt (1980), diante desse modelo nota-se que entre os pontos (b-c) a taxa de crescimento é elevada, resultando em maior deposição muscular e maior eficiência alimentar (Figura 1). O ponto (c) marca o início da puberdade, neste ponto ocorre uma mudança no crescimento. Quando o animal atinge a maturidade (d), o crescimento muscular e ósseo cessa, depositando somente gordura (OWENS et al., 1993).

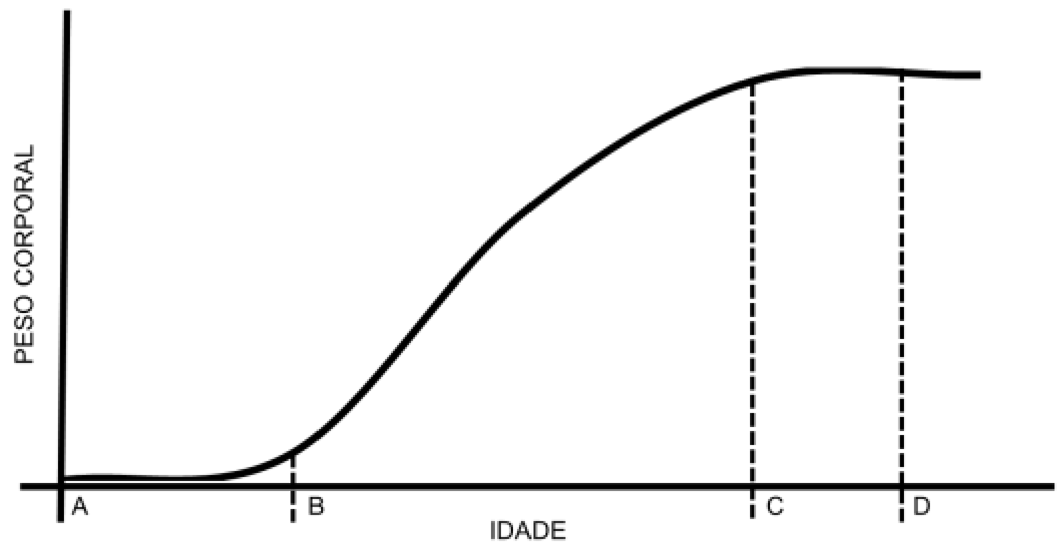

Figura 1. Curva de crescimento de ruminantes, (a) concepção, (b) nascimento, (c) puberdade e (d) maturidade. Adaptado de Batt (1980).

A avaliação dos efeitos do crescimento prévio sobre o observado na fase posterior, permite a adoção de tecnologias para obtermos os melhores resultados ao longo da vida do bovino. Como relatado por Lana (1997), a deposição de gordura requer quatro vezes mais energia que a deposição muscular. E sabe-se que a qualidade da gordura animal, varia de acordo com o sistema de criação (CARRASCO et al., 2009), assim Teixeira et al., (2017) trabalhando com touros Nelore e Angus observaram maior gordura intramuscular, devido ao maior SREBF1, fator de transcrição de ligação do elemento regulador de esterol 1, para bovinos Angus.

O teor gordura intramuscular ou marmoreio é uma característica importante para a indústria de carne bovina, uma vez que pode afetar positivamente as características sensoriais de qualidade da carne e a satisfação do consumidor (BAZILE et. al., 2019). Além do teor de lipídeos, a cor da carne está entre os principais aspectos relacionados à qualidade da carne, fator que afeta as decisões de compra dos consumidores (MANCINI & HUNT, 2005).

O sistema de produção tem que ser capaz de manter o desenvolvimento dos bovinos, independente da estação do ano, para isso, o uso de planos nutricionais crescentes se torna importante para atender as exigências nutricionais dos bovinos

(REIS et al., 2009). Deste modo, a suplementação da dieta dos bovinos surge como uma forma de corrigir possíveis ou reais deficiências no valor nutritivo das forrageiras (PAULINO et al., 2006), ou seja, para melhorar o aproveitamento da forragem colhida. Essa ferramenta possibilita um aumento no desempenho dos bovinos, consequentemente aumentado a deposição muscular e deposição de gordura. Outra consequência benéfica ao sistema de produção é o fato de a suplementação possibilitar um incremento na taxa de lotação e de modular a fermentação ruminal (REIS et al., 2012), melhorando a eficiência de utilização dos nutrientes.

2.5. Uso de alimentos que não competem com a alimentação humana

Um estudo da FAO publicado na Global Food Security, relata que os produtos pecuários são responsáveis por cerca de 18% do suprimento das calorias globais e 25% do consumo global de proteínas (FAOSTAT, 2016), além de suprir micronutrientes essenciais, vitamina B12, ferro e cálcio (MURPHY & ALLEN, 2003; RANDOLPH et al., 2007).

Acredita-se que em 2050, o mundo contará com 9,6 bilhões de pessoas, sendo que 70% da população viverá nas cidades, assim, a produção de alimentos é absolutamente prioritária para a sociedade, visto a crescente demanda mundial. A pecuária é frequentemente criticada pela baixa eficiência alimentar dos bovinos, devido a utilização de dietas ricas em cereais convertidas em proteína animal (MOTTET et al., 2017). De acordo com diversos autores para ser produzido um quilo de carne são necessários de 6 a 20kg de grãos (GARNETT, 2009; GODFRAY et al., 2010; ELLIOT, 2012; ESHEL et al., 2014). Esse consumo de grãos acontece na fase de terminação de bovinos em confinamento, contudo, esse sistema de produção de carne corresponde de 7 a 13% do total de carne produzida mundialmente (FAO, 2009; GERBER et al., 2015; MOTTET et al., 2017), sendo que os maiores consumidores de grãos são aves e suínos.

A produção de ruminantes permite a utilização de produtos que não competem com a alimentação humana “non-edible food” (TEDESCHI et al., 2015), cuja utilização é de extrema importância em sistemas sustentáveis (CARDOSO et al., 2020). Nesta linha de alimentos encontram-se os pastos, resíduos de colheitas e os coprodutos e subprodutos da agroindústria, correspondendo a 90% do total ingerido na produção de carne (MOTTET et al., 2017), que além de ajudarem na preservação do ambiente, sua utilização traz benefícios com redução nos custos da dieta, resultando em maior lucratividade do sistema produtivo.

Neste contexto o Brasil pode utilizar os coprodutos e subprodutos da indústria, sendo: polpa cítrica, gérmen de milho, farelo de soja, de amendoim e de algodão, bagaço *in natura* de cana de açúcar, melaço de cana, glicerina bruta, DDG (dry distiller grain – resíduo da indústria de álcool de milho) e casquinha de soja, entre muitos outros alimentos que possuem potencial de utilização na alimentação de bovinos em terminação.

No Brasil cerca de 87% de toda carne produzida é proveniente de sistemas a pasto (ABIEC, 2020), utilizando pequenas quantidades de cereais com potencial uso na alimentação humana, sendo muitas vezes utilizados coprodutos e subprodutos, devido ao entorno agrícola da propriedade/região. A produção animal, em suas muitas formas, desempenha um papel importante na cadeia produtiva de alimento, esses sistemas utilizam-se de terras marginais, transformando pastos, co-produtos e subprodutos, que não seriam consumidos pelos humanos, em alimentos altamente nutritivos, ricos em aminoácidos essenciais e ácidos graxos poliinsaturados. Assim nosso País cumpre a normativa de produzir carne via “non-edible food”, utilizando pastagens durante a recria e coprodutos/subprodutos para a terminação em confinamento.

Portanto a intensificação da produção de bovinos de corte implica em acelerar o crescimento e a terminação dos bovinos, de modo a promover o abate em idade cada vez mais cedo, levando em consideração, aspectos de serviços ecossistêmicos (suprimento, suporte, regulador e cultural [SANDERSON & LIEBIG, 2020]) e econômicos (diminuição do custo fixo, aumento da margem de lucro e controle do fluxo de caixa [EL-MEMARI NETO, 2019; PIMENTEL, 2020]) do sistema de produção.

3. Hipótese

As hipóteses dessa pesquisa são: a intensificação do sistema produtivo melhora o desempenho animal, aumenta à produtividade do sistema, melhora a utilização dos nutrientes digestíveis, diminui a pegada de carbono, melhora a qualidade da carne, altera a expressão de genes ligados ao crescimento e deposição de gordura de tourinhos Nelore e F1 ½ Angus x ½ Nelore em dois sistemas de produção (leniente e intensificado) durante a recria e a terminação.

4. Objetivo

Avaliar o impacto da intensificação de um sistema produtivo sobre o consumo, produção e valor nutritivo da forragem, digestibilidade de nutrientes, emissão de metano entérico, desempenho animal e crescimento animal, expressão gênica e qualidade da carne de tourinhos Nelore e F1 ½ Angus x ½ Nelore em dois sistemas de produção.

5. Referências Bibliográficas

ABIEC, **Associação Brasileira das Indústrias Exportadoras de Carne. Beef Report: Perfil da Pecuária no Brasil**, 2020. http://abiec.com.br/publicacoes/beef-report-2020/.

AMARAL, P.M.; MARIZ, L.D.S.; ZANETTI, D.; PRADOS, L.F.; MARCONDES, M.I.; SANTOS, S.A.; DETMANN, E.; FACIOLA, A.P.; VALADARES FILHO, S.C. Effect of dietary protein content on performance, feed efficiency and carcass traits of feedlot Nellore and Angus × Nellore cross cattle at different growth stages. **Journal of Agricultura Science**, Londres v. 156, 2018. Disponível em: < https://doi.org/10.1017/S0021859617000958>.

ARTMANN, T. A.; TOMA, H.; PINHEIRO, J.; ROMERO, J.; CARVALHO, A.; & TOMA, C. M. Melhoramento genético de bovinos ½ sangue taurino x ½ sangue zebuino no Brasil**. Revista Científica Eletrônica de Medicina Veterinária**, São Paulo, v. 22, n. 1, p. 1-20, 2015.

ASSAD, EDUARDO DELGADO; MARTINS, SUSIAN. A evolução de um novo paradigma. **AgroANALYSIS**, São Paulo, v. 35, n. 3, p. 32-34, 2015.

BARBERO. R.P.; MALHEIROS. E. B.; ARAÚJO. T. L. R.; NAVE. R. L. G.; MULLINIKS. J.T.; BERCHIELLI. T. T.; RUGGIERI. A.C.; REIS. R.A. Combining Marandu grass grazing height and supplementation level to optimize growth and productivity of yearling bulls. **Animal Feed Science and Technology**. Amsterdam, v. 209. 2015. Disponível em: < https://doi.org/10.1016/j.anifeedsci.2015.09.010>.

BARBERO, R. P.; MALHEIROS, E. B.; NAVE, R. L.; MULLINIKS, J. T.; DELEVATTI, L. M.; KOSCHECK, J. F.; RUGGIERI, A. C. Influence of post-weaning management system during the finishing phase on grasslands or feedlot on aiming to improvement of the beef cattle production. **Agricultural Systems**, Amsterdam, v. 153, 2017. Disponível em: < https://doi.org/10.1016/j.agsy.2017.01.015>.

BARBOSA, F. A.; SOARES FILHO, B. S.; MERRY, F. D.; AZEVEDO, H. D. O.; COSTA, W. L. S.; COE, M. T.; RODRIGUES, H. O. **Cenários para a pecuária de corte amazônica.** Universidade Federal de Minas Gerais: Belo Horizonte, 2015. 154 p.

BARKER, B. P.; MIES, W. L.; TURNER. J. W.; LUNT, D. K.; SMITH, S. B. Influence of production system on carcass characteristics of F1 Wagyu×Angus steers and heifers. **Meat Science**, Amsterdam, v. 41., 1995. Disponível em: < https://doi.org/10.1016/0309-1740(94)00071-E>.

BRAZ, S.P.; URQUIAGA, S.; ALVES, B.J.R.; JANTALIA, C.P.; GUIMARÃES, A.P.; DOS SANTOS, C.A.; DOS SANTOS, S.C.; MACHADO PINHEIRO, É.F.; BODDEY, R.M., Soil Carbon Stocks under Productive and Degraded Brachiaria Pastures in the Brazilian Cerrado. **Soil Science Society of America Journal**, USA, v. 77., 2013 Disponível em :< https://doi.org/10.2136/sssaj2012.0269>.

BATT, R. A.L., **Influences on animal growth and development**. Edward Arnold., 1980.

BAZILE, J.; PICARD, B.; CHAMBON, C.; VALAIS, A.; BONNET, M. Pathways and biomarkers of marbling and carcass fat deposition in bovine revealed by a combination of gel-based and gel-free proteomic analyses. **Meat Science**, Amsterdam, v. 156, 2019. Disponível em: < https://doi.org/10.1016/j.meatsci.2019.05.018>.

CAMPOS, J. A. A., ONGARATTO, F., REIS, R. A., FERNANDES, M. H. M. R., RIGOBELLO, I. L., GOMES, L. M. Como diferentes níveis de intensificação da pecuária de corte alteram as variáveis morfogênicas do capim marandu? In: Simpósio Brasileiro de Agricultura Sustentável, 10, 2020, Viçosa. **Anais eletrônicos...** Viçosa: UFV, 2020. Disponível em: https://www.simbras-as.com.br/. Acesso em 09 out. 2020.

CARDOSO, A. S.; BERNDT, A.; LEYTEM, A.; ALVES, B. J.; DE CARVALHO, I. D. N.; DE BARROS SOARES, L. H.; BODDEY, R. M. Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use. **Agricultural Systems**, Amsterdam, v. 143, 2016. Disponível em: < https://doi.org/10.1016/j.agsy.2015.12.007>.

CARDOSO, A. S.; DE FIGUEIREDO, L. F.; JANUSCKIEWICZ, E. R.; MORGADO, E. DA S.; BARBERO, R. P.; KOSCHECK, J. F. W.; REIS, R. A.; RUGGIERI, A. C. Impact of grazing intensity and seasons on greenhouse gas emissions in tropical grassland. **Agricultural Systems**, Basel, v. 20, n. 4, 2017. Disponível em:< https://doi.org/10.1007/s10021-016-0065-0>.

CARDOSO, A. D. S.; BARBERO, R. P.; ROMANZINI, E. P.; TEOBALDO, R. W.; ONGARATTO, F.; FERNANDES, M. H. M. D. R.; REIS, R. A. Intensification: A key strategy to achieve great animal and environmental beef cattle production sustainability in Brachiaria grasslands. **Sustainability**, Basel, v. 12, n. 16, 2020. Disponível em:< https://doi.org/10.3390/su12166656>.

CARRASCO, S.; RIPOLL, G.; SANZ, A.; ÁLVAREZ-RODRÍGUEZ, J.; PANEA, B.; JOY, M. Effect of feeding system on growth and carcass characteristics of Churra Tensina light lambs. **Livestock Science**, Amsterdam, v. 121, n. 1, 2009. Disponível em: <https://doi.org/10.1016/j.livsci.2008.05.017>

CARVALHO, J.R.R.; CHIZZOTTI, M.L.; SCHOONMAKER, J.P.; TEIXEIRA, P.D.; LOPES, R.C.; OLIVEIRA, C.V.R.; LADEIRA, M.M.; Performance, carcass characteristics, and ruminal pH of Nellore and Angus young bulls fed a whole shelled corn diet. **Journal of Animal Science**, Champaign, v. 94, 2016.Disponível em:< https://doi.org/10.2527/jas.2015-0162>

CEZAR, I. M., DE QUEIROZ, H. P., THIAGO, L. D. S., GARAGORRY, F. L., & COSTA, F. P. **Sistemas de produção de gado de corte no Brasil: uma descrição com ênfase no regime alimentar e no abate**. Campo Grande: Embrapa Gado de Corte, 2005. (Embrapa, Documentos, 151)

COAN. R.M.; REIS. R. **A Adubação nitrogenada em pastagens: eficiência no processo**. Nota de consultoria. 2011. 4 p.

COSTA, K. A. P.; FAQUIN, V.; OLIVEIRA, I. P. Doses e fontes de nitrogênio na recuperação de pastagens do capim-marandu. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**. Belo Horizonte. v. 62., n. 1., 2010. Disponível em:< http://dx.doi.org/10.1590/S0102-09352010000100026>.

DALEY, C. A.; ABBOTT, A.; DOYLE, P. S.; NADER, G. A.; LARSON, S. A. Review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. **Nutrition Journal**, Amsterdam, v. 9, n. 1, 2010. Disponível em:< https://doi.org/10.1186/1475-2891-9-10>.

DALLANTONIA. E. E.. **Associação de aditivos na suplementação de bovinos terminados a pasto no período das águas**. 2006. 66 f. Dissertação (Mestrado em Zootecnia) – Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista "Júlio Mesquito Filho", Jaboticabal, 2017.

DE FIGUEIREDO, E. B.; JAYASUNDARA, S.; BORDONAL, R. O.; REIS, R. A.; WAGNER-RIDDLE, C.; LA SCALA, N. Greenhouse gas balance and carbon footprint of beef cattle in three contrasting pasture-management systems in Brazil. **Journal of Cleaner Production**, Amsterdam,v. 142, 2016. Disponível em:< https://doi.org/10.1016/j.jclepro.2016.03.132>.

DELEVATTI, L.M.; CARDOSO, A.D.S.; BARBERO, R.P.; LEITE, R.G.; ROMANZINI, E.P.; RUGGIERI, A.; REIS, R.A. Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. **Scientific Reports**, Londres, v. 9, 2019. Disponível em: <http//doi:10.1038/s41598-019-44138-x>.

ELER. J. P. **Teorias e métodos em melhoramento genético animal III - sistemas de acasalamento**. USP: Pirassununga. 2015. p. 175.

ELER. J. P. **Teorias e métodos em melhoramento genético animal: bases do melhoramento genético animal**. USP: Pirassununga, 2017. p. 239.

ELLIOT. L. **The era of cheap food may be over**. The Guardian, 2012.

EL-MEMARI NETO, A.C. **Como Ganhar Dinheiro na Pecuária**. Inttegra: Maringá, 2019. p. 343.

ESHEL, G.; SHEPON, A.; MAKOV, T.; MILO, R. Land. irrigation water. greenhouse gas. and reactive nitrogen burdens of meat. eggs. and dairy production in the United States. **Proceedings of the National Academy of Sciences**, New York, v. 111, n. 33, 2014.Disponível em: <http://www.pnas.org/content/111/33/11996.full.pdf>.

EUCLIDES, V.P.B.; COSTA, F.P.; EUCLIDES FILHO, K.; MONTAGNER, D.B.; FIGUEIREDO, G.R. Biological and economic performance of animal genetic groups under different diets. **Biosciense Journal**, Uberlândia, v. 34, n. 6, 2018. Disponível em:< https://doi.org/10.14393/bj-v34n6a2018-39808>.

FAGUNDES. J.L.; FONSECA. D.M.; MISTURA. C. et al. Características morfogênicas e estruturais do capim-braquiária em pastagem adubada com nitrogênio avaliadas nas quatro estações do ano. **Revista Brasileira de Zootecnia**, Viçosa, v.35. n.1, 2006. Disponível em: < http://dx.doi.org/10.1590/S1516-35982006000100003.>.

FAO, Part. Livestock in the balance. **The state of food and agriculture**, Rome, 2009.

FAOSTAT. **Food and agriculture organization of the United Nations Database.** Food and Agriculture Organization Corporate Statistical Database, Rome, 2016.

FGV - EESP: **Intensificação da produção pecuária: desmatamento evitado e impactos na produção de carne no Brasil com redução de emissões de GEE**. Relatório completo. 2016.

GARNETT, T. Livestock-related greenhouse gas emissions: impacts and options for policy makers. **Environmental Science & Policy,** Amsterdam, v. 12, n. 4, 2009. Disponível em: <https://doi.org/10.1016/j.envsci.2009.01.006>.

GASTAL, F.; LEMAIRE, G.; Defoliation, Shoot Plasticity, Sward Structure and Herbage Utilization in Pasture: Review of the Underlying Ecophysiological Processes. **Agriculture**, Basel, v. 5, n. 4, 2015. Disponível em: <https://doi.org/10.3390/agriculture5041146.>

GERBER, P.J.; MOTTET, A.; OPIO, C.I.; TEILLARD, F. Environmental impacts of beef production: review of challenges and perspectives for durability. **Meat Science**, Amesterdan, v. 109, 2015. Disponível em: < https://doi.org/10.1016/j.meatsci.2015.05.013>.

GODFRAY, H.C.J.; BEDD INGTON, J.R.; CRUTE, I.R.; HADDAD, L.; LAWRENCE, D.; MUIR, J.F.; TOULMIN, C. Food security: the challenge of feeding 9 billion people. **Science,** London**, v.** 327, 2010. Disponível em: < https://DOI: 10.1126/science.1185383>.

GUERRA, G.L., MIZUBUTI, I.Y., DE AZAMBUJA RIBEIRO, E.L., PRADO-CALIXTO, O.P., DAS DORES FERREIRA DA SILVA, L., PEREIRA, E.S., MASSARO, F.L., GUERRA, A.L., FERNANDES, F., HENZ, É.L., Supplementation of beef cattle grazing brachiariabrizantha during the dry and rainy seasons: performance and carcass ultrasound prediction. **Semina Ciências Agrárias**, Londrina, v. 37, 2016. < https://doi.org/10.5433/1679-0359.2016v37n5p3277>.

IPCC - Intergovernamental Panel on Climate Change. Emissions from livestock and manure management. In: Eggleston. H. S.; Buendia. L.; Miwa. K.; Ngara. T.; Tabane. K. (eds). **IPCC Guideliness for nacional greenhouse gas inventories. Hayama**: IGES. p. 747-846. 2006.

JOSÉ NETO, A.; MESSANA, J. D.; RIBEIRO, A. F.; SAN VITO, E.; ROSSI, L. G.; BERCHIELLI, T. T. Effect of starch-based supplementation level combined with oil on intake. performance. and methane emissions of growing Nellore bulls on pasture. **Journal of Animal Science,** Champaign**,** v. 93, n. 5. 2015. Disponível em: < https://doi.org/10.2527/jas.2014-8500>.

LANA. D.P. Fatores condicionantes e predisponentes de puberdade e da idade de abate. In: SIMPÓSIO SOBRE PECUÁRIA DE CORTE, 4., 1997. **Anais**.... Piracicaba: FEALQ, 1997. p. 41-78.

LAZIA. B. **Mais bem sucedido resultado de cruzamento industrial dos últimos tempos**. Viçosa, 2017. Disponível em: http://www.portalagropecuario.com.br/bovinos/pecuaria-decorte/cruzamento-industrial-angus-nelore-bem-sucedido-resultado-ultimos-tempos/.

LEMAIRE. G.; CHAPMAN. D. Tissue flows in grazed plant communities. In: HODGSON. J.; ILLIUS. A. W. (Ed.). **The ecology and management of grazing systems**. New York, CABI International, 1996. p. 3-36.

MACEDO. M.. ZIMMER. A. H.. KICHEL. A.. ALMEIDA. R.. ARAUJO. A. Degradação de pastagens. alternativas de recuperação e renovação. e formas de mitigação.In: **Encontro de Adubação de Pastagens da SCOT Consultoria** – TEC - FÉRTIL. Ribeirão Preto: Scot Consultoria. 2013.

MANCINI, R. A.; HUNT, M. C. (2005). Current research in meat color. **Meat Science**, Amesterdan, v. 71. n.1, 2005. Disponível em: <https://doi.org/10.1016/j.meatsci.2005.03.003>.

MARTHA JÚNIOR. G. B.. VILELA. L.. BARIONI. L. G.. et al. Manejo da adubação nitrogenada em pastagens. In: Simpósio sobre Manejo da Pastagem. 21: 2004. Piracicaba. SP. **Anais.**.. Piracicaba: FEALQ, 2004. p. 155-215.

MOTTET, A.; DE HAAN, C.; FALCUCCI, A.; TEMPIO, G.; OPIO, C.; GERBER, P. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate.

Global Food Security, Amesterdan, v. 14. 2017. Disponível em: < https://doi.org/10.1016/j.gfs.2017.01.001>.

MURPHY, S.P.; ALLEN, L.H. Nutritional importance of animal source foods. **The Journal of Nutrition,** Oxford**,** v. 133, n. 11, 2003. Disponível em: <https://doi.org/10.1093/jn/133.11.3932S>.

OWENS, F.N;. DUBESKI, P.; HANSON, C.F. Factors that alter the growth and development of ruminants. **Journal of Animal Science**, Champaign, v. 71., 1993. Disponível em: < https://doi.org/10.2527/1993.71113138x>.

PAULINO. M.F.; DETMANN. E.; VALADARES FILHO. S.C. Suplementação animal em pastejo: energética ou protéica? In: SIMPÓSIO SOBRE MANEJO ESTRATÉGICO DA PASTAGEM. 3. 2006. Viçosa. **Anais**... Viçosa: UFV/DZO. 2006. p. 359-392.

PAULINO, V.T.; TEIXEIRA, E.M.L.C. Sustentabilidade de pastagens – Manejo adequado como medida redutora da emissão de gases de efeito estufa. **PUBVET**. Londrina. v. 4. n. 24., 2010.

PEREIRA. J. C. C. **Melhoramento Genético aplicado à produção animal**. Belo Horizonte: FEPMVZ. 2008. 586 p.

PEREIRA, P.M.R.C.; PINTO, M.F.; ABREU, U.G.P.; LARA. J.A.F. Características de carcaça e qualidade de carne de novilhos superprecoces de três grupos genéticos. **Pesquisa Agropecuária Brasileira,** Brasília**,** v.44. n.11., 2009. Disponível em: < https://doi.org/10.1590/S0100-204X2009001100021.>.

PIMENTEL, L. **Administre o Risco de Preços Pecuários: Um Guia Prático Para o Hedge de Sucesso.** Agrifatto: São Paulo, 2020. P. 324.

PIZZOL, J. G. dal. **Comparação entre vacas da raça holandesa e mestiças das raças holandesa x jersey quanto à sanidade, imunidade e facilidade de parto**. 2012. 55 f. Dissertação (Mestrado) - Curso de Ciências Agroveterinárias, Universidade do Estado de Santa Catarina, Lages, 2012.

RANDOLPH, T.F.; SCHELLING, E.; GRACE, D.; NICHOLSON, C.F.; LEROY. J.L.; COLE, D.C.; RUEL. M. Role of livestock in human nutrition and health for poverty reduction in developing countries. **Journal Animal Scince,** Champaign**,** v. 85, n. 11., 2007. Disponível em: <https://doi.org/10.2527/jas.2007-0467>.

REIS, R.A.; RUGGIERI, A.C.; CASAGRANDE, D.R.; PÁSCOA, A.G. Suplementação da dieta de bovinos de corte como estratégia do manejo das pastagens. **Revista Brasileira de Zootecnia**, Viçosa, v. 38, (supl. especial), 2009. Disponível em: <http://dx.doi.org/10.1590/S1516-35982009001300016>.

REIS, R.A.; RUGGIERI, A.; OLIVEIRA, A.A.; AZENHA, M.V.; ASAGRANDE, D.R. Suplementação como estratégia de produção de carne de qualidade em pastagens tropicais. **Revista Brasileira de Saúde e Produção Animal**. Salvador, v.13. n.3., 2012. Disponível em: < http://dx.doi.org/10.1590/S1519-99402012000300005>.

RESTLE, J.; Pacheco, P. S.; Pádua, J. T.; Rocha, M. G.; Vaz, R. Z.; Eifert, E. D. C.; Freitas, A. K. D. Eficiência biológica de vacas de dois grupos genéticos amamentando bezerros puros ou F1, mantidas em diferentes condições de alimentação. **Revista Brasileira de Zootecnia**, Viçosa, v. 33, n. 6, 2004. Disponível em: < http://dx.doi.org/10.1590/S1516-35982004000700021>.

RODRIGUES, R. T. D. S., CHIZZOTTI, M. L., VITAL, C. E., BARACAT-PEREIRA, M. C., BARROS, E., BUSATO, K. C., GOMES, R. A., LADEIRA, M. M., & MARTINS, T. D. S. (2017). Differences in beef quality between Angus (Bos taurus taurus) and Nellore (Bos taurus indicus) cattle through a proteomic and phosphoproteomic approach. **Plos One**, 12(1), e0170294. Disponível em: <https://doi.org/10.1371/journal.pone.0170294>.

ROSA. A. do N.; MARTINS, E. N.; MENEZES, G. R. de O.; SILVA, L. O. C. da; **Melhoramento genético Aplicado em Gado de Corte**. Brasília: Embrapa. 2013. 258 p.

SANDERSON, MATT A.; LIEBIG, MARK A. **Forages and the Environment**. In: Forages: The Science of Grassland Agriculture, v. 2, p. 249-259, 2020. Disponível em: < https://doi.org/10.1002/9781119436669.ch13>.

SANTIAGO. A. A. Os cruzamentos na pecuária bovina: raças taurinas. raças zebuinas. cruzamentos. Campinas. SP : **Instituto Campineiro de Ensino Agrícola**. p.549. 1984.

SANTOS. M.E.R.; FONSECA. D.M.; BALBINO. E.M. et al. Capim-braquiária diferido e adubado com nitrogênio: produção e características da forragem. **Revista Brasileira de Zootecnia**, Viçosa, v.38. n.4. 2009. Disponível em: < http://dx.doi.org/10.1590/S1516-35982009000400009>.

SANTOS. R. **Os cruzamentos na pecuária tropical: edição comemorativa dos 100 anos de pesquisas de cruzamentos no Brasil (1898 – 1998).** Uberaba: Agropecuária Tropical. 1999.

SAN VITO, E.; LAGE, J. F.; DALLANTONIA, E. E.; MESSANA, J. D.; REIS, R. A.; NETO, A. J.; FRIGHETTO, R. T. S.; BERCHIELLI, T. T. Performance and methane emissions of grazing Nellore bulls supplemented with crude glycerin. **Journal of Animal Science, Champaign**, v.94, n.11, 2016. Disponível em: < https://doi.org/10.2527/jas.2016-0530>.

SEEG. **Análise da evolução das emissões de GEE no Brasil**. São Paulo: Observatório do Clima, 2018.

SILVA, R. DE O., BARIONI, L.G., HALL, J.A.J., MORETTI, A.C., FONSECA VELOSO, R., ALEXANDER, P., CRESPOLINI, M., MORAN, D. Sustainable intensification of Brazilian livestock production through optimized pasture restoration. **Agriculture System**, Amesterdan, v. 153, 2017. Disponível em: < https://doi.org/10.1016/j.agsy.2017.02.001>.

SMITH, S.B.; LUNT. D.K.; CHUNG. K.Y.; CHOI, C. B.; TUME, R.K.; ZEMBAYASHI, M. Adiposity, fatty acid composition, and delta-9 desaturase activity during growth in beef cattle. **Animal Science Journal**. Champaign, n. 77., 2006. Disponível em: < https://doi.org/10.1111/j.1740-0929.2006.00375.x>.

TEDESCHI, L. O.; MUIR, J. P.; RILEY, D. G.; FOX, D. G. The role of ruminant animals in sustainable livestock intensification programs. **International Journal of Sustainable Development & World Ecology**, Lancs, v. 22, n. 5, 2015. Disponível em: < https://doi.org/10.1080/13504509.2015.1075441>.

TEIXEIRA, P. D., OLIVEIRA, D. M., CHIZZOTTI, M. L., CHALFUN-JUNIOR, A., COELHO, T. C., GIONBELLI, M., LADEIRA, M. M. Subspecies and diet affect the expression of genes involved in lipid metabolism and chemical composition of muscle in beef cattle. **Meat science**, Amesterdan, v. 133, 2017. Disponível em: <https://doi.org/10.1016/j.meatsci.2017.06.009>.

TSUTSUMI, M.; ONO, Y.; OGASAWARA, H.; HOJITO, M. Life-cycle impact assessment of organic and non-organic grass-fed beef production in Japan**. Journal of Cleaner Prodoction**, Amesterdan, V. 172, 2018 .Disponível em: <https://doi.org/10.1016/j.jclepro.2017.11.159>.

SNIFFEN, C. J.; O'CONNOR, J. D.; VAN SOEST, P. J.; FOX, D. G.; RUSSELL, J. B. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. **Journal of Animal Science**, Champaign, v. 71. n. 5, 1992. Disponível em: < https://doi.org/10.2527/1992.70113562x>.

WEDEKIN, Ivan; PINAZZA, Luiz A.; LEMOS, F. K**. Economia da pecuária de corte: fundamentos e ciclo de preços**. São Paulo: Wedekin Consultores, p. 180, 2017.

VALADARES FILHO, S. DE C.; MARCONDES, M. I.; CHIZZOTTI, M. L.; PAULINO, P. V. R. **Exigências nutricionais de zebuínos puros e cruzados**. Editora UFV: Viçosa, Brazil, 2016.

ZAMBONI. V. T. **Correlação entre escores visuais de conformação e indicadores de desempenho. características de carcaça e de carne de novilhos Nelore e cruzados Aberdeen Angus x Nelore**. 2012. 44 f. **Dissertação** (Mestrado em Ciência Animal) - Faculdade de Odontologia e Curso de Medicina Veterinária - Universidade Estadual Paulista “Júlio de Mesquita Filho”, Araçatuba, 2012.

CHAPTER 2

Este capítulo está regido conforme normas de publicação para ser submetido a revista "Livestock Science".

CHAPTER 2 – PERFORMANCE AND CARBON FOOTPRINT OF NELLORE AND F1 ANGUS X NELLORE YOUNG BULLS IN TROPICAL PRODUCTION SYSTEMS

Abstract

This study investigated the performance, carcass traits, and carbon footprint of Nellore and F1 Angus × Nellore yearling bulls raised under two [lenient (S1) and intensified (S2)] production systems during the backgrounding and finishing phases. S1 was practiced on a 18.6 ha palisade grass pasture, divided into eight paddocks, which was not fertilized and managed using continuous stocking at a constant rate of two animals per hectare during backgrounding. Then, 20 Nellore [initial body weight (BWi), 277±13 kg; initial age, 15.2±1.1 months] and 20 F1 Angus × Nellore (BWi, 304±21 kg; initial age, 15.8±0.44 months) yearling bulls were randomly allocated to four paddocks for each breed. During finishing, animals remained on the pasture and received high supplementation. S2 was practiced on a 11.4 ha palisade grass pasture, divided into six paddocks, which was fertilized (150 kg $N \cdot ha^{-1} \cdot year^{-1}$) and managed using continuous stocking at variables rates during backgrounding. Then, 24 Nellore (BWi, 288±16 kg; initial age, 15.6±0.65 months) and 24 F1 Angus × Nellore (BWi, 325±18 kg; initial age, 15.8±0.42 months) yearling bulls were randomly allocated to three paddocks for each breed. During finishing, the bulls were moved to feedlots. During backgrounding, F1 Angus × Nellore bulls in S2 achieved the highest average daily gain (ADG) and final shrunk body weight (SBWf), whereas Nellore bulls in S1 achieved the lowest ADG and SBWf. During finishing, ADG and SBWf were greater in S2 than in S1 as well as for F1 Angus × Nellore bulls than for Nellore bulls. From the beginning of backgrounding until the end of finishing, the ribeye area of F1 Angus × Nellore bulls in S2 was larger than that of other bulls. The greatest backfat deposition occurred during finishing, resulting in greater backfat thickness of bulls in S2 than that of bulls in S1. The carbon footprint of F1 Angus × Nellore bulls in S2 (10.8 $kg \cdot CO_2e \cdot kg^{-1}$ carcass) was similar to that of Nellore bulls in S1, but it was approximately 13% and 11.5%

lower than that of Nellore bulls in S2 and F1 Angus × Nellore bulls in S1, respectively. This study demonstrated that the enhancement of productivity through improving genetic merit and pasture management is a suitable strategy to reduce environmental impact and achieve environmental sustainability.

Keywords

beef, carcass, carbon footprint, Nellore, Angus, sustainable intensification

1. Introduction

Brazil holds the largest commercial cattle herds, with almost 215 million animals, standing as the second biggest beef producer in the world (FAO, 2017). Pastures constitute the backbone of this industry, with approximately 87% of the slaughtered animals raised in pasture-based systems (ABIEC, 2020). Of the 116 million hectares of cultivated pastures in Brazil, nearly 43% are seeded with the grass *Urochloa brizantha*, representing the world's largest monoculture in terms of area (Evangelista et al., 2015).

Being essentially pasture-based, the Brazilian livestock industry is highly competitive (Romanzini et al., 2020). Nevertheless, the concerns raised regarding environmental impact highlight the negative effects of beef production systems and their productive indices (Cardoso et al., 2016). Production of more meat within smaller areas in pasture-based systems meets the need for increased sustainability. In this light, intensified production systems require technologies that can boost productivity and economic viability without harming the environment (Pedrosa et al., 2019). Moreover, pasture and by-products are unsuitable for human consumption and produce high net feed yield (Ertl et al., 2016), leading to cleaner beef production.

Among diverse technologies, sustainable intensification of pasture-based systems can be achieved by soil fertility improvement, mainly through nitrogen fertilization (Delevatti et al., 2019a) and feed supplementation (Delevatti et al., 2019b; Fernandes et al., 2010; Sampaio et al., 2017). Improvement of breeding performance through genetic manipulation has also been proposed as an alternative to enhance productivity; however, different genotypes show variable performances in diverse production systems (Rashid et al., 2016). *Bos indicus* cattle, mostly Nellore sire, are the predominant breed in the Brazilian herd (Oliveira and Millen, 2014), and the cross between F1 Angus (*Bos taurus*) and Nellore improves growth potential due to breed complementarity in feedlot-based systems (Amaral et al., 2018). Meanwhile, environmental constraints can markedly affect the genetic potential of animals (Mulliniks et al., 2015). Hence, the genetic potential of crossbred bulls could be hindered in less intensified pasture-based systems, due to their inferior ability to cope with heat stress in tropical regions, for instance (Dikmen et al., 2018).

Beef cattle produce nitrous oxide (N_2O) from animal excreta and pasture nitrogen fertilizations (Cardoso et al., 2019); and enteric methane (CH_4) during forage digestion (Berça et al., 2019). However, the shortening of fattening time of cattle could decrease the effects of greenhouse gas (GHG) emission in temperate and tropical production systems (Cardoso et al., 2016; Cerri et al., 2016; Thornton and Herrero, 2010). Carbon footprint (CF) is an effective means to analyze GHG emission through one kilogram of a product, represented as a carbon dioxide equivalent (CO_2e), which is a standard unit of integrated emission of different gases. Previous comparative studies on the CF of beef production systems have assessed the environmental mitigation potential of production type (Cardoso et al., 2016), deforestation (decoupling effect) (Silva et al., 2016), or diet (de Vries et al., 2015). However, most studies used scenarios, as field experimental data are limited. Additionally, the effects of genetic groups have not been evaluated thus far.

Based on previous reports, we hypothesized that managing *Urochloa brizantha* at higher light interception (95%) and greater herbage mass on offer would result in better animal performance (Delevatti et al., 2019a) and, this management, when coupled with the use of crossbreeds, would reduce the environmental impacts of beef cattle production in tropical pasture systems. Furthermore, we hypothesized that F1 Angus × Nellore bulls raised in intensified systems would show higher production efficiency (body weight gain) and smaller CF than bulls raised in lenient and less intensified systems.

Therefore, we investigated the performance, carcass traits, and CF of Nellore and F1 Angus × Nellore raised in two production systems (lenient and intensified) during the backgrounding and finishing phases and compared the results with the findings of other Brazilian production systems. The study objectives were (1) to compare animal performance and carcass production; (2) to assess GHG emission of the lenient and intensified systems based on CFs combining the measured and estimated data; and (3) to identify strategies for reducing GHG emission from the beef production system.

2. Material and Methods

2.1. Goal and scope

The goal of this study was to compare GHG emission from two typical beef cattle production systems currently practiced with improved management (genetic, grassland management, and nutrition) in Central Brazil. The functional units that determined the scope and system boundary of this CF study were (1) kilogram of CO_2 equivalents per kilogram of product ($kg \cdot CO_2e \cdot kg^{-1}$) and (2) production of one kilogram of carcass.

To calculate the CF, we developed a life cycle inventory of GHG emissions resulting from on-farm activities, such as animal activities (enteric CH_4, N_2O, and CH_4 from manure), nitrogen fertilization of the grassland, use of diesel fuel, and CO_2 emission from fuel and machinery. Inputs and outputs of the studied systems are presented in Figure 1. Primary data from a field experiment and secondary data were used to assess the effects of GHG emissions. Primary data included forage and animal production, carcass traits, and enteric CH_4 emission during the backgrounding phase, and secondary data were used to calculate GHG emission. The system boundary of beef cattle production was simplified and divided into two stages: backgrounding and finishing phases. A detailed description of the system is provided in section 2.2 below.

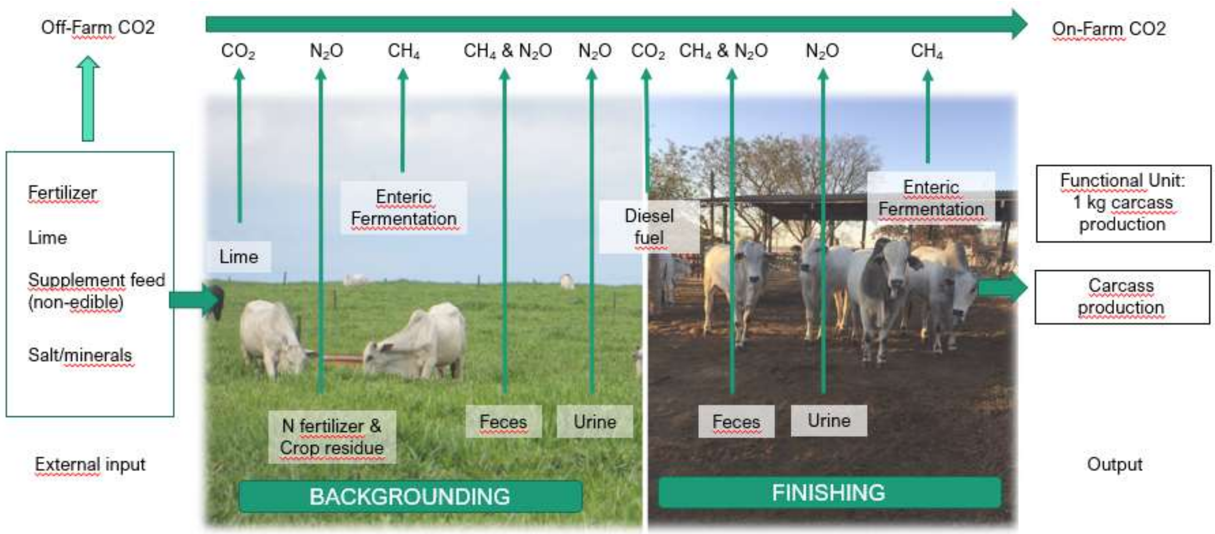

Figure 1. Schematic diagram showing system boundary and inputs and outputs.

2.2. Primary data measurement

We obtained all primary data used in the life cycle inventory from a field experiment described below.

2.3. Experimental site

The experiment was conducted at São Paulo State University "Julio de Mesquita Filho", Jaboticabal, SP, Brazil (21°15′22″S 48°18′08″W, 595 m altitude). The typical climate is humid subtropical, with mild, dry winters and hot, wet summers.

Animals involved in this study were cared for according to the rules of the São Paulo State University Animal Care and Use Committee and the National Council of Animal Experimentation Control (protocol approval number 12703/15).

The experiment lasted from December 2016 to September 2017 and was divided in two stages, including a backgrounding phase (rainy season, from December to May) that lasted 164 days, and a finishing phase (dry season, from June to September) that lasted 90 days (15-day acclimatization period and 75-day experimental period). During the experimental period, average temperature was 22.4±2.5°C and total rainfall was 927.4 mm (Supplementary material - Table S1).

2.4. Treatments and pasture and animal management

The experiments were performed using completely randomized design with a 2×2 factorial scheme and included two breeds (Nellore and F1 Angus × Nellore) and two production systems [lenient (S1) and intensified (S2)], as described below. These treatments were used as the system boundary to assess the effects of GHG emission and calculate the CF.

2.5. S1: Lenient production system

This system was practiced on a Marandu palisade grass (*Urochloa brizantha* Hochst ex A. Rich Stapf 'Marandu') pasture divided into eight paddocks of 2.2 ha (n= 4), 1.9 ha (n=2), or 3.0 ha (n=2). The pasture was established in 2005–2006 and has not been fertilized for at least past 5 years. In this pasture, continuous stocking was implemented at a constant rate of two animals per hectare. Twenty Nellore [initial body weight (BWi), 277±13 kg; initial age, 15.2±1.1 months) and 20 F1 Angus × Nellore (BWi, 304±21 kg; initial age, 15.8±0.44 months) yearling bulls were used. Animals of each breed were randomly allocated to half the area (four paddocks for each breed).

During backgrounding, animals received a mineral mix *ad libitum* (Supplementary material - Table S2) from December to February and a mineral supplement (1 $g \cdot kg^{-1}$ BW) (Table S2) from March to May. During finishing, from June to September, animals remained on the pasture and received intense supplementation at a rate of 2.0 $kg \cdot 100\ kg^{-1}$ BW twice a day (8h00 and 16h00), comprising cottonseed meal, defatted corn germ meal, urea, and minerals (Supplementary material - Table S3). All supplements were free of antibiotics and were based on human non-edible feedstock.

2.6. S2: Intensified production system

This system was practiced on a Xaraes palisade grass *(Urochloa brizantha* Hochst ex A. Rich Stapf 'Xaraes') pasture divided into six paddocks of 1.9 ha each. The pasture was established in 2001 and has been fertilized since then. In this pasture, continuous stocking was implemented at variable rates. The put-and-take method of stocking (Allen et al., 2011) was adopted, with a fixed canopy height (30 cm) during the rainy season. Canopy height was measured weekly at 80 random points per paddock to estimate and manage mean paddock height. Maintenance fertilizer was applied to all paddocks at 40 $kg \cdot P_2O_5 \cdot ha^{-1}$ and 40 $kg \cdot K_2O \cdot ha^{-1}$ in December. Urea was supplied at 150 $kg\ N \cdot ha^{-1}$, over three applications according to the precipitation schedule.

Twenty-four Nellore (BWi, 288±16 kg; initial age, 15.6±0.65 months) and 24 F1 Angus × Nellore (BWi, 325±18 kg; initial age, 15.8±0.42 months) yearling bulls were used. Animals of each breed were randomly allocated to half the area (three paddocks for each breed).

During backgrounding, animals received a mineral mix *ad libitum* (Table S2) from December to February and a mineral supplement (1 g·kg^{-1} BW) (Table S2) from March to May. During finishing, from June to September, animals were moved to feedlots and assigned to 12 pens (4 bulls per pen). The pens measured 5.0 m × 6.0 m and were equipped with automatic waterers. The feedlot-finishing diet was the same for all animals and comprised sugarcane bagasse as roughage [15% on a dry matter (DM) basis] and cottonseed meal, defatted corn germ meal, urea, and minerals as concentrate (85% on a DM basis) (Table S3). Animals were allowed *ad libitum* access to diet, adjusted to approximately 5% refusal of the total amount supplied daily. Feed was provided three times daily (7h00, 14h00, and 18h00). All supplements and the feedlot-finishing diet were free of antibiotics and were based on human non-edible feedstock.

2.7. Performance and ultrasound measurements

Animals were weighed at the beginning and end of each phase (backgrounding and finishing) after fasting for 12 h. Intermediate weighing was performed every 28 days (without fasting) to monitor and adjust the supplementation rate. Frame score was determined at the beginning of the backgrounding phase by combining the age of the bull with the hip height measured on 30th day using equations published by the Beef Improvement Federation (BIF, 2010) for bulls between the age of 5 and 21 months.

Carcass development of the animals was assessed based on backfat thickness (**FAT**) and ribeye area (**REA**) measured via *in vivo* ultrasound imaging (Aloka 500V, Hitachi Aloka Medical, Ltd, Toquio, Japan). Measurements were obtained at the beginning and end of backgrounding as well as at beginning, middle, and end of finishing. Images were acquired by a certified Ultrasound Guideline Technician Council and interpreted using Biosoft Toolbox® II (Biotronics, Inc., Ames, Iowa, USA).

Animals were slaughtered in a commercial slaughterhouse, following the slaughter line of establishment. Immediately after slaughter, hot carcass weight (kg) was determined to calculate carcass dressing weight relative to the final BW.

2.8. Forage sampling

Forage mass from all experimental paddocks was estimated every 28 days (January to May 2017) during the rainy season and twice (July and August 2017) during the dry season in S1. Forage was collected from paddocks at four sites, with average sward height, after clipping at 5 cm above soil level, of all plants included within the perimeter of a rising plate (0.25 m^2) representing mean forage mass of paddocks. Samples were then separated into dead material, stem + leaf sheath, and green leaves and dried at 55°C to a constant weight to estimate forage DM per hectare. In the same period, additional forage samples were hand plucked (Bonnet et al., 2011) to estimate chemical composition. Canopy characteristics and chemical composition of the hand-plucked forage samples from both production systems during the rainy season and from S1 during the dry season are described in supplementary material (Supplementary material - Table S4).

2.9. Intake, digestibility, urinary excretion, and enteric CH4

During backgrounding, individual intake was measured in 24 animals (8 animals per treatment) from day 144 to 154 (May 2017) after measurement.

DM intake (DMI) of grazing bulls was calculated using two markers to estimate fecal excretion, total DMI, and chromium and indigestible neutral detergent fiber (iNDF) contents. To estimate fecal excretion, chromium oxide was supplied orally for 10 days, at a rate of 10 $g \cdot Cr_2O_3 \cdot day^{-1}$ per animal, wherein the first 7 days were allocated for acclimatization and the last 3 days for fecal collections at 12 h intervals. Feces were oven-dried (55°C for 72 h), ground, and separated by animal. Fecal excretion was calculated based on marker concentration determined through atomic absorption spectrophotometry (Williams et al., 1962).

Individual forage intake was estimated using the internal marker iNDF content. To represent the diet (forage) consumed by grazing animals in each paddock, forage samples were hand plucked (Bonnet et al., 2011) during the same period. Canopy characteristics and chemical composition of the hand-plucked forage are described in supplementary material (Supplementary material - Table S5). The iNDF contents of forage, supplement, and fecal samples were estimated as described previously (Valente et al., 2011). Forage intake was estimated as described previously (San Vito et al., 2016). Individual supplement intake (backgrounding and finishing phases) was estimated by dividing the total concentrate provided by the number of animals in each paddock. In backgrounding, urine of grazing animals was collected as a spot sample during spontaneous urination before supplementation. Daily urinary volume was estimated based on creatinine excretion, as described previously (Santos et al., 2016). Approximately 40 mL of pure urine was separated for analysis of total nitrogen.

During backgrounding, enteric CH_4 through eructation was measured using the tracer gas [sulfur hexafluoride (SF_6)] method according to the manual of Global Research Alliance for Greenhouse Gases on Agriculture (Berndt et al., 2014) in the same animals whose intake was measured. Briefly, capsules with a constant release of SF_6 (137.4 ± 2.34 $\mu g \cdot h^{-1}$) were orally introduced through rumen. The sampling apparatus comprised a polyvinylchloride collection vessel and a capillary tube extending from the collection canister to just above the mouth and nostrils of the animals. The canister was attached to a collar around the neck of the bull. To initiate sample collection, the attached canister was connected to the transfer line, and a valve on the collection vessel was opened. The collection vessel was changed daily for 6 consecutive days at 24 h intervals. Moreover, a blank canister was installed daily in the paddocks to measure the background CH_4 concentration. Gas chromatography (Shimadzu GC2014 Gas

Chromatograph, Kyoto, Japan) was used to analyze CH_4 and SF_6 concentrations. Daily enteric CH_4 emission was calculated as described previously (Berça et al., 2019).

During feedlot, the offered feed and orts were recorded daily for individual pens, sampled twice a week. DM of the samples was measured by pen for further chemical analysis.

2.10. Chemical analysis

Samples of forage, feed ingredients, orts, and feces were dried at 55°C for 72 h in a forced-air oven, ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA, USA), and passed through a 1 mm screen. The ground samples were subjected to DM analysis by drying at 105°C to a constant weight (method 934.01; (AOAC International, 1990) and to ash analysis by complete combustion in a muffle furnace at 600°C for 24 h (AOAC, 1990; Method 942.05). Total nitrogen content was determined according to the Dumas principle (CN628, Leco Instruments Inc., St. Joseph, MI, USA). Ether extract was determined based on the weight loss of dry samples upon extraction with petroleum ether in a Soxhlet apparatus for 6 h (AOAC, 1990; method number 920.39). NDF content without ash (aNDF; Van Soest et al., 1991) was determined using an Ankom 200 fiber analyzer (Ankom Technology, Fairport, NY). Gross energy (GE) was measured using a bomb calorimeter (Parr Instrument Co., Moline, IL, USA). Nitrogen content of urine was determined as previously described (CN628, Leco Instruments Inc., St. Joseph, MI, USA). Total crude protein content (CP) was determined by multiplying nitrogen content by 6.25.

2.11. GHG emission and CF determination

To assess the environmental impact, we adopted a CF approach in which only GHG emission was taken into account. System boundaries were limited to the backgrounding and finishing phases, with a timeline of 272 days. Bulls entered the backgrounding phase at the age of 15.6±0.44 months and were slaughtered at the age of 24.6±0.44 months. GHG emission was calculated as CH_4 production from enteric fermentation and cattle dung; N_2O emission from dung and urine deposited in the pasture or in pens; N_2O emission from fertilizer applications in the field; and fossil CO_2 emission from the production, manufacture, and transport of animal feeds and fertilizers, from the use of diesel for on-farm operations, and from the production of electricity. Emissions associated with buildings and machinery or with veterinary product and pesticide production as well as emissions generated beyond the farm gate (transport for slaughter and carcass processing, among others) were omitted from the analysis. Soil organic carbon was assumed to be at equilibrium across all production systems. GHG emission from each treatment was calculated using Tier 2 methodologies of Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2019).

In this study, we used local emission factors (EFs) when available. Enteric CH_4 emission was modeled using Tier 2 refinement methods of IPCC (IPCC, 2019). During backgrounding, average daily CH_4 emission measured using the SF_6 tracer gas was considered. During the finishing phase, a default CH_4 conversion factor of 13.6 g $CH_4 \cdot kg^{-1}$ DM intake was applied, considering the actual and measured intakes. CH_4 emission from pastorally deposited excreta is 0.54 kg $CH_4 \cdot head^{-1} \cdot year^{-1}$, according to a Brazilian study performed at same location (Cardoso et al., 2019). In the feedlot, CH_4 emission from feces was determined based on total fecal production from the measured intake and digestibility during backgrounding and based on the measured intake and estimated digestibility of 75% during finishing (Table 10.2 of IPCC, 2019). We used equation 10.23 from the methodology to estimate CH_4 EFs and equation 10.24 to estimate volatile solid production (IPCC, 2019).

Nitrogen excreted through feces and urine during backgrounding was measured in the field. Nitrogen supplied through manure during finishing was estimated based on the nitrogen retention fraction from Table 10.20 of the IPCC manual and actual nitrogen intake. During backgrounding, direct N_2O emission from feces and urine excreted on the pasture was estimated separately using N_2O–N EFs (EF_{3PRP}) for grazing beef cattle (0.36% and 1.02%, respectively) derived from a Brazilian study (Cardoso et al., 2019). During finishing, direct N_2O emission from manure in S1 (EF_{3PRP}) was 0.34%, according to a Brazilian study (Cardoso et al., 2019). In S2, direct N_2O emission from a dry lot was estimated using the default EF recommended in chapter 10 of IPCC (Table 10.21 of IPCC, 2019). For both phases and systems, indirect N_2O emission was estimated based on EFs recommended in chapter 11 (Table 11.3 of IPCC, 2019), excluding the fractions of total nitrogen from animal manure and urine emitted as NH_3 (FracGASM) in the pasture during backgrounding and finishing (6.4% and 11.5%, respectively) (Cardoso et al., 2019).

GHG emissions from fuel, energy, fertilizers, and feeds used in the production systems were accounted for using the IPCC factors and other sources identified and cited in the literature (Cardoso et al., 2016; Joglekar et al., 2019; Mekonnen et al., 2018; Vellinga et al., 2013). The assumptions and EFs used for each source and input are described in Table 1.

Table 1. Emission factors for production of purchased resources and feeds

Source	unit	Value	Reference
Diesel fuel use	kg CO2e/L	3.53	Cardoso et al. (2016)
Eletricity	kg CO2eq/MWh	115	EPE (2015)
Lime	kg CO2eq/kg	0.476	Cardoso et al. (2016)
Fertilizer			
Nitrogen (urea)	kg CO2eq/kg	3.88	Cardoso et al. (2016)
Phosphorus	kg CO2eq/kg	2.7	Cardoso et al. (2016)
Potassium	kg CO2eq/kg	1.11	Cardoso et al. (2016)
Purchased feed			
Mixed mineral	kg CO2eq/kg	0.16	Cardoso et al. (2016)
Cottonseed meal	kg CO2eq/kg	0.91	Feedprint[1]
Deffated corn germ meal	kg CO2eq/kg	0.27	Feedprint[1]
Sugarcane bagasse	kg CO2eq/kg	0.15	Mekonen et al. (2018); Joglebar et al. (2019)

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

2.12. Impact assessment

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

2.13. Statistical analyses

All statistical analyses were performed using the MIXED Procedure in SAS (SAS Inst. Inc., Cary, NC, USA). Data were analyzed with two different models, wherein data from each phase (backgrounding and finishing) were collected using a completely randomized design in a 2×2 factorial scheme with two production systems (S1 and S2) and tow breeds (Nellore and F1 Angus × Nellore). The models included production system, breed, and their interactions as the fixed effects and residual error as the random effect. Residuals were plotted against the predicted values to validate model assumptions. Values with a studentized residuals outside the ±2.5 range values were considered outliers. No outliers were identified. Due to its differences between breeds and production systems, initial shrunk BW (SBWi) was used as a covariate to assess other performance variables. BW and ultrasound variables were collected using a completely randomized design with a 2×2 factorial scheme by repeated measurements using the MIXED Procedure (SAS 9.2). Treatments and time were considered the fixed effects, and animals were considered the random effects. Data were tested for the best covariance structure with the lowest corrected Akaike information criterion and then included in the REPEATED statement to complete the analysis. Means were compared using Fisher's protected least significant difference test. For all analyses, significance was determined as $P \leq 0.05$.

3. Results

3.1. Performance, intake, digestibility, and carcass traits

During backgrounding, both breed and environment (systems) affected ADG and final SBW (SBWf; Table 2). F1 Angus × Nellore bulls in S2 achieved the greatest ADG and SBWf, whereas Nellore bulls in S1 achieved the lowest ADG and SBWf. However, ADG and SBWf were similar between Nellore bulls in S2 and F1 Angus × Nellore bulls in S1.

The CH_4 emission and digestibility were measured at the end of backgrounding (from day 144 to 154). DMI relative to BW was greater in bulls from S1 than in those from S2, although total DMI did not differ between breeds and systems (Table 2). Additionally, the apparent DM digestibility, CP content, and GE of F1 Angus × Nellore bulls in S2 were greater than the values of other bulls, but digestible energy in S2 was greater than that in S1. Individual daily CH_4 emission of bulls in S1 was greater than that of bulls in S2 (Table 2). Daily CH_4 emission relative to carcass gain during backgrounding was lower in S2 than in S1, lower in F1 Angus × Nellore bulls than in Nellore bulls, and tended (P of interaction = 0.10) to be the lowest in F1 Angus × Nellore in S2.

ADG of F1 Angus × Nellore bulls in S2 remained higher throughout the experimental period (Figure 2).

Table 2. Performance, digestibility and enteric methane emission of Nellore and F1 Nellore x Angus yearling bulls at different production systems during backgrounding in wet season.

Variable[3]	System 1[1]		System 2[2]		SEM	P		
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	B*S
Performance								
Frame score	5.3	6.6	6.0	6.8	0.17	<.0001	0.004	0.11
SBWi. kg	304	277	326	288	4.0	<.0001	<.0001	0.17
SBWf. kg	435[b]	423[b]	470[a]	433[b]	4.2	<.0001	<.0001	0.0005
ADG. kg/d	0.97[b]	0.88[c]	1.22[a]	0.95[b]	0.030	<.0001	<.0001	0.0005
Stocking rate. AU/ha	1.94	1.75	4.69	4.30	0.11	0.01	<.0001	0.33
Intake and Digestibility coefficient[4]								
Supplement. kg/d	0.49	0.42	0.53	0.46	0.01	<.0001	0.0004	0.88
Forage. kg/d	10.69	8.00	7.78	7.66	1.11	0.19	0.13	0.23
Dry Matter. kg/d	11.18	8.42	8.31	8.12	1.12	0.17	0.15	0.23
Crude Protein. kg/d	1.03	0.79	0.89	0.83	0.09	0.103	0.57	0.29
NDF. kg/d	7.40	5.51	5.18	5.06	0.75	0.17	0.073	0.22
Gross Energy. MJ/d	179.42	131.80	132.65	129.24	19.10	0.17	0.184	0.23
DMI. %BW	2.29	2.00	1.56	1.77	0.23	0.86	0.039	0.26
Dry Matter	0.42[b]	0.46[b]	0.51[a]	0.48[b]	0.017	0.83	0.0039	0.048
Crude Protein	0.42[b]	0.44[b]	0.52[a]	0.42[b]	0.024	0.09	0.0915	0.020
NDF	0.53	0.55	0.56	0.58	0.019	0.25	0.0566	0.85
Energy	0.45[b]	0.45[b]	0.53[a]	0.46[b]	0.016	0.05	0.0054	0.032
DE. MJ/kg DM	7.17	7.02	8.46	7.34	0.320	0.05	0.0143	0.12
Methane Emission								
CH4. g/d	158.3	138.3	87.1	109.8	10.6	0.90	0.0002	0.056
Y (%)	5.64	6.07	3.76	5.04	0.909	0.35	0.12	0.64
CH4. g/ kg DMI	16.2	17.2	10.8	14.2	2.5	0.37	0.104	0.62
CH4. g/ kg carcass gain	311.7	308.2	142.0	252.6	33.6	0.12	0.0032	0.10

[1] *System 1 – Lenient production system.* Marandu palisadegrass *(Brachiaria brizantha* Hochst ex A. Rich Stapf cv. Marandu) pasture. [2] *System 2 – Intensive production system.* Xaraes palisadegrass *(Brachiaria brizantha* Hochst ex A. Rich Stapf cv. Xaraes). SBWi = initial shrunk body weight. SBWf = final shrunk body weight. BW= body weight. ADG= average daily gain. AU= animal unity of 450 kg BW. NDF = neutral detergent fiber. DMI = dry matter intake. DE = digestible energy. Y = proportional of gross energy intake lost as methane. [4]Total tract apparent digestibility coefficient. g/g.

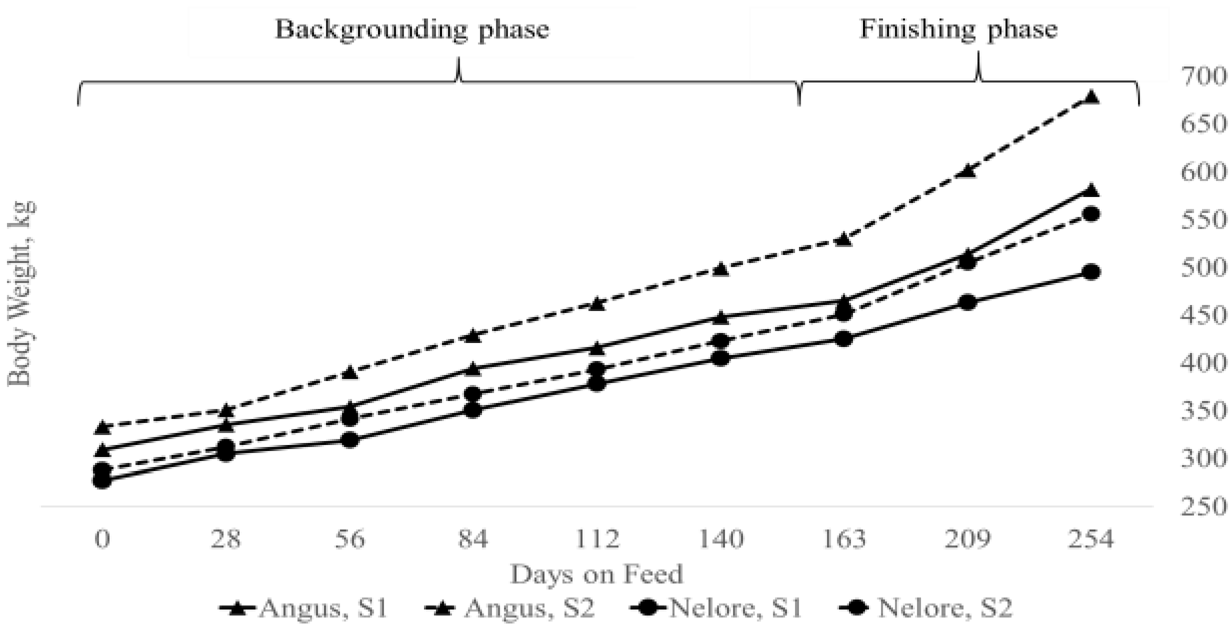

Figure 2. Body weight development during backgrounding and finishing of Nellore and F1 Nellore x Angus yearling bulls at different production systems. *System 1 – Lenient production system* (see text for more details). *System 2 – Intensified production system* (see text for more details). Breed: P <0.0001; system: P <0.0001; day: P <0.0001; breed*system*day: P = 0.0004.

Following the same pattern as backgrounding, SBWi during finishing differed between breed and production systems; therefore, SBWi was used as a covariate to assess other variables. During finishing, SBWf and ADG were greater in S2 than in S1 as well as in F1 Angus × Nellore bulls than in Nellore bulls (Table 3). Furthermore, DMI, ADG, and hot carcass weight were the greatest in F1 Angus × Nellore bulls in S2, the lowest in Nellore bulls in S1, and similar between Nellore bulls in S2 and F1 Angus × Nellore bulls in S1. Feed efficiency in S2 was 13% greater than that in S1, and the value in F1 Angus × Nellore bulls was 20% greater than that in Nellore bulls (Table 3).

Table 3. Performance of Nellore and F1 Nellore x Angus yearling bulls at different production systems during finishing in dry season.

Variable[3]	System 1[1]		System 2[2]			P		
	F1Angus	Nellore	F1Angus	Nellore	SEM	Breed	System	B*S
SBWi. kg	443[b]	409[c]	495[a]	422[c]	5.80	<.0001	<.0001	0.001
SBWf. kg	557	529	606	557	8.00	<.0001	<.0001	0.089
ADG. kg/d	1.24	0.93	1.77	1.24	0.09	<.0001	<.0001	0.089
CG. kg/d	1.02[b]	0.81[c]	1.36[a]	0.96[b]	0.05	<.0001	<.0001	0.035
HCW. kg	316[b]	297[c]	347[a]	309[b]	5.50	<.0001	<.0001	0.028
Dressing. %	56.70	56.10	57.30	55.40	0.65	0.0714	0.9686	0.188
DMI[4]. kg/d	10.70[c]	9.90[d]	14.10[a]	11.20[b]	0.15	<.0001	<.0001	<.0001
DMI. % BW	2.10[c]	2.00[d]	2.70[a]	2.30[b]	0.03	<.0001	<.0001	<.0001
FE. ADG/DMI	0.116	0.094	0.128	0.110	0.01	0.0170	0.0340	0.6700
BE. CG / DMI	0.095	0.082	0.099	0.084	0.01	0.0100	0.5100	0.8800

[1] *System 1 – Lenient production system.* [2] *System 2 – Intensive production system.* [3]SBWi = initial shrunk body weight. SBWf = final shrunk body weight; CG = Carcass gain; ADG= average daily gain. BW= body weight; HCW= hot carcass weight; DMI = dry matter intake. FE = Feed Efficiency. BE = Biological Efficiency. [4]In the intensive system. it represents the total mixed ration intake. In the semi-intensive system. it represents the supplement intake only plus 0.5% BW forage.

Regarding carcass development, the REA of F1 Angus × Nellore bulls in S2 was larger than that of other bulls since the beginning of backgrounding until the end of finishing (Figure 3A). In S2, mean REA deposition rate was faster during backgrounding (0.14 cm2·day-1; Supplementary material - Table S6) and the first half of feedlot (0.17 cm2·day-1), when bulls weighed up to 600 kg (Figure 2), but slowed down during the second half of feedlot (0.03 $cm^2 \cdot day^{-1}$; Table S6). Meanwhile, REA of Nellore bulls in S1 was smaller since the beginning of backgrounding until the first half of finishing (on pastures with intense supplementation), when bulls weighed up to 463 kg, but increased during the latter half of finishing (0.23 $cm^2 \cdot day^{-1}$; Table S6), resulting in similar REAs between Nellore bulls in S1 and S2. Throughout backgrounding and finishing, REA of F1 Angus × Nellore bulls in S1 and Nellore bulls in S2 showed similar trends (Figure 3A).

At the beginning, FAT was similar for all animals (Figure 3B). During backgrounding, mean rump fat deposition was faster in F1 Angus bulls (0.010 $cm \cdot day^{-1}$; Table S6) than in Nellore bulls (0.007 $cm \cdot day^{-1}$) as well as in bulls in S2 (0.010 $cm \cdot day^{-1}$) than those in S1 (0.007 $cm \cdot day^{-1}$). The highest rump fat deposition rate was achieved during finishing, resulting in greater mean FAT of bulls in S2 (5.87 cm) than that of bulls in S1 (4.87 cm).

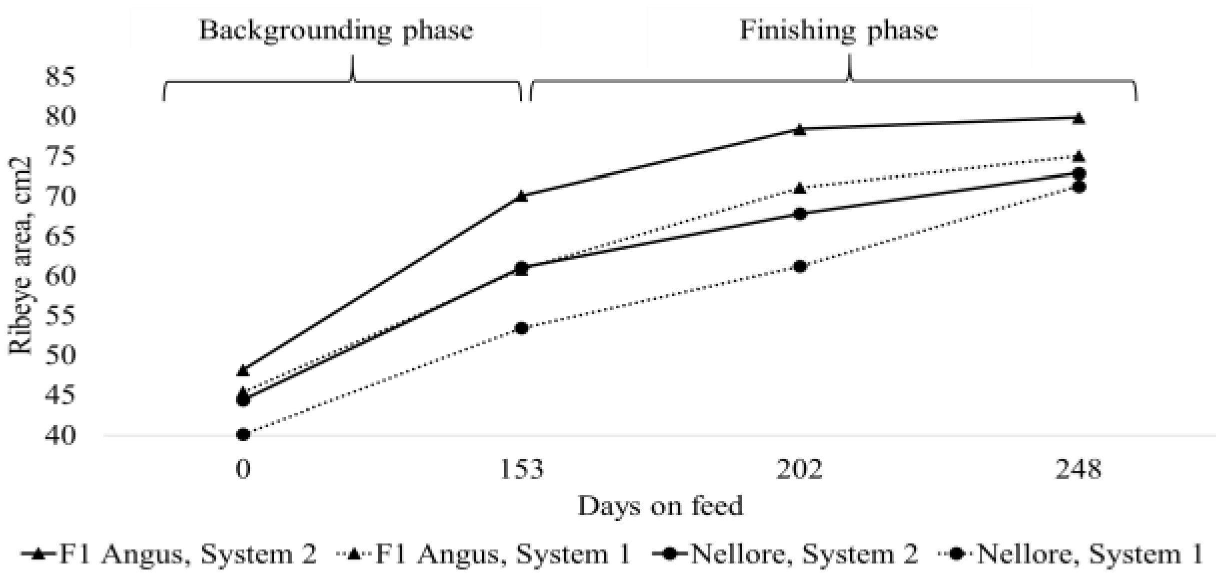

Figure 3A. Ribeye area of Nellore and F1 Nellore x Angus young bulls at different production systems. during backgrounding and finishing. System 1 – Lenient production system (see text for more details). System 2 – Intensive production system. Breed: P <0.0001; system: P <0.0001; day: P <0.0001; breed*system*day: P = 0.58.

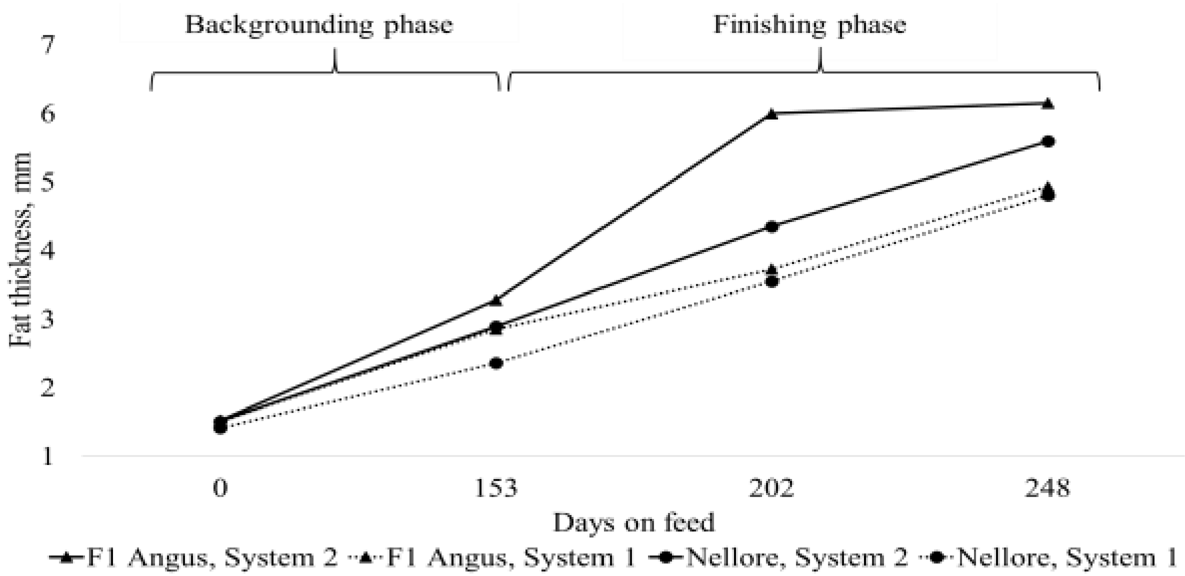

Figure 3B. Rump fat thickness of Nellore and F1 Nellore x Angus young bulls at different production systems. during backgrounding and finishing. *System 1 – Lenient production system* (see text for more details). *System 2 – Intensive production system* Breed: P = 0.0002; system: P <0.0001; day: P <0.0001; breed*system*day: P = 0.019.

3.2. GHG emission

Considering the environmental impact of the tested systems, total GHG emission (from backgrounding to farm gate) of each herd, representing the sum of direct (field emissions) and indirect emissions (upstream emissions), was greater from S2 than from S1 (Table 4). Nonetheless, carcass production from F1 Angus × Nellore bulls in S2 was the greatest, followed by that from Nellore bulls in S2 and bulls of both breeds in S1 (Table 4). Consequently, CF expressed on the carcass weight basis of F1 Angus × Nellore bulls in S2 was like that of Nellore bulls in S1 but approximately 13% and 11.5% lower than those of Nellore bulls in S2 and F1 Angus × Nellore bulls in S1, respectively (Table 4).

Enteric CH_4 emission ($kg \cdot CO_2e \cdot kg^{-1}$ carcass) of F1 Angus × Nellore bulls in S1 was approximately 38% higher the value of F1 Angus × Nellore bulls in S2 and 13% higher than that of Nellore bulls in both S1 and S2. Manure emission ($kg \cdot CO_2e \cdot kg^{-1}$ carcass), which was the sum of CH_4 emission from feces and N_2O emission from dung and urine deposited in the pasture or pens, was higher in S2 (in which animals were confined during finishing) than in S1 (in which animals remained on the pasture during finishing) (Table 4).

Despite being the main source of emission in both production systems, the contribution of enteric CH_4 to GHG emission was greater in S1 than in S2, while the opposite trend was observed for the contribution of manure to GHG emission (Figure 4).

Table 4. Greenhouse gas emission of Nellore and F1 Angus x Nellore yearling bulls at different production systems, during period of backgrounding and finishing.

Variable	System 1[1]		System 2[2]		SEM	P		
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	B*S
CO_2e[3] (Mg/herd)	9.90	9.10	21.40	21.20	0.840	0.540	<.001	0.680
CP[4] (Mg/herd)	0.81[c]	0.85[c]	1.99[a]	1.71[b]	0.069	0.091	<.001	0.031
Carbon footprint (kg CO_2e/kg carcass)								
Enteric methane	7.80[a]	6.80[b]	4.80[c]	6.00[b]	0.390	0.930	0.001	0.013
Manure[5]	1.20[c]	1.00[d]	2.30[b]	2.60[a]	0.073	0.450	<.001	0.003
Feed supplements	2.90[a]	2.70[b]	2.80[a]	2.90[a]	0.060	0.150	0.940	0.022
SF (N.P K)	0.00[c]	0.00[c]	0.71[b]	0.83[a]	0.012	0.001	<.001	<.001
Fossil fuels[6]	0.25	0.24	0.09	0.10	0.011	0.900	<.001	0.255
Total	12.20[a]	10.70[b]	10.80[b]	12.40[a]	0.460	0.890	0.730	0.004

[1] *System 1 – Lenient production system.*[2] *System 2 – Intensive production system* - pasture (see text for more details). [3]CO_2e = CO_2 equivalent; [4]CP = Carcass production [5]Feces and urine; [6]Sum of Electricity and diesel usage; SF = Synthetic fertilizers.

4. Discussion

The better performance of F1 Angus × Nellore bulls observed in both systems clearly demonstrated the effects of environment (production system) on genetic potential (heterosis), which is crucial to design profitable strategies for increasing meat production while decreasing the environmental impact.

4.1. Performance and carcass traits

F1 Angus × Nellore bulls were heavier than Nellore bulls at arrival, despite their similar age and farm origin, and they remained heavier until slaughtering (Figure 2). In terms of genetic improvement, the major genetic distance between Angus and Nellore breeds has been considered to produce high heterosis in Nellore × Angus crosses, resulting in greater muscular tissue accumulation rates (Cardoso et al., 2017). In this study, irrespective of the production system, F1 Angus × Nellore bulls performed better than Nellore bulls. Likewise, greater ADG of F1 Angus × Nellore crossbreeds than that of pure breeds (Amaral et al., 2018; Cardoso et al., 2017; Guerra et al., 2016) or taurine and Zebu crossbreeds (Cardoso et al., 2017; Euclides et al., 2018) have been reported in previous studies.

However, Dickerson (1962) stated that genetic differences can only be perceived if the environment allows gene expression of the trait of interest. Therefore, the better performance of F1 Angus × Nellore bulls than that of Nellore bulls was more pronounced in S2, in which the animals were provided with better feeding conditions. For instance, apparent DM, CP, and energy digestibility of F1 Angus × Nellore bulls in S2 was greater than those of other bulls, and digestible feed energy in S2 was greater than that in S1. These results are consistent with the better performance of F1 Angus × Nellore bulls in S2 than that of other bulls as well as of bulls in S2 that that of bulls in S1. These differences in DMI and digestibility were presumably an outcome of differences in sward structure due to short- and long-term management. Pastures from S2 have been managed and fertilized for years, indicting a high proportion of leaves, which is the most digestible portion of sward. Conversely, swards from S1 showed a small proportion of leaves and high proportion of dead material, increasing the intake of low digestible portions of the canopy.

Furthermore, during finishing, F1 Angus × Nellore bulls consumed more feed, supporting their greater ADG than that of Nellore bulls. The greater intake and performance of Angus and their crossbred bulls than those of Nellore bulls have also been observed in other studies (Carvalho et al., 2016; Guerra et al., 2016). These results can be attributed to the fact that, under *ad libitum* feeding conditions, *Bos taurus* cattle consume more feed relative to their maintenance requirements than *Bos indicus* cattle, thereby growing faster and more efficiently. In fact, our results also support the better feed efficiency of F1 Angus × Nellore bulls than that of Nellore bulls during finishing.

BW remained stable from day 140 to 163 because of the periods of digestibility trial during backgrounding and acclimatization during finishing. During finishing, bulls in S1 remained in their paddocks and were supplemented with a high proportion of concentrate or supplement (approximately 1.5% of BW daily), while bulls in S2 were moved to a feedlot barn.

The greater SBWi and ADG of F1 Angus × Nellore bulls resulted in greater SBWf, CW, and REA than those of Nellore bulls, presumably due to high heterosis and breed complementarity of Angus × Nellore crosses, which resulted in genetic gains. Meanwhile, differences in FAT indicated the genotype × environment interaction. In S2, F1 Angus × Nellore bulls were provided with better feeding conditions and consumed more feed (mainly during finishing) than Nellore bulls, which supplied the energy required for expressing greater genetic potential related to fat deposition. In contrast, in S1, F1 Angus × Nellore bulls were managed under a more restrictive nutritional plan, resulting in a similar FAT to Nellore bulls in the same environment. Similarly, no differences between crossbred and purebred Angus bulls were observed in a previous study when animals were subjected to a poor nutritional plan; however, differences were observed when animals were subjected to an improved nutritional plan (Cardoso et al., 2017). The authors attributed this genotype × environment interaction to phenotypic plasticity; genotypes with high variability between and within environments are plastic, whereas those with little variability are robust.

Moreover, FAT of F1 Angus × Nellore bulls in S2 sharply decreased after the second half of finishing (in this case, feedlot), suggesting differences in precocity between F1 Angus × Nellore and Nellore bulls. In a previous study, F1 Angus × Nellore steers showed the lowest age at slaughter, evaluated considering fat thickness as the end point (Euclides et al., 2018). This result was attributed to the early-maturing characteristics of this genetic group (Euclides et al., 2018). In early-maturing breeds, such as the British breeds (Angus and Hereford), fat deposition starts earlier in life than in late-maturing breeds, such as Zebu (Brahman and Nellore). In this study, F1 Angus × Nellore bulls exhibited small frame size (mean, 5.6), indicating earlier fat deposition, as opposed to Nellore bulls, which showed moderate frame size (mean, 6.7). These differences in frame size support the higher fat deposition in Nellore bulls and the stable rate of fat deposition in F1 Angus × Nellore bulls. in the second half of finishing.

4.2. *CF and sustainable intensification*

The concept of sustainable intensification of animal husbandry relies on the need for increasing animal production per unit area, considering production alternatives that completely address the three pillars of sustainability, namely social, environmental, and economic (Tedeschi et al., 2015). In this study, production system intensification referred to increasing the number of animals per unit area, mainly in grazing-based systems. According to previous plans, during backgrounding and rainy season, the stocking rate measured in terms of animal units (AU = one animal of 450 kg BW) per hectare in S2 was approximately 1.5 times greater than that in S1, supporting an additional 2.65 $AU{\cdot}ha^{-1}$. Considering the average SBW of 369 kg BW, S2 can accommodate approximately three more animals than S1. This intensification was achievable due to previous fertilization and management of pastures, resulting in greater forage mass production potential and nutritional value.

Several studies have showed that the environmental impact per unit product weight decreased with increasing animal productivity (Cardoso et al., 2016; de Vries et al., 2015; Tsutsumi et al., 2018). Furthermore, the combination of productivity potential (of different breeds) with pasture and feeding management strongly affects the CF resulting from the genotype × environment interaction (de Vries et al., 2015). The lowest CF was observed in F1 Angus × Nellore bulls in S2 due to the combination of high productivity (ADG) and good feeding management, which increased feed quality and decreased CH_4 emission. Conversely, the highest CF was observed in F1 Angus × Nellore bulls in S1 because low productivity of this breed could not offset its CH_4 emission. CF of Nellore bulls exhibited the opposite trend, probably because this breed is highly robust and can perform satisfactorily even in a less improved production system. According to Dikmen et al. (2018), Nellore cattle cope well with heat stress and low forage quality in tropical environments.

CH_4 generated from enteric fermentation was the main source of GHG emission in both production systems (Table 2). Indeed, the quality of ingested feed is one of the main characteristics affecting enteric CH_4 production. In this context, greater individual daily CH_4 emission of animals in S1 than that of animals in S2 was probably because of the poorer quality of forage in S1 and its lower digestibility. Additionally, the CH_4 emission factor and CH_4 yield reported in this study (mean 5.1% and 14.6 g $CH_4 \cdot kg^{-1}$ DMI) were slightly lower than those adopted by IPCC Tier 2 (IPCC, 2019) for diets with more than 75% forage and less than 62% energy digestibility (7% and 23.3 g $CH_4 \cdot kg^{-1}$ DMI). In fact, this lower CH_4 emission factor than the IPCC Tier 2 values (IPCC, 2019; 2006) has been consistently reported in previous studies in Brazilian tropical pastures (Barbero et al., 2015; Berça et al., 2019; Oliveira et al., 2018). This divergence is presumably a result of improvements in management achieved over time. Likewise, a previous sensitivity analysis reported that the CH_4 estimate based on IPCC Tier 2 (IPCC, 2006) was nearly 36% greater than the on-farm value measured based on SF_6 tracer gas in grass-based systems. This difference was attributed to the inherent uncertainties of IPCC methodology in representing a wide variety of diets and different management strategies in beef finishing (Sykes et al., 2019).

N_2O emissions from manure and fertilizers in S2 were increased by three-fold compared with values in S1 (Figure 3; Table 5). Increased N_2O emission from S2 is consistent with previously reported trends (Cardoso et al., 2016; Cerri et al., 2016). Indeed, to improve forage production, nitrogen fertilization is essential, and this practice increases plant CP content and digestibility and reduces fiber content, ultimately decreasing enteric CH_4 emission (Berça et al., 2019). The benefits of supplement and fertilizer usage include increased animal productivity and reduced enteric CH_4 and N_2O emissions.

CFs of contrasting beef production systems have been assessed and are well-known to vary largely across systems (O’Brien et al., 2020; Sykes et al., 2019). This variation is attributed to different methodologies adopted, mainly related to system boundaries, which hampers direct comparison. Cardoso et al. (2016) found that the environmental impacts of beef production systems varied depending on diet type, calving rate, and production type. For instance, systems using supplements showed smaller environmental impacts per unit of beef produced than systems based solely on grazing.

Considering the boundaries between the backgrounding and finishing phases, the range of CF in this study was within that reported for grazing systems in the Cerrado biome in Brazil (Florindo et al., 2017; Silva et al., 2017) as well as for grass pasture and feedlot finishing systems in the High Plains of southern United States (Heflin et al., 2019). Mean CF in the present study was approximately 50% and 25% greater than the values reported based on feedlot- and grass-finishing models in a previous study (Stanley et al., 2018). This difference may be attributed to system boundaries, which were limited to the finishing phase in Stanley et al.’s study, thus excluding the cow–calf and backgrounding phases. According to Tsutsumi et al. (2018), the cow–calf phase can show a great environmental impact, accounting for over 50% of CF of a certain system. Future studies should focus on the effects of cow–calf phase management, feeding, and genetic groups on the environmental impacts of production systems and their alternatives to achieve sustainable intensification.

Although previous life cycle assessments have attributed the majority of CF of the whole system to the cow–calf phase (from cradle to farm gate), differences in environmental impacts of beef production systems arise primarily due to various finishing strategies employed. In this context, previous studies have indicated that feedlot-finishing systems produce a lower CF because grass-finishing systems result in greater enteric CH_4 emission, longer finishing period, and lower animal productivity. However, in this study, differences in CFs between grass- or feedlot-finishing systems varied according to breed, indicating that breed is a new variable that should be accounted for when modelling GHG emissions.

Furthermore, most differences between emission estimates between grass-fed (throughout the life cycle) or grass-finished (limited to the finishing phase) systems and feedlot systems did not incorporate soil carbon sequestration into emission intensities (Cerri et al., 2016; Florindo et al., 2017). For instance, a previous study demonstrated that when soil carbon sequestration was incorporated, CF of grass-finishing systems reduced sharply and was lower than that of feedlot-finishing systems (Stanley et al., 2018). In the present study, the CF estimate was related only to emissions from farm inputs and activities and did not consider the effect of carbon sequestration on reducing the associated CO_2 emission in S2, in which pastures were better fertilized and produced more forage mass (carbon stocks). Previous studies have indicated increased soil carbon stocks in well-managed pastures in Brazil (Braz et al., 2013; Silva et al., 2017), suggesting another factor reducing the CF of S2. However, the use of supplements to produce and transport concentrates can enhance GHG emissions.

Of note, all feeds used in both systems in our study were non-edible for humans and free of antibiotics. Utilization of human non-edible by-products as supplement and improved pasture can increase the efficiency of nutrient utilization, reduce the use of human edible food, increase animal performance, improve gain per area, and reduce slaughter age (Peyraud, 2017).

Moreover, according to our results, the employed production system could reduce environmental impacts.

5. Conclusions

Our results demonstrated that enhancement of productivity through improvement of genetic merit (heterosis) as well as of pasture management and diet formulation and quality is a suitable strategy to decrease environmental impact and achieve sustainability. Crossbred F1 Angus × Nellore bulls are heavier, grow faster, and produce fatter carcass than Nellore bulls. Therefore, introducing crossbred F1 Angus × Nellore breed is viable to reduce environmental impacts of intensified production systems only, while Nellore breed is better suited for lenient production systems. Finally, our results offer insights for improving systems using high-forage diets for mitigating the environmental impacts of beef production in Brazil as well as in other countries.

CRediT authorship contribution statement

E. E. Dallantonia: Investigation, Resources, Writing - review & editing, **M H M R Fernandes:** Conceptualization, Methodology, Supervision, Data curation, Formal Analysis, Writing - original draft, review & editing, **A. S. Cardoso:** Writing - review & editing, **R. G. Leite:** Investigation, Resources, Writing - review & editing, **A Ferrari:** Investigation, Resources, **F Ongaratto:** Writing - review & editing, **J F Lage:** Conceptualization, Methodology, Writing - review & editing, **M A A Balsalobre:** Conceptualization, Methodology, **R A Reis:** Conceptualization, Methodology, Funding acquisition, Project administration, Supervision, Writing - review & editing.

Acknowledgments

The authors thank the members of UnespFOR (Brazilian forage Team) for the contributions during the field trial setup. We thank Trouw Nutrition forthe supply of mineral mix and supplements. We would like to thank Editage (www.editage.com) for English language editing.

The authors acknowledge the São Paulo Research Foundation (FAPESP, grant #15/16631-5), the National Council for Scientific and Technological Development by financial support.

6. References

ABIEC, 2020. Beef Report 2019. Brazilian Beef Exporters Association. URL http://abiec.com.br/en/publicacoes/beef-report-2019-2/ (accessed 3.16.20).

Allen, V.G., Batello, C., Berretta, E.J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., Sanderson, M., 2011. An international terminology for grazing lands and grazing animals. Grass Forage Sci. 66, 2–28. https://doi.org/10.1111/j.1365-2494.2010.00780.x

Amaral, P.M., Mariz, L.D.S., Zanetti, D., Prados, L.F., Marcondes, M.I., Santos, S.A., Detmann, E., Faciola, A.P., Valadares Filho, S.C., 2018. Effect of dietary protein content on performance, feed efficiency and carcass traits of feedlot Nellore and Angus × Nellore cross cattle at different growth stages. J. Agric. Sci. 156, 110–117. https://doi.org/10.1017/S0021859617000958

AOAC International, 1990. Official Methods of Analysis of the AOAC International, 15th ed. Association of Official Analytical Chemists International, Arlington, VA.

Barbero, R.P., Malheiros, E.B., Araújo, T.L.R., Nave, R.L.G., Mulliniks, J.T., Berchielli, T.T., Ruggieri, A.C., Reis, R.A., 2015. Combining Marandu grass grazing height and supplementation level to optimize growth and productivity of yearling bulls. Anim. Feed

Sci. Technol. 209, 110–118. https://doi.org/10.1016/j.anifeedsci.2015.09.010

Beef Improvement Federation (BIF), 2010. Guidelines for Uniform Beef Improvement Programs, 9th ed. Beef Improvement Federation, Raleigh, NC.

Berça, A.S., Cardoso, A.D.S., Longhini, V.Z., Tedeschi, L.O., Boddey, R.M., Berndt, A., Reis, R.A., Ruggieri, A.C., 2019. Methane production and nitrogen balance of dairy heifers grazing palisade grass cv. Marandu alone or with forage peanut. J. Anim. Sci. 97, 4625–4634. https://doi.org/10.1093/jas/skz310

Berndt, A., Boland;, T.M., Deighton, M.H., Gere, J.I., Grainger, C., Hegarty, R.S., Iwaasa, a. D., Koolaard, J.P., Lassey, K.R., Luo, D., Martin, R.J., Martin, C., Moate, P.J., Molano, G., Pinares-Patiño, C., Ribaux, B.E., Swainson, N.M., Waghorn, G.C., Williams., S.R.O., 2014. Guidelines for use of sulphur hexafluoride (SF 6) tracer technique to measure enteric methane emissions from ruminants. Ministry of Primary Industries, Wellington, New Zealand.

Bonnet, O., Hagenah, N., Hebbelmann, L., Meuret, M., Shrader, A.M., 2011. Is Hand Plucking an Accurate Method of Estimating Bite Mass and Instantaneous Intake of Grazing Herbivores? Rangel. Ecol. Manag. 64, 366–374. https://doi.org/10.2111/REM-D-10-00186.1

Braz, S.P., Urquiaga, S., Alves, B.J.R., Jantalia, C.P., Guimarães, A.P., dos Santos, C.A., dos Santos, S.C., Machado Pinheiro, É.F., Boddey, R.M., 2013. Soil Carbon Stocks under Productive and Degraded Brachiaria Pastures in the Brazilian Cerrado . Soil Sci. Soc. Am. J. 77, 914–928. https://doi.org/10.2136/sssaj2012.0269

Cardoso, A. da S., Oliveira, S.C., Janusckiewicz, E.R., Brito, L.F., Morgado, E. da S., Reis, R.A., Ruggieri, A.C., 2019. Seasonal effects on ammonia, nitrous oxide, and methane emissions for beef cattle excreta and urea fertilizer applied to a tropical pasture. Soil Tillage Res. 194, 104341. https://doi.org/10.1016/j.still.2019.104341

Cardoso, A.S., Berndt, A., Leytem, A., Alves, B.J.R., de Carvalho, I. das N.O., de Barros Soares, L.H., Urquiaga, S., Boddey, R.M., 2016. Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use. Agric. Syst. 143, 86–96. https://doi.org/10.1016/j.agsy.2015.12.007

Cardoso, L.L., Biegelmeyer, P., Cardoso, F.F., 2017. Genotype x environment interaction on post-weaning performance and carcass in beef cattle. Semin. Agrar. 38, 481–489. https://doi.org/10.5433/1679-0359.2017v38n1p481

Carvalho, J.R.R., Chizzotti, M.L., Schoonmaker, J.P., Teixeira, P.D., Lopes, R.C., Oliveira, C.V.R., Ladeira, M.M., 2016. Performance, carcass characteristics, and ruminal pH of Nellore and Angus young bulls fed a whole shelled corn diet. J. Anim. Sci. 94, 2451–2459. https://doi.org/10.2527/jas.2015-0162

Cerri, C.C., Moreira, C.S., Alves, P.A., Raucci, G.S., Castigioni, B.D.A., Mello, F.F.C., Cerri, D.G.P., Cerri, C.E.P., 2016. Assessing the carbon footprint of beef cattle in Brazil: A case study with 22 farms in the State of Mato Grosso. J. Clean. Prod. 112, 2593–2600. https://doi.org/10.1016/j.jclepro.2015.10.072

de Vries, M., van Middelaar, C.E., de Boer, I.J.M., 2015. Comparing environmental impacts of beef production systems: A review of life cycle assessments. Livest. Sci. 178, 279–288. https://doi.org/10.1016/j.livsci.2015.06.020

Delevatti, L.M., Cardoso, A.S., Barbero, R.P., Leite, R.G., Romanzini, E.P., Ruggieri, A.C., Reis, R.A., 2019a. Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. Sci. Rep. 9. https://doi.org/10.1038/s41598-019-44138-x

Delevatti, L.M., Romanzini, E.P., Koscheck, J.F.W., da Ross de Araujo, T.L., Renesto, D.M., Ferrari, A.C., Barbero, R.P., Mulliniks, J.T., Reis, R.A., 2019b. Forage management intensification and supplementation strategy: Intake and metabolic parameters on beef cattle production. Anim. Feed Sci. Technol. 247, 74–82. https://doi.org/10.1016/j.anifeedsci.2018.11.004

Dickerson, G.E., 1962. Implications of genetic-environmental interaction in animal breeding. Anim. Prod. 4, 47–63.

Dikmen, S., Mateescu, R.G., Elzo, M.A., Hansen, P.J., 2018. Determination of the optimum contribution of brahman genetics in an angus-brahman multibreed herd for regulation of body temperature during hot weather. J. Anim. Sci. 96, 2175–2183. https://doi.org/10.1093/jas/sky133

Euclides, V.P.B., Costa, F.P., Euclides Filho, K., Montagner, D.B., Figueiredo, G.R., 2018. Biological and economic performance of animal genetic groups under different diets. Biosci. J. 34, 1683–1692. https://doi.org/10.14393/bj-v34n6a2018-39808

Ertl, P., Knaus, W., Zollitsch, W., 2016. An approach to including protein quality when assessing the net contribution of livestock to human food supply. Animal 10, 1883–1889. https://doi.org/10.1017/S1751731116000902Evangelista, A.R., Avila, C.L.S., Casagrande, D.R., Lara, M.A.S., Bernardes, T.F., 2015. International Conference on Forages in Warm Climates. Forages Warm Clim. 1–141.

FAO, 2017. Food and Agriculture Organization of the United Nations [WWW Document]. FAOSTAT. URL www.fao.org/faostat (accessed 1.15.20).

Fernandes, L. de O., Reis, R.A., Paes, J.M.V., 2010. Supplementation effect on the performance of beef cattle steers maintained in Brachiaria brizantha cv. Marandu pasture. Cienc. e Agrotecnologia 34, 240–248. https://doi.org/10.1590/s1413-70542010000100031

Florindo, T.J., de Medeiros Florindo, G.I.B., Talamini, E., da Costa, J.S., Ruviaro, C.F., 2017. Carbon footprint and Life Cycle Costing of beef cattle in the Brazilian midwest. J. Clean. Prod. 147, 119–129. https://doi.org/10.1016/j.jclepro.2017.01.021

Guerra, G.L., Mizubuti, I.Y., De Azambuja Ribeiro, E.L., Prado-Calixto, O.P., Das Dores Ferreira Da Silva, L., Pereira, E.S., Massaro, F.L., Guerra, A.L., Fernandes, F., Henz, É.L., 2016. Supplementation of beef cattle grazing Brachiariabrizantha during the dry and rainy seasons: Performance and carcass ultrasound prediction. Semin. Agrar. 37, 3277–3292. https://doi.org/10.5433/1679-0359.2016v37n5p3277

Heflin, K.R., Parker, D.B., Marek, G.W., Auvermann, B.W., Marek, T.H., 2019. Greenhouse-gas emissions of beef finishing systems in the Southern High PLAINS. Agric. Syst. 176, 102674. https://doi.org/10.1016/j.agsy.2019.102674

IPCC, 2019. IPCC, in: Bartram, D.M., Cai, B., Buendia, E.C., Dong, H., Garg, A., Guendehou, G.H.S., Limmeechokchai, B., MacDonald, J.D., Ogle, S.M., Ottinger, D.A., Pipatti, R.K., Rojas, Y., Romano, D., Sanchez, M.J.S., Sturgiss, R., Tanabe, K., Rocha, M.T., Towprayoon, S., Weitz, M.M., Wirth, T., Witi, J. (Eds.), Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. Task Force on National Greenhouse Gas Inventories (TFB), Canada.

IPCC, 2006. IPCC, in: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Publishing Institute of Global Environmental Strategy (IGES), Japan.

Joglekar, S.N., Tandulje, A.P., Mandavgane, S.A., Kulkarni, B.D., 2019. Environmental Impact Study of Bagasse Valorization Routes. Waste and Biomass Valorization 10, 2067–2078. https://doi.org/10.1007/s12649-018-0198-9

Mekonnen, M.M., Romanelli, T.L., Ray, C., Hoekstra, A.Y., Liska, A.J., Neale, C.M.U., 2018. Water, Energy, and Carbon Footprints of Bioethanol from the U.S. and Brazil. Environ. Sci. Technol. 52, 14508–14518. https://doi.org/10.1021/acs.est.8b03359

Mulliniks, J.T., Rius, A.G., Edwards, M.A., Edwards, S.R., Hobbs, J.D., Nave, R.L.G., 2015. FORAGES AND PASTURES SYMPOSIUM : Improving efficiency of production in pasture- and range-based beef and dairy systems 1 FORAGES AND PASTURES SYMPOSIUM : Optimizing the use of fibrous residues in beef and dairy diets 1 1–3. https://doi.org/10.2527/jas2014-8595

Myhre, G., Shindell, D., Breon, F.M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H., 2013. Anthropogenic and natural radiative forcing, in: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and NY, USA.

O'Brien, D., Herron, J., Andurand, J., Caré, S., Martinez, P., Migliorati, L., Moro, M., Pirlo, G., Dollé, J.B., 2020. LIFE BEEF CARBON: A common framework for quantifying grass and corn based beef farms' carbon footprints. Animal 834–845. https://doi.org/10.1017/S1751731119002519

Oliveira, C.A., Millen, D.D., 2014. Survey of the nutritional recommendations and management practices adopted by feedlot cattle nutritionists in Brazil. Anim. Feed Sci. Technol. 197, 64–75. https://doi.org/10.1016/j.anifeedsci.2014.08.010

Oliveira, L.F., Ruggieri, A.C., Branco, R.H., Cota, O.L., Canesin, R.C., Costa, H.J.U., Mercadante, M.E.Z., 2018. Feed efficiency and enteric methane production of Nellore cattle in the feedlot and on pasture. Anim. Prod. Sci. 58, 886–893. https://doi.org/10.1071/AN16303

Pedrosa, L.M.H., Hoshide, A.K., Abreu, D.C. De, Molossi, L., Couto, E.G., 2019. Financial transition and costs of sustainable agricultural intensification practices on a beef cattle and crop farm in Brazil’s Amazon. Renew. Agric. Food Syst. 1–12. https://doi.org/10.1017/S1742170519000413

Peyraud, J.L., 2017. The role of grassland-based production system for sustainable protein production, in: 54th Annual Meeting of Brazilian Society of Animal Science. Brazilian Society of Animal Science, ISSN 1983-4357, Foz do Iguaçu, Brazil, p. 243.

Rashid, M.M., Hoque, M.A., Huque, K.S., Bhuiyan, A.K.F.H., 2016. Genotype×environment interactions in growth performance of brahman crossbred cattle in bangladesh. Asian J. Anim. Sci. 10, 68–76. https://doi.org/10.3923/ajas.2016.68.76

Romanzini, E.P., Barbero, R.P., Reis, R.A., Hadley, D., Malheiros, E.B., 2020. Economic evaluation from beef cattle production industry with intensification in Brazil’s tropical pastures. Trop. Anim. Health Prod. https://doi.org/10.1007/s11250-020-02304-8

Sampaio, R.L., de Resende, F.D., Reis, R.A., de Oliveira, I.M., Custódio, L., Fernandes, R.M., Pazdiora, R.D., Siqueira, G.R., 2017. The nutritional interrelationship between the growing and finishing phases in crossbred cattle raised in a tropical system. Trop. Anim. Health Prod. 49, 1015–1024. https://doi.org/10.1007/s11250-017-1294-8

San Vito, E., Lage, J.F., Messana, J.D., Dallantonia, E.E., Frighetto, R.T.S., Reis, R.A., Neto, A.J., Berchielli, T.T., 2016. Performance and methane emissions of grazing nellore bulls supplemented with crude glycerin. J. Anim. Sci. 94, 4728–4737. https://doi.org/10.2527/jas.2016-0530

Santos, S.A., Rotta, P.P., Fernando, L., Clara, A., Menezes, B., 2016. Protein ruminal degradation of feeds and microbial protein synthesis, in: Valadares Filho, S.D.C., e Silva, L.F.C., Gionbelli, M.P., Rotta, P.P., Marcondes, M.I., Chizzotti, M.L., Prados, L.F. (Eds.), Nutrient Requirements of Zebu and Crossbred Cattle. Suprema Grafica, Viçosa, p. 314. https://doi.org/http://dx.doi.org/10.5935/978-85-8179-111-1.2016B002

Silva, R. de O., Barioni, L.G., Hall, J.A.J., Folegatti Matsuura, M., Zanett Albertini, T., Fernandes, F.A., Moran, D., 2016. Increasing beef production could lower greenhouse gas emissions in Brazil if decoupled from deforestation. Nat. Clim. Chang. 3–8. https://doi.org/10.1038/nclimate2916

Silva, R. de O., Barioni, L.G., Hall, J.A.J., Moretti, A.C., Fonseca Veloso, R., Alexander, P., Crespolini, M., Moran, D., 2017. Sustainable intensification of Brazilian livestock production through optimized pasture restoration. Agric. Syst. 153, 201–211. https://doi.org/10.1016/j.agsy.2017.02.001

Stanley, P.L., Rowntree, J.E., Beede, D.K., DeLonge, M.S., Hamm, M.W., 2018. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. Agric. Syst. 162, 249–258. https://doi.org/10.1016/j.agsy.2018.02.003

Sykes, A.J., Topp, C.F.E., Rees, R.M., 2019. Understanding uncertainty in the carbon footprint of beef production. J. Clean. Prod. 234, 423–435. https://doi.org/10.1016/j.jclepro.2019.06.171

Tedeschi, L.O., Muir, J.P., Riley, D.G., Fox, D.G., 2015. The role of ruminant animals in sustainable livestock intensification programs. Int. J. Sustain. Dev. World Ecol. 22, 1–14. https://doi.org/10.1080/13504509.2015.1075441

Thornton, P.K., Herrero, M., 2010. Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. Proc. Natl. Acad. Sci. 107, 19667–19672. https://doi.org/10.1073/pnas.0912890107

Tsutsumi, M., Ono, Y., Ogasawara, H., Hojito, M., 2018. Life-cycle impact assessment of organic and non-organic grass-fed beef production in Japan. J. Clean. Prod. 172, 2513–2520. https://doi.org/10.1016/j.jclepro.2017.11.159

Valente, T.N.P., Detmann, E., de Queiroz, A.C., de Campos Valadares Filho, S., Gomes, D.I., Figueiras, J.F., 2011. Evaluation of ruminal degradation profiles of forages using bags made from different textiles. Rev. Bras. Zootec. 40, 2565–2573. https://doi.org/10.1590/S1516-35982011001100039

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. J. Dairy Sci. 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M., Starmans, D., 2013. Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization. Livest. Res. Rep. 674 121.

Williams, C.H., David, D.J., Iismaa, O., 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agric. Sci. 59, 381–385. https://doi.org/10.1017/S002185960001546X

SUPPLEMENTARY MATERIAL

Table S1. Monthly temperature and rainfall during experimental period

Month/year	Maximum temperature, °C	Minimum temperature, °C	Average temperature, °C	Rainfall, mm
Dec/2016	31.5	20.0	24.7	184.4
Jan/2017	30.2	20.6	24.1	217.7
Feb/2017	32.0	20.0	25.0	118.3
Mar/2017	31.9	19.3	24.4	126.3
Apr/2017	30.0	17.9	22.8	135.7
May/2017	28.0	16.5	21.2	113.4
Jun/2017	26.7	13.2	19.0	4.7
Jul/2017	26.2	11.1	17.8	0.0
Aug/2017	29.0	14.1	20.9	19.9
Sep/2017	33.3	16.1	24.1	7.0

Table S2. Ingredients and chemical composition of mixed mineral and supplement for grazing bulls in the backgrounding stage during the wet season.

Ingredients (g/kg DM)	Mixed Mineral	Supply level - 0.1% BW
Cottonseed meal	-	369.9
Deffated corn germ meal	-	219.0
Urea	-	45.6
Mineral nucleus	1000	365.5
Chemical composition (g/kg DM)		
Calcium (g/kg DM)	145	130
Phosphorus (g/kg DM)	80	20
Magnesium (g/kg DM)	10	2
Sulfur (g/kg DM)	40	20
Sodium (g/kg DM)	130	30
Crude protein (g/kg DM)	-	32.45
aNDF (g/kg DM)	-	14.48
EE (g/kg DM)	-	
GE (MJ/kg DM)	-	9.7

BW = body weight; DM = dry matter; aNDF= neutral detergent fiber; EE = ether extract; GE =gross energy.

Table S3. Composition of the supplement and the pasture of production system 1. and the feedlot diet of production system 2. in the finishing stage during dry season.

Ingredient (g/kg DM)	Supplement	Pasture[1]	Feedlot diet
Sugarcane bagasse	-	-	15.0
Cottonseed meal	4.7	-	4
Deffated corn germ meal	90.6	-	77.0
Urea	1.5	-	1.3
Mineral nucleus	3.2	-	2.7
Chemical composition[2]			
Dry matter (g/kg as basis)	88.1		
Organic matter (g/kg DM)	87.4	93.4	86.9
Crude protein (g/kg DM)	18.4	5.9	15.7
aNDF (g/kg DM)	17.8	71.7	19.8
EE (g/kg DM)	3.0	3.0	2.6
GE (MJ/kg DM)			

[1]*System 1 – Lenient production system.* Marandu palisadegrass *(Brachiaria brizantha* Hochst ex A. Rich Stapf cv. Marandu) pasture.[2] DM = dry matter; aNDF= neutral detergent fiber; EE = ether extract; GE =gross energy.

Table S4. Characteristics of *Brachiaria* pastures at different production systems in the backgrounding stage during wet season[1].

Item	System 1[2]	System 2[3]
Herbage mass (10^3 kg DM/ha)	4.7 ± 0.97	7.4 ± 1.14
Green leaves (g/kg)	20 ± 3.2	29 ± 10.8
Stem + sheath (g/kg)	17 ± 5.0	33 ± 7.1
Dead material (g/kg)	63 ± 7.3	38 ± 15.9
Forage availability (kg DM/kg BW)	2.5 ± 0.64	2.0 ± 0.50
Leaf availability (kg DM/kg BW)	0.9 ± 0.27	1.2 ± 0.31
Chemical composition[4]		
Dry matter (g/kg as basis)		
Organic matter (g/kg DM)	92.5 ± 0.26	93.4 ± 0.36
Crude protein (g/kg DM)	8.0 ± 0.38	9.0 ± 0.29
aNDF (g/kg DM)	68.8 ± 0.95	65.5 ± 0.58
EE (g/kg DM)	2.9 ± 0.52	3.1 ± 0.34
GE (MJ/kg DM)	16.1 ± 0.38	16.2 ± 0.34

[1]Means from January to May 2017. ± standard deviation.[2] *System 1 – Lenient production system.* [3] *System 2 – Intensive production system.* [4] BW = body weight; DM = dry matter; aNDF= neutral detergent fiber; EE = ether extract; GE =gross energy.

Chapter 3

Este capítulo está regido conforme normas de publicação para ser submetido a revista

“Meat Science”, exceto no número de palavras.

CHAPTER 3 - HOW DOES THE INTENSIFICATION OF THE PRODUCTION SYSTEM INFLUENCE GENE EXPRESSION AND MEAT QUALITY FOR NELLORE AND F1 ANGUS X NELLORE?

Abstract

The objective of this research was to determine the impact of the intensification of the beef production system on the variables of quality of meat and expression of genes related to lipid metabolism in the muscle Longissimus thoracis quality of Nelore and F1 ½ Angus x ½ Nelore, in two production systems [lenient (S1) and intensified (S2)] during the rearing and finishing phases. Thus, we hypothesized that animals submitted to intensive production systems would show better meat quality in both physical properties and chemical properties. In the S1 was practiced in 18.6 ha of Marandu grass pasture, divided in eight paddocks, which were not fertilized and managed with continuous stocking and constant rate of two animals per hectare, during the rearing. Then, 20 Nelore (initial body weight (BWi), 277 ± 13 kg) and 20 F1 Angus × Nelore (BWi, 304 ± 21 kg) were randomly allocated to four plots for each breed. During the finishing phase, the animals remained in the pasture and received supplementation. S2 was practiced in 11.4 ha of Xaraés grass pasture, divided in six paddocks, which were fertilized (150 kg N ha^{-1} $year^{-1}$) and managed with continuous stocking with variable rate of stocking, during rearing. Then, 24 Nelore (BWi, 288 ± 16 kg) and 24 F1 Angus × Nelore (BWi, 325 ± 18 kg) were randomly allocated in three pickets for each breed. During finishing phase, the animals were transferred to feedlot. All statistical procedures were performed using the mixed procedure in SAS. Data were analyzed was performed as a completely randomized design in a 2 x 2 factorial scheme, two production systems (lenient and intensive) and breed (Nellore and F1 Angus x Nellore). Significance was declared at $P \leq 0.05$. An interaction between breed x system was observed for moisture, crude fat, and collagen. An interaction (P = 0.006) between the breed x system x time was observed for pH. The meat of Nellore bulls showed (P = 0.016) lower shear force and sarcomere length compared to F1 Angus bulls (54.82 vs. 60.90 N, and 1.52 vs. 1.58 µm, respectively. The intensive system can improve the meat quality of bulls through increased of tenderness and colour meat. In addition, the crossbreed Angus present the improve the meat quality when yield in intensive system, which supply better feeding condition to these bulls express the genetic potential and increase the fat intramuscular deposition.

Keywords: Beef production, F1 Angus x Nelore, Intensification, *Longissimus thoracis*, meat quality

1. Introducion

The national livestock has evolved significantly in recent decades, this evolution is mainly due to searching for more efficient and sustainable production systems. Thus, the adoption of technologies enables increased productivity indices of production systems, the sum of these actions took there a smaller advance of cattle on the Amazon forest. making it the most sustainable system that way.

In the current context, beef meat industry seeks for products that meet the demands of consumers, however, to meet this market, producers need to adapt their production systems through the intensification of production processes respecting environmental standards and profitability.

The intensification of livestock production is based on increase of farm productive indexes, for instance, the increase in weight gain and carrying capacity of productive areas. Thus, a reduction in the age at slaughter is observed, increasing the offtake rate of the herd. As a positive consequence, the intensification has a beneficial effect on increasing the meat quality.

The intensification of the systems is based on increase in productive indexes of rural properties, among several factors highlight the increase in weight gain and stocking rate of productive areas. Thus, a reduction in the age at slaughter is observed, increasing the rate of enjoyment of the herd. As a positive consequence, the intensification has a beneficial effect on increasing the quality of beef.

The production system has a strong influence on the quality of the meat, animals that are raised exclusively in systems with low technology, so these animals have a higher age at slaughter, lower fat content and less tenderness, when compared to animals finished in feedlot. The quality of animal fat, as already seen, varies according to the breeding system (Carrasco, Ripoll, Panea, Alvarez-Rodrigez and Joy, 2009). However, little is known about the interactions between fatty acids and the expression of some genes related to the rate of muscle and fat deposition. In this way, we can identify which strategies to be adopted to produce meat with quality, in a sustainable and economically viable way to meet the global demand for products of animal origin.

The objective was to evaluate the behavior of two genetic groups under the influence of intensified farming system on the quality of meat and expression of genes related to lipid metabolism in the muscle *Longissimus thoracis* (LT). Thus, we hypothesized that animals submitted to intensive production systems would show better meat quality in both physical properties and chemical properties.

2. Material and Methods

The experiment was conducted at Sao Paulo State University "Julio de Mesquita Filho" (UNESP). in Jaboticabal. SP. Brazil (21º15'22''S and 48º18'08''W; 595 m elevation). The typical climate is humid subtropical mild, dry winters and hot, wet summers. Animals involved in this study were cared for according to the rules of the São Paulo State University Animal Care and Use Committee and the National Council of Animal Experimentation Control, under approval of the protocol number 12703/15.

The experiment lasted from December 2016 to September 2017 divided in two stages: backgrounding (rainy season: December to February and rainy-dry transition: March to May, 164 days) and finishing period (dry season: June to September, 90 days: 15 days for adaptation and 75 experimental days). Treatments consisted of two breeds (Nellore and F1 Nellore x Angus) raised under two production systems (lenient and intensive) as described below.

2.1. System 1 – Lenient production system:

The area was comprised of Marandu palisadegrass (Brachiaria brizantha Hochst ex A. Rich Stapf cv. Marandu) pasture divided into 8 paddocks with area: 2.2 ha (n = 4), 1.9 (n = 2) and 3.0 (n = 2). The pasture was implemented in 2005/2006 and had not been fertilized for at least five years. In this area the continuous stocking grazing method was used with 2 fixed animals per hectare. Twenty Nellore yearling bulls (initial body weight (BW) of 277 ± 13 kg and initial age of 15.2 ± 1.1 months) and 20 F1 Nellore x Angus yearling bulls (initial BW of 304 ± 21 kg and initial age of 15.8 ± 0.44 months) were used. Animals of each breed were randomly allocated into half area (four paddocks for each breed).

During backgrounding, animals received a mineral mix *ad libitum* (Table 1) from December to February; and a mineral supplement (Table S1) offered at 1g/kg BW from March to May. During finishing from June to September, animals remained on the pasture and received supplementation at a rate of 2.0 kg/100 kg BW (Table S2) which was offered twice a day (8h00 e 16h00).

2.2. System 2 – Intensive production system:

The area was comprised of Xaraes palisadegrass (Brachiaria brizantha Hochst ex A. Rich Stapf cv. Xaraes) pasture divided into 6 paddocks with 1.9 ha each. The pasture was implemented in 2001 and has been fertilized since then. In this area the method of continuous stocking with variable stocking rate ("put and take" stocking; (Allen et al.. 2011) was adopted and the grazing height was fixed at 30 cm during the rainy season. Grazing heights were measured weekly at 80 random points per paddock to estimate and manage average paddock height. Maintenance fertilizer was applied to all paddocks at 40 kg P2O5/ha and 40 kg K2O/ha in December. Urea was applied at 150 kg N/ha, split into three applications according to precipitation schedule.

Twenty-four Nellore yearling bulls (initial BW of 288 ± 16 kg and initial age of 15.6 ± 0.65 months) and 24 F1 Nellore x Angus (F1 Angus) yearling bulls (initial BW of 325 ± 18 kg and initial age of 15.8 ± 0.42 months) were used. Animals of each breed were randomly allocated into half area (three paddocks for each breed).

During backgrounding animals received a mineral mix ad libitum (Table S1) from December to February; and a mineral supplement (Table S1) offered at 1g/kg BW from March to May. During finishing from June to September. animals were moved to feedlot and assigned to 12 pens (4 bulls/pen). Pens were 5.0 by 6.0 m. with automatic waterers. The feedlot-finishing diet were the same for all animals and consisted of sugarcane bagasse as roughage (15% on a dry matter. DM. basis) and concentrate (85% on a DM basis, Table S2). Animals were allowed ad libitum access to diet adjusted to approximately 5% refusal of total amount supplied daily. Feed was provided thrice daily (7h00, 14h00 and 18h00).

2.3. Slaughter procedure and muscle sampling

All bulls were transported to a commercial slaughterhouse (Minerva Foods Barretos - São Paulo, Brazil) located 90 km from the experimental area and 01:30 h transport. After a total of 24 hours of feed withdraw (a combination of transport time plus rest period) all bulls were slaughtered following the usual practices of the Brazilian beef industry according to the Brazilian RIISPOA – Regulation of Industrial and Sanitary Inspection of Animal Products. Afterward the carcasses were divided medially from the sternum to spine resulting in two similar halves. After these procedures, muscle samples were taken from the *Longissimus thoracis* muscle of the left half-carcass (12^{th} to 13^{th} rib). The muscle samples were frozen and transported in liquid nitrogen and stored at −80°C for gene expression. Subsequently the half-carcasses were washed identified and stored in a chilling chamber at 4º C for 48 h. After chilling the LT muscle, meat and fat samples were taken between the 9^{th} and the 13^{th} ribs for meat composition, cooking loss, water holding capacity, Warner-Bratzler shear force, sarcomere length, meat colour, and fat colour measurements. The sample was labelled stored in plastic bags vacum and transported to the Animal Science Laboratory at the São Paulo State University (Jaboticabal) and stored at -20 °C until analyzes are performed.

2.4. pH measurement

The pH was measured between the 12th and 13th ribs of the LT muscle at times 0, 3, 6. 12, 24, and 48 hours after slaughter using a Mettler 1140 portable digital pH meter (Mettler Toledo International Inc. Columbus. EUA).

2.5. Meat composition

Meat composition was performed at the Federal University of Lavras. The sample steak was thawed at room temperature ground and used for chemical composition analyses using the FoodScan Meat Analyser TMr (FOSS. Hillerod. Denmark) with near-infrared spectrophotometer technology (analyzes AOAC method: 2007-04).

2.6. Gene expression

Five target genes (SREBP-1c. ACCα. SCD1. LPL. and PPAR-α) and two target gene reference (β-actina e GAPDH) werw used as proposed by Vandesompele et al. (2002). The design of target and reference primers was performed using sequences that are registered and published in the GenBank public data bank a National Center for Biotechnology Information platform (Table 1). Primers were designed using OligoPerfect Designer software (Invitrogen. Karlsruhe. Germany) and synthesized (Invitrogen Carlsbad, CA, USA). Total RNA was extracted muscle tissue. adipose tissue free. The extraction was performed using the RNeasy Lipid Tissue Mini Kit (Qiagen Valencia, CA, USA) according to manufacturer recommendations. carried out at the Laboratory of Biochemistry and Molecular Biology (LBM) of Department of Technology of the Faculty of Agrarian Sciences and Veterinary Sciences of Unesp Jaboticabal. The RNA contamination (260/280 and 260/230) and concentration (ng/ µl) were checked in a NanoDrop 1000 spectrophotometer (Thermo Fisher Scientific. Santa Clara. CA. EUA. 2007). The RNA quality was assessed using Agilent 2100 Bioanalyzer (Agilent. Santa Clara. CA. EUA. 2009) and the Agilent RNA 6000 Nano Chip kit (Agilent Santa Clara. CA. EUA). The mRNA was converted to double stranded cDNA using the Kit SuperScript III

First-Strand Synthesis SuperMix for qRT-PCR (Invitrogen. Carlsbad. CA. EUA) according to the manufacturer's instructions. The equipment used for the qRT-PCR reactions was the 7500 Real-Time PCR (Applied Biosystems. Foster. CA. USA. 2009) with an SYBR green RT-PCR kit from Bio-Rad. The cycling conditions comprised 2 min polymerase activation at 95 °C and 40 cycles at 95 °C for 15 s and 60 °C for 30 s. All PCR efficiencies were above 96%. Relative gene expression of mRNA was analyzed using the CT of the target and reference gene (β-actin and GAPDH). The calibration was determined by ΔΔCT using an internal control (Nellore from system 1). The relative expression of each candidate gene was determined by the fomula $2^{-\Delta\Delta CT}$ method (Schmittgen and Livak. 2008).

2.7. *Cooking loss and water holding capacity*

The steak was thawed at 4 °C for 24 hours. For cooking water loss, each sample was cooked in a pre-heated grill (George Foreman GR 30) at 200 °C until an internal temperature of 72 °C was reached that was monitored using an internal thermocouple (Incoterm 145 mm, Incoterm LTDA, Brazil). After, the sample was removed from the oven and chilling in a refrigerator for 24 hours at a temperature of 4 ºC. Total cooking water loss was calculated as the difference between the weight of the steaks before and after grill-broiling. The water holding capacity (WHC) was calculated by the difference of weight of a meat sample (approximately 2 grams) before and after subjected to the pressure of 10 kg for five minutes.

2.8. *Warner Bratzler shear force (WBSF)*

The shear force analyses were determined according to procedures of (AMSA. 1995). The sample from cooking loss were cut into six homogeneous cylinders 1.27 cm in diameter parallel to the orientation of the muscle fibers. avoiding connective tissue and fat were using a stainless-steel sampler. The cylindrical samples were sheared perpendicularly to the orientation of the muscular fibers using shear force equipment (model CT3 25K – texture analyzer-Brookfield) with Warner-Bratzler blade.

2.9. *Sarcomere length*

The sarcomere length was measured as described by Cross West and Dutson (1981). The sample from Warner-Bratzler shear force was incubated in 0.1 M NaHPO4 +0.2 M Sucrose buffer overnight at 4 ºC. After that. the fibers were removed and subjected to Laser diffusion (Thorlabs; model HNL020R USA). For the calculation, the sarcomere length was used:

$$\mu = \frac{0.6328 \text{ x D x } \sqrt{\left(\frac{T^2}{D}\right) + 1}}{\text{T}}$$

D = Distance (mm) of the sample to the sheet where the image will be drawn (preferably 100 mm); T = Space (mm) between the diffraction bands; laser wavelength (632.8 x 10-3).

2.10. Instrumental meat colour

The colour was evaluated for lightness (L*) redness (a*) and yellowness (b*) based on the CIE (Commission Internationale de I'Eclairage). Five measurements of colour were made for each steak (2.54 cm) were measured after blooming for 30 min using a portable spectrophotometer MiniScan EZ (model 4500L; Hunter Associates Laboratory Inc. Reston, Virginia. USA) using D65 illuminant and 10º standard observer which was calibrated just before use (Cañeque et al., 2004; Pflanzer & de Felício, 2011).

2.11. Instrumental fat colour

The colour was evaluated for lightness (L*) redness (a*) and yellowness (b*) based on the CIE (Commission Internationale de I'Eclairage). Five measurements of colour were measured for each fat sample using a portable spectrophotometer MiniScan EZ (model 4500L; Hunter Associates Laboratory Inc. Reston, Virginia, USA) using D65 illuminant and 10º standard observer which was calibrated just before use.

2.12. Statistical analyses

All statistical procedures were performed using the mixed procedure in SAS (SAS Inst. Inc. Cary. NC. USA). Data were analyzed was performed as a completely randomized design in a 2 x 2 factorial scheme. two production systems (lenient and intensive) and breed (Nellore and F1 Angus x Nellore). The model included the fixed effects of production systems. breed. and their interactions. When significant. means were compared using Fisher's protected LSD Residuals were plotted against predicted values to check model assumptions. Outliers were defined as those values with a Studentized residuals outside ±2.5 range values. No outliers were identified. Significance was declared at $P \leq 0.05$.

The pH value was analyzed as a completely randomized design in a 2x2 factorial scheme with repeated measurements using the MIXED procedure (SAS 9.2 version Inst. Inc. Cary. NC). The treatments and time were considered fixed effects. and animal were considered random effects. The data were tested for the best covariance structure with the lowest Akaike information criterion corrected and then included in the REPEATED statement to complete the analysis. Differences between means were determined using the Fisher's protected least significant difference (LSD) test Significance was deemed at $P < 0.05$.

3. Results

3.1. Gene expression

There were no effect of breed or system and their interaction ($P \geq 0.050$) for ACACα, SCD1, and LPL, (data are showing in tTable 2). Although, there was no interaction effect between breed x system for SREBP-1c was observed, there was breed and system effect ($P = 0.007$ and $P = 0.028$, respectively) on SREBP-1c concentration of, the F1 Angus bulls presented the highest valuewas higher than Nellore bulls ($P = 0.007$), the same was observedas well as, SREBP-1c concentration of animals fromto system 2 was higher than compared to system 1 (2.01 vs. 1.25, and 1.93 vs. 1.33, respectively; $P = 0.028$). In addition, there was a system effect ($P = 0.015$) for PPARα, the bulls finished in system 2 showed higher PPARα concentration compared to system 1 (1.40 vs. 0.97, respectively; $P = 0.015$).

3.2. Chemical composition

An interaction between breed x system was observed for moisture, crude fat, and collagen (Table 3). The F1 Angus bulls finished in system 2 presented ($P = 0.022$; Table 3) the lowest moisture content. On the other hand, the same group, F1 Angus finished in system 2 showed the highest crude fat ($P = 0.027$; Table 3) and collagen content ($P = 0.033$; Table 3) than F1 Angus finished in system 1 and Nellore finished in systems 1 or 2 (2.18, 1.78, 1.89, and 1.92%, and 2.15, 0.81, 1.1 and 1.72%, respectively).

Table 1. Primer sequences used for quantitative RT-PCR analyses

Gene	Target gene (5'-3') Forward (F) and Reverse (R)	Name	R2	Efficiency
SREBP-1c	F: GAGCCACCCTTCAACGAA R: TGTCTTCTATGTCGGTCAGCA	Sterol regulatory element-binding protein-1c	0.999	100.593
ACCα	F: TGAAGAAGCAATGGATGAACC R: TTCAGACACGGAGCCAATAA	Acetyl CoA carboxylase α	0.998	101.32
SCD1	R: TTGTAGGAAGTCTGCCGAGAG R: TTGTCATAAGGGCGGTATCC	Stearoyl-CoA desaturase	0.997	94.776
LPL	F: CTCAGGACTCCCGAAGACAC R: GTTTTGCTGCTGTGGTTGAA	Lipoprotein lipase	0.993	94.257
PPAR-α	F: CAATGGAGATGGTGGACACA R: TTGTAGGAAGTCTGCCGAGAG	Peroxisome proliferator-activated receptor α	0.994	91.665

Table 2. Relative expression of lipogenic gene in the *Longissimus thoracis* muscle from Nellore and F1 Nellore x Angus young bulls at different production systems

	System 1[1]		System 2[2]		SEM	*P-value*		
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	B*S
SREBP	1.632	1.037	2.393	1.465	0.203	0.007	0.028	0.515
ACAC	1.123	1.032	1.21	1.46	0.163	0.674	0.182	0.372
SCD	1.081	1.012	1.349	1.215	0.186	0.672	0.331	0.891
LPL	2.228	1.018	1.171	1.144	0.329	0.166	0.292	0.184
PPARα	0.926	1.014	1.372	1.422	0.133	0.672	0.015	0.905

[1]System 1 – Lenient production system. [2]System 2 – Intensive production system.

Table 3. Chemical composition of meat from Nellore and F1 Nellore x Angus young bulls at different production systems

	System 1[1]		System 2[2]		SEM	P-value		
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	B*S
Moisture	73.52b	73.21b	72.1a	73.22b	0.330	0.187	0.023	0.022
Crude protein	23.07	23.5	23.66	22.92	0.370	0.643	0.996	0.088
Crude fat	0.81c	1.10c	2.15a	1.72b	0.170	0.643	<0.001	0.027
Ash	2.59	2.19	2.09	2.15	0.200	0.344	0.136	0.213
Collagen	1.78b	1.89b	2.18a	1.92b	0.090	0.379	0.014	0.033

[1]System 1 – Lenient production system. [2] System 2 – Intensive production system.

3.3. pH, water holding capacity, cooking loss, WBSF, and sarcomere length

An interaction (P = 0.006) between the breed x system x time was observed for pH (Table 4). At 6 hours the LT of Nellore bulls finished in system 1 present the highest pH compared to the other groups. At 12 hours, the LT of Nellore bulls finished in system 1 showed higher pH than F1 Angus and Nellore finished in system 2, and F1 Angus finished in system 1 had pH like the other treatments. At 24 hours, all groups present similar pH. On the other hand, at 48 hours, the Nellore bulls finished in system 2 presented higher pH value than F1 Angus finished in system 1 or 2, and the Nellore bulls finished in system 1 showed similar pH to the other treatments (5.83, 5.63, 5.55, and 5.7, respectively; Table 4).

There was no interaction (P ≥ 0.050) between breed and system for water holding capacity, cooking loss, shear force or sarcomere length (Table 5). The meat from F1 Angus had lower water holding capacity and higher cooking loss than Nellore bulls (58.31 vs. 61.06%, and 27.03 vs. 25.36%, respectively). In addition, the meat from bulls finished in system 1 presented an increase (P < 0.001) of cooking loss compared to bulls finished in system 2 (27.91 vs. 24.48%, respectively; Table 5).

The meat of Nellore bulls showed (P = 0.016) lower shear force and sarcomere length compared to F1 Angus bulls (54.82 vs. 60.90 N, and 1.52 vs. 1.58 µm, respectively: Table 5). In addition, the meat of bulls finished in system 2 had a decrease of 11.35% on shear force and 4.64% increase in sarcomere length compared to system 1 (54.37 vs. 61.34 N, 1.58 vs. 1.51 µm, respectively; Table 5).

Table 4. pH values during the postmortem of Nellore and F1 Nellore x Angus young bulls at different production systems

Time, h	System 1[1]		System 2[2]		SEM	*P-value*						
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	Time	B*S	B*H	S*H	B*S*H
0 h	7.01	6.95	6.81	7.00	0.086							
6 h	6.31b	6.49a	6.17bc	6.12c	0.060							
12 h	6.18ab	6.29a	6.10b	6.03b	0.066	0.201	0.028	<0.001	0.533	0.176	<0.001	0.006
24 h	5.96	6.07	6.11	5.91	0.072							
48 h	5.63b	5.70ab	5.55b	5.83a	0.063							

[1]System 1 – Lenient production system. [2] System 2 – Intensive production system.

Table 5. Water holding capacity, cooking loss, shear force and sarcomere length of Nellore and F1 Nellore x Angus young bulls at different production systems

	System 1[1]		System 2[2]		SEM	*P - value*		
	F1Angus	Nellore	F1Angus	Nellore		Breed	System	B*S
WHC. %	58.03	62.25	58.58	59.86	0.770	0.006	0.234	0.060
CL. %	28.93	26.89	25.13	23.82	0.660	0.012	<0.001	0.570
WBSF. kgF	64.23	58.44	57.56	51.19	0.250	0.016	0.006	0.900
SL. µm	1.53	1.49	1.62	1.54	0.660	0.009	0.046	0.720

[1]System 1 – Lenient production system. [2] System 2 – Intensive production system. WHC = water holding capacity. CL = Cooking Loss. SF = Shear Force. SL = Sarcomere Length.

3.4. Instrumental meat and fat colour

An interaction between breed x system was observed for parameters L* (P = 0.009) and b* (P = 0.002) of meat (Table 6). The meat of F1 Angus finished in system 2 showed the highest L* and b* parameters value compared to other groups. There was no interaction (P = 0.106) between breed x system for a* meat parameter (Table 6). However, the meat of F1 Angus had higher (P < 0.001) a* value compared to meat of Nellore bulls (16.96 vs. 14.60, respectively). In addition, the bulls finished in system 2 also present higher a* value compared to system 1 (17.30 vs. 14.27, respectively).

There was an interaction (P = 0.024) between breed x system for fat L* (Table 6). Fat from F1 Angus bulls finished in system 2 had higher L* value compared to F1 Angus finished in system 1 and Nellore bulls finished in system 1 or 2 (75.80, 72.60, 73.73, and 73.80, respectively; Table 6). The a* fat parameter was affected (P = 0.001) by system, where the bulls finished in system 2 presented the highest a* value compared to system 1 (Table 6). In addition, there was effect of breed (P = 0.001) for b* fat parameter, the Nellore bulls showed the fat with increase of b* fat parameter compared to F1 Angus group (16.48 vs. 15.09, respectively; Table 6).

Table 6. Meat and fat colour (L*, a* e b*) of Nellore and F1 Nellore x Angus young bulls at different production systems

	System 1[1]		System 2[2]			*P - value*		
	F1Angus	Nellore	F1Angus	Nellore	SEM	Breed	System	B*S
	Meat colour							
L*	33.79b	34.58b	37.61a	34.88b	0.660	0.143	0.002	0.009
a*	15.07	13.46	18.85	15.74	0.480	<0.001	<0.001	0.106
b*	12.07b	12.51b	14.80a	12.16b	0.500	0.023	0.014	0.002
	Fat colour							
L*	72.60b	73.73b	75.8a	73.78b	0.710	0.520	0.020	0.024
a*	7.01	6.81	7.67	9.06	0.460	0.180	0.001	0.077
b*	15.36	16.32	14.82	16.65	0.380	0.001	0.790	0.240

[1]System 1 – Lenient production system. [2] System 2 – Intensive production system.

4. Discussion

Our later hypothesis was that the system 2 (intensive) would improve the meat of bulls due to feed available during background and finished in feedlot, which increase of SREBP-1c and consequently higher fat intramuscular content, compared to system 1 (lenient). However, this hypothesis was partially verified. Pasture from system 2 presented high proportion of leaves (the most digestible portion of sward) during background, and during the finishing phase, the bulls were moved to a feedlot, which provided less energy expense. Animals raised in pasture presented higher energy requirement compared to feedlot system (Valadares Filho et. al., 2016). In this sense the bulls from system 2 presented increase the SREBP-1c, gene can used as markers of adipocyte development (Hocquete et al., 2010), but did not result in higher intramuscular fat. On the other hand, the system 2 showed higher PPARα, gene expressed more in the liver, has an important role in increasing the oxidation of long-chain fatty acid. Possibly the increased of synthesis observed to animals from system 2, could also have provided higher degradation (Teixeira et al., 2017).

In addition, the higher relative expression of SREBP-1c in F1 Angus crossbreed was expected, since that this gene related with synthesis of adipocyte (Hocquete et al., 2010). Teixeira et al. (2017) working with Nellore and Angus bulls found greater intramuscular fat due to higher SREBF1 (sterol regulatory element binding transcription factor 1), which was partially observed in our study. This result does not correspond to the directly increase of lipid content in meat only F1 Angus bulls and in meat of animals finished in system 2, but an interaction between both. In this way, an increase of fat content observed in meat of F1 Angus bulls finished in system 2 can be explained by the fact that these animals had greater hot carcass weight (HCW) compared to F1 Angus finished in system 1 and Nellore from system 1 or 2 (347, 316, 297, and 309 kg, respectively; data not shown), once that the lipid fat contented is positively relate to HCW, where the slaughter body weight has the strongest effect (Lancaster et al., 2014).

The lipid content or also called intramuscular fat content and marbling is an important trait for beef industry because of its positive effect on sensory quality traits in beef and consumer satisfaction (Bazile et. al., 2019). The higher intramuscular fat content in F1Angus bulls was expected, once that Nellore bulls is a medium sized breed and reach the maturity later and begin fat deposition later compared to British breed (Angus), which is a small sized breed and have more marbling (Rodrigues et. al., 2017). Another factor is related with the frame of the breed, in this study, F1 Angus animals exhibited smaller frame size, which featured earlier deposition of fat, contrasting the Nellore animals, which had a medium frame size (5.6 vs. 6.7, respectively, data not shown), supporting the higher intramuscular fat found in meat of ½ Angus from system 2.

In addition, the use of crosses between Bos indicus and Bos taurus breed, is an alternative to improve the intramuscular fat deposition. In this sense, the F1 Angus breed combined with the better feeding condition (system 2), supplied the energy requirements to express the genetic potential for fat intramuscular deposition that was greater than Nellore bulls. On the other hand, system 1 was not enough to express the genetic potential by F1 Angus, that presented similar fat content to Nellore bulls from system 1.

In present study, the average of chemical composition, exception for lipid fat content, is in accordance with previous report to (Reis et al.; (2020) who found concentration of approximately 73% water and 22% protein. On the other hand, the lipid content observed in this experiment, can be considered “low fat” for all treatments, range between 2 to 5% (Scollan et al., 2006). The decreased of moisture content observed in meat of F1 Angus finished in system 2, can be due was consequential to the negative related relationship between lipid and moisture content.

The pH ultimate measuring is important because it is an indicator of quality meat and can directly influence the tenderness, color, and water holding capacity of the meat (Wu 2014). The meat pH decreased for all treatments with the increase of time, at 6 and 12 hours the meat of Nellore bulls finished in system 1 presented higher pH.

A high pH means a greater possibility of bacterial growth compared to adequate pH (below 5.8), as the meat ages, the bacterial load also increases. Most previous studies (Duarte et al., 2011, Castagnino et al., 2018) measured the postmortem pH after 24 hours postmortem (Duarte et al., 2011, Castagnino et al., 2018) as the established time of rigor mortis. Although at 24 hours the meat pH was similar between treatments, the average pH values for all groups were above of adequate pH considered for the meat industry. After 48 hours, the average pH value was adequate, and the F1 Angus breed regardless the system presented the lower meat pH value compared to Nellore from system 2. This could be the effect of Bos indicus breed, which are characterized by more agitated temperament (Sant’Anna et al., 2013), resulting in increased stress susceptibility and thus reducing glycogen reserves at the time of slaughter, which prevents the reduction of pH of meat (Gomez 2019).

During the rigor mortis process, the losses of water are inevitable, that increase as pH u decreases and due to shrinkage of myofibrils (Huff-Lonergan & Lonergan, 2005). In the present study, the meat of Nellore breed presented higher water holding capacity, and the opposite was observed to cooking loss. Although the higher cooking loss found in meat of F1 Angus and the meat of bulls finished in system 2, the average values are within the considered normal (Castagnino et al., 2018, Simoneli et. al., 2015).

An increase in tenderness during postmortem process is observed because of enzymatic degradation of muscle tissue (Cashman et al., 2019) and is one of the most important features related to consumer satisfaction. The F1 Angus bulls regardless the finishing system presented higher values of shear force even showing more adequate pH values compared to Nellore bulls. These results were not expected, due to Bos indicus breeds are being reported to have less tender meat than Bos taurus (Pereira et. al., 2015). Hence that all bulls were slaughter at same time, having same management during postmortem, the F1 Angus breed used in this experiment were half-brothers from the same bull-father, thus probably these results can be related with individual characteristic.

However, in this study differences in meat tenderness of Nellore or F1 Angus breed might not be notice in a sensory analysis, because consumer can only detect a noticeable difference between steaks of about 1 kgf or 9.81 N (Huffman et. al., 1996). On the other hand, the system 2 reduced 11.35% of shear force of meat compared to system 1, although we did not measured, this results can may related with the muscle fiber type, once that the system have influence in muscle fibre characteristics (Vestergaard 2000), thus, the bulls from system 1 were finished in pasture, which promotes greater activity than feedlot system (system 2), and can have present increases the frequency of slow-twitch fibres, which exhibit greater mitochondrial density and can affect the tenderness of meat (Dang et. al., 2020).

According to Bataglia et al. (2019), there is a weak correlation between WBSF and sarcomere length measured by laser. Thus, contrary to what was observed for shear force, the F1 Angus breed presented higher sarcomere length compared to Nellore. Sarcomere length is mainly influenced by carcass cooling temperature during the rigor mortis (Bowling 1997), in this sense both breed (F1 Angus and Nellore) showed higher fat thickness, which was not the cause for the difference between sarcomere length for breed (5.56 vs. 5.23 mm, respectively; data not shown). However, according to Honikel et al. (2004) the average found for sarcomere lengths measured in this study indicates that the samples were not subjected to cold shortening.

On the other hand, higher fat thickness found in bulls finished in system 2, may have prevented excessive shortening at the time of cooling for these animals compared to system 1 (5.87 vs. 4.87 mm; data not showing), since that cattle producers should target at fat thickness at least 5.00 mm to prevent fiber shortening.

Meat colour is among the main aspects related to meat quality, factor affecting purchasing decisions of consumers (Mancini & Hunt, 2005). Our results show that F1 Angus breed finished in system 2 had higher L* value, which can be due to same bulls presented sarcomere numerically higher compared to the other groups, once shorter sarcomere length in meat less lightness is associated with less light scattering (Hughes et al., 2017). Another factor can have affected the meat color parameters is meat ultimate pH (Priolo 2001), thus the F1 Angus presented meat pH numerically lower which can have contributed to higher lightness meat.

The higher a* value observed to F1 Angus breed can be related to pH decline during postmortem. Yi et al. (2018) found beef lighter and redder in sample with a faster pH decline (normal group; 5.40-5.79) and was less in beef with intermediate pH group (5.80 to 6.09) and explained that the pH effect on beef redness is likely to oxygen consumption, once that during slaughter the mitochondrial activity decreases, while oxymyoglobin level increases and beef redness. The meat colour is also determined by quantity and oxidative status of myoglobin (Fruet et. al., 2018), thus the group of bulls finished in system 2 which presented higher a* value and similar pH to group 1, possible these bulls from system 2 could have great percentage of myoglobin in oxymyoglobin form, which increased the a* concentration. In addition, the increased of b* parameter is also relationship with intramuscular fat, which in our study we observed higher intramuscular fat in meat of F1 Angus finished in system 2.

The consumers can reject fat more yellowness and less lightness, once that can associate meat from older animals and less tender meat. In the present study, the higher L* fat parameter found in F1 Angus breed finished in system 2, can be resulted of higher fat thickness found in the same group (Knight, Cosgrove, Death, & Anderson, 1999). The yellow fat is related to carotenoid consumption by animal (Dunne, Monahan, O´Mar, & Moloney, 2009). In this sense, the increased ofd b* fat parameter in F1 Angus, can be explain once that different breed can present b* fat variation (Dunne et. al., 2009).

5. Conclusion

The intensive system can improve the meat quality of bulls through increased of tenderness and colour meat. In addition, the crossbreed Angus bulls show improved meat quality when raised in intensive system, which supply better feeding condition to these bulls express the genetic potential and increase the fat intramuscular deposition.

6. References

AMSA. (1995). Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. In A. M. S. Association (Ed.), *American Meat Science Association* (pp. 48). Savoy, IL: National Livestock and Meat Board.

Aurousseau B, Bauchart D, Calichon E, Micol D, Priolo A. Effect of grass or concentrate feeding systems and rate of growth on triglyceride and phospholipid and their fatty acids in the M. longissimus thoracis of lambs. Meat Sci. 2004;66(3):531-541. doi:10.1016/S0309-1740(03)00156-6

Battaglia, C., Vilella, G. F., Bernardo, A. P., Gomes, C. L., Biase, A. G., Albertini, T. Z., & Pflanzer, S. B. (2019). Comparison of methods for measuring shear force and sarcomere length and their relationship with sensorial tenderness of longissimus muscle in beef. Journal of texture studies, 51(2), 252 - 262. doi: https://doi.org/10.1111/jtxs.12473

Bazile, J., Picard, B., Chambon, C., Valais, A., & Bonnet, M. (2019). Pathways and biomarkers of marbling and carcass fat deposition in bovine revealed by a combination of gel-based and gel-free proteomic analyses. Meat Science, 156, 146-155.

Bowling, R., Dutson, T., Smith, G., & Savell, J. (1987). Effects of cryogenic chilling on beef carcass grade, shrinkage and palatability characteristics. Meat Science, 21(1), 67-72.

Cañeque, V., Pérez, C., Velasco, S., Dı, amp, x, . . . De la Fuente, J. (2004). Carcass and meat quality of light lambs using principal component analysis. Meat Science, 67(4), 595-605. doi: http://dx.doi.org/10.1016/j.meatsci.2004.01.002

Cashman, D., Hall, H., Garmyn, A., O'Quinn, T., Brooks, J., & Miller, M. (2019). Palatability of beef strip loin steaks representing various marbling and maturity levels from grain-fed beef. Meat and Muscle Biology, 3(1).

Castagnino, P. S., Fiorentini, G., Dallantonia, E. E., San Vito, E., Messana, J. D., Torrecilhas, J. A., Sobrinho, A. G. S., & Berchielli, T. T. (2018). Fatty acid profile and carcass traits of feedlot Nellore cattle fed crude glycerin and virginiamycin. Meat Science, 140, 51-58.

Cross, H., West, R., & Dutson, T. (1981). Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. *Meat Science, 5*(4), 261-266.

Dang, D. S., Buhler, J. F., Davis, H. T., Thornton, K. J., Scheffler, T. L., & Matarneh, S. K. (2020). Inhibition of mitochondrial calcium uniporter enhances postmortem proteolysis and tenderness in beef cattle. Meat Science, 162, 108039.

Dervishi E, Serrano C, Joy M, Serrano M, Rodellar C, Calvo JH. Effect of the feeding system on the fatty acid composition, expression of the Delta9-desaturase, Peroxisome Proliferator-Activated Receptor Alpha, Gamma, and Sterol Regulatory Element Binding Protein 1 genes in the semitendinous muscle of light lambs of the Rasa Aragonesa breed. BMC Vet Res. 2010;6:40. Published 2010 Jul 22. doi:10.1186/1746-6148-6-40.

Duarte, M., Paulino, P., Fonseca, M., Diniz, L., Cavali, J., Serão, N., Gomide, L., Reis, S., & Cox, R. B. (2011). Influence of dental carcass maturity on carcass traits and meat quality of Nellore bulls. Meat Science, 88(3), 441-446.

Dunne, P., Monahan, F., O'mara, F., & Moloney, A. (2009). Colour of bovine subcutaneous adipose tissue: A review of contributory factors, associations with carcass and meat quality and its potential utility in authentication of dietary history. Meat Science, 81(1), 28-45.

Fruet, A., De Mello, A., Trombetta, F., Stefanello, F., Speroni, C., De Vargas, D., De Souza, A., Júnior, A. R., Tonetto, C., & Nörnberg, J. (2018). Oxidative stability of beef from steers finished exclusively with concentrate, supplemented, or on legume-grass pasture. Meat Science, 145, 121-126. doi: https://doi.org/10.1016/j.meatsci.2018.06.015

Gómez, J., Netto, A. S., Antonelo, D., Silva, J., Sene, G., Silva, H., Dias, N., Leme, P., & Silva, S. (2019). Effects of immunocastration on the performance and meat quality traits of feedlot-finished Bos indicus (Nellore) cattle. Animal Production Science, 59(1), 183-190.

Honikel, K. (2014). Chemical and physical characteristics of meat| pH measurement.

Huffman, K., Miller, M., Hoover, L., Wu, C., Brittin, H., & Ramsey, C. (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. Journal of animal science, 74(1), 91-97. doi: https://doi.org/10.2527/1996.74191x

International Organization for Standardization. Iso. Animal and vegetable fats and oils – Preparation of methyl esters of fatty acids. Method Iso 5509. Geneve: 1978. P. 1 – 6.

Lancaster, P., Krehbiel, C., & Horn, G. (2014). Ameta-analysis of effects of nutrition and management during the stocker and backgrounding phase on subsequent finishing performance and carcass characteristics. The Professional Animal Scientist, 30(6), 602-612. doi: https://doi.org/10.15232/pas.2014-01330

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. Meat Science, 71(1), 100-121.

Pereira, A., Baldi, F., Sainz, R., Utembergue, B., Chiaia, H., Magnabosco, C., Manicardi, F., Araujo, F., Guedes, C., & Margarido, R. (2015). Growth performance, and carcass and meat quality traits in progeny of Poll Nellore, Angus and Brahman sires under tropical conditions. Animal Production Science, 55(10), 1295-1302.

Pflanzer, S. B., & de Felício, P. E. (2011). Moisture and fat content, marbling level and color of boneless rib cut from Nellore steers varying in maturity and fatness. Meat Science, 87(1), 7-11. doi: http://dx.doi.org/10.1016/j.meatsci.2010.08.009

Priolo, A., Micol, D., & Agabriel, J. (2001). Effects of grass feeding systems on ruminant meat colour and flavour. A review. Animal Research, 50(3), 185-200. doi: https://doi.org/10.1051/animres:2001125

Reis, V. A., Reis, R. A., de Araújo, T. L. D. R., Lage, J. F., Teixeira, P. D., Gionbelli, T. R. S., Lanna, D. P., & Ladeira, M. M. (2020). Performance, beef quality and expression of lipogenic genes in young bulls fed low-fat dried distillers grains. Meat Science, 160, 107962.

Rodrigues, R. T. d. S., Chizzotti, M. L., Vital, C. E., Baracat-Pereira, M. C., Barros, E., Busato, K. C., Gomes, R. A., Ladeira, M. M., & Martins, T. d. S. (2017). Differences in beef quality between Angus (Bos taurus taurus) and Nellore (Bos taurus indicus) cattle through a proteomic and phosphoproteomic approach. PloS one, 12(1), e0170294.

Scerra M, Caparra P, Foti F, Galofaro V, Sinatra MC, Scerra V. Influence of ewe feeding systems on fatty acid composition of suckling lambs. Meat Sci. 2007;76(3):390-394. doi:10.1016/j.meatsci.2006.04.033

Schmittgen, T.D., Livak, K.J., 2008. Analyzing real-time PCR data by the comparative C T method. Nat. Protoc. 3, 1101

Scollan, N., Hocquette, J.-F., Nuernberg, K., Dannenberger, D., Richardson, I., & Moloney, A. (2006). Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. Meat Science, 74(1), 17-33.

Simonetti, L. R., Lage, J. F., Berchielli, T. T., Oliveira, E. A., Dallantonia, E. E., & Delevatti, L. M. (2015). Aging time of five muscles from carcass of Nellore young bulls. Acta Scientiarum. Animal Sciences, 37(4), 397-404.

Vandesompele J, De Preter K, Pattyn F, Poppe B, Van Roy N, et al. (2002) Accurate normalization of real-time quantitative RT-PCR data by geometric averaging of multiple internal control genes. Genome biology 3: research0034. 0031.

Vestergaard, M., Therkildsen, M., Henckel, P., Jensen, L., Andersen, H., & Sejrsen, K. (2000). Influence of feeding intensity, grazing and finishing feeding on meat and eating quality of young bulls and the relationship between muscle fibre characteristics, fibre fragmentation and meat tenderness. Meat Science, 54(2), 187-195. doi: https://doi.org/10.1016/S0309-1740(99)00098-4.

SUPPLEMENTARY MATERIAL

Table S1. Ingredients and chemical composition of mixed mineral and supplement for grazing bulls in the backgrounding stage during the wet season.

Ingredients (g/kg DM)	Mixed Mineral	Supply level - 0.1% BW
Cottonseed meal	-	369.9
Deffated corn germ meal	-	219.0
Urea	-	45.6
Mineral nucleus	1000	365.5
Chemical composition (g/kg DM)		
Calcium (g/kg DM)	145	130
Phosphorus (g/kg DM)	80	20
Magnesium (g/kg DM)	10	2
Sulfur (g/kg DM)	40	20
Sodium (g/kg DM)	130	30
Crude protein (g/kg DM)	-	32.45
aNDF (g/kg DM)	-	14.48
EE (g/kg DM)	-	
GE (MJ/kg DM)	-	9.7

BW = body weight; DM = dry matter; aNDF= neutral detergent fiber; EE = ether extract; GE =gross energy.

Table S2. Composition of the supplement and the pasture of production system 1. and the feedlot diet of production system 2. in the finishing stage during dry season.

Ingredient (g/kg DM)	Supplement	Pasture[1]	Feedlot diet
Sugarcane bagasse	-	-	15.0
Cottonseed meal	4.7	-	4
Deffated corn germ meal	90.6	-	77.0
Urea	1.5	-	1.3
Mineral nucleus	3.2	-	2.7
Chemical composition[2]			
Dry matter (g/kg as basis)	88.1		
Organic matter (g/kg DM)	87.4	93.4	86.9
Crude protein (g/kg DM)	18.4	5.9	15.7
aNDF (g/kg DM)	17.8	71.7	19.8
EE (g/kg DM)	3.0	3.0	2.6
GE (MJ/kg DM)			

[1]*System 1 – Lenient production system.* Marandu palisadegrass *(Brachiaria brizantha* Hochst ex A. Rich Stapf cv. Marandu) pasture.[2] DM = dry matter; aNDF= neutral detergent fiber; EE = ether extract; GE =gross energy.

Table S3. Characteristics of *Brachiaria* pastures at different production systems in the backgrounding stage during wet season[1].

Item	System 1[2]	System 2[3]
Herbage mass (10^3 kg DM/ha)	4.7 ± 0.97	7.4 ± 1.14
Green leaves (g/kg)	20 ± 3.2	29 ± 10.8
Stem + sheath (g/kg)	17 ± 5.0	33 ± 7.1
Dead material (g/kg)	63 ± 7.3	38 ± 15.9
Forage availability (kg DM/kg BW)	2.5 ± 0.64	2.0 ± 0.50
Leaf availability (kg DM/kg BW)	0.9 ± 0.27	1.2 ± 0.31
Chemical composition[4]		
Dry matter (g/kg as basis)		
Organic matter (g/kg DM)	92.5 ± 0.26	93.4 ± 0.36
Crude protein (g/kg DM)	8.0 ± 0.38	9.0 ± 0.29
aNDF (g/kg DM)	68.8 ± 0.95	65.5 ± 0.58
EE (g/kg DM)	2.9 ± 0.52	3.1 ± 0.34
GE (MJ/kg DM)	16.1 ± 0.38	16.2 ± 0.34

[1]Means from January to May 2017. ± standard deviation.[2] *System 1 – Lenient production system.* [3] *System 2 – Intensive production system.* [4] BW = body weight; DM = dry matter; aNDF = neutral detergent fiber; EE = ether extract; GE = gross energy.

IMPLICAÇÕES PRÁTICAS

A produção de bovinos de corte no Brasil é baseada em sistemas pastoris e conhecendo as limitações do ecossistema pastoril é permitido estabelecer metas e estratégias para intensificar a produtividade da pecuária. Duas formas de intensificação do sistema de produção de bovinos de corte são: o cruzamento com raças especializadas na produção de carne, onde usamos matrizes da raça Nelore com touros Aberdeen Angus (em sua maioria) e a adubação nitrogenada do dossel.

Devemos ficar atentos na hora de adotar a estratégia de intensificação com o uso de “cruzamento industrial”. Nos últimos anos foi observada uma rápida expansão do uso de genética Angus nos rebanhos comerciais do País; em 2019 a venda de sêmen da raça Angus foi de 5,8 milhões de doses, 18% a mais que 2018. Diante desse cenário eu lhes pergunto: Estamos prontos para produzir esses bovinos? Como sabemos os F1 (½ Nelore ½ Angus) possuem uma maior exigência nutricional, sendo que quando criados em sistemas extensivos é observado menor desenvolvimento corporal, deste modo seu maior potencial genético não é expresso. Já os bovinos Nelore, os quais tem menor exigência nutricional, não são tão prejudicados em sistemas extensivos.

Esse efeito foi observado neste trabalho, sendo que os bovinos F1 (½ Nelore ½ Angus) ao serem expostos a condições favoráveis de manejo (adubação e ajuste de lotação) tiveram um GMD de 1,22 kg/dia, contra um GMD de 0,97 kg/dia em condições desfavoráveis (sem adubação e ajuste de lotação), diferença de 0,25 kg/dia. Já os bovinos Nelore apresentaram um GMD de 0,95 kg/dia contra 0,88 kg/dia, para pastos adubados e não adubados, respectivamente, resultando em uma diferença de 0,07 kg/dia.

Isso comprova/demonstra o efeito da menor exigência nutricional. Diante desses fatos e antes de iniciar um sistema de produção intensivo, com o uso de cruzamento industrial, primeiramente devemos começar a melhorar a nutrição dos mesmos, sendo principalmente a qualidade da forragem (consumo de forragem + valor nutricional) e garantir o status sanitário sadio aos bovinos.

Antes de iniciar um projeto de intensificação via adubação, uma ressalva, é necessário ter um planejamento financeiro bem estruturado, pois estima-se que a cada R$1,00 investido em adubo, é preciso investir de R$5,00 a R$6,00 em animais, para colher o excedente de produção de forragem.

Assim o uso das mais diversas tecnologias deve estar sempre acompanhado de um bom planejamento, sempre perguntando a si mesmo:

Onde estou?

Onde quero estar?

Como chegar lá?

Ao responder essas perguntas, antes de qualquer implantação de sistemas intensivos de produção (especialmente os que utilizam cruzamento industrial e adubação), evitamos uma serie de erros, tornando o sistema mais eficiente e rentável.

APÊNDICE

Apêndice 1: Certificado de aprovação dos protocolos experimentais pela comissão de ética no uso de animais, FCAV, UNESP, Câmpus de Jaboticabal, SP.

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

CEUA – COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o Protocolo nº 12703/15 do trabalho de pesquisa intitulado **"Management strategies to reduce environmental impacts of beef cattle production systems"**, sob a responsabilidade do Prof. Dr. Ricardo Andrade Reis está de acordo com os Princípios Éticos na Experimentação Animal adotado pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA) e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), em reunião ordinária de 07 de agosto de 2015.

Jaboticabal, 07 de agosto de 2015.

Prof.ª Dr.ª Paola Castro Moraes
Coordenadora – CEUA

Faculdade de Ciências Agrárias e Veterinárias
Via de Acesso Prof. Paulo Donato Castellane, s/n CEP 14884-900 - Jaboticabal - SP - Brasil
Tel. 16 3209 2600 - fax 16 3202 4275 www.fcav.unesp.br

Apêndice 2.1: Características de fertilidade do solo na área experimental do setor de Forragicultura e Pastagens da FCAV/UNESP, Câmpus de Jaboticabal, SP, sendo a area utilizada no Sistema 1.

Propriedade: Fazenda FCAV											
Município: Jaboticabal						Estado: SP					
Entrada: 10-08-2016						Saída: 29-08-2016					
Amostra nº		P resina	MO	pH $CaCl_2$	K^+	Ca^{2+}	Mg^{2+}	H+Al	SB	CTC	V
Seção	Interessado										
		mg/dm^3	g/dm^3		---------------------- $mmol_c/dm^3$ ----------------------						%
0560	01-B1	4	22	4,4	1,3	6	5	36	12	48	25
0561	02-B2	4	21	4,1	1,0	7	5	42	13	55	24
0562	03-B3	6	23	4,3	1,1	8	6	34	15	49	31
0563	04-B4	6	24	4,2	1,3	8	4	40	13	53	25
0564	05-B5	4	22	4,6	0,8	13	7	31	21	52	40
0565	06-B6	6	27	5,1	0,9	24	10	26	35	61	57
0566	07-B7	6	30	5,1	0,9	20	9	28	30	58	52
0567	08-B8	4	24	5,0	0,8	19	9	28	29	57	51

Apêndice 2.2: Características de fertilidade do solo na área experimental do setor de Forragicultura e Pastagens da FCAV/UNESP, Câmpus de Jaboticabal, SP, sendo a area utilizada no Sistema 2.

Propriedade: Fazenda FCAV											
Município: Jaboticabal						Estado: SP					
Entrada: 10-08-2016						Saída: 29-08-2016					
Amostra nº		P resina	MO	pH $CaCl_2$	K^+	Ca^{2+}	Mg^{2+}	H+Al	SB	CTC	V
Seção	Interessado										
		mg/dm^3	g/dm^3		---------------------- $mmol_c/dm^3$ ----------------------						%
0591	32-T1	7	27	4,7	1,0	17	9	38	27	65	42
0592	33-T2	6	26	4,4	1,5	12	6	50	20	70	28
0593	34-T3	6	22	4,5	0,7	12	6	42	19	61	31
0594	35-T4	7	23	4,6	2,9	13	6	38	22	60	37
0595	36-T5	8	24	4,8	1,9	17	9	34	28	62	45
0596	37-T6	7	26	5,0	1,5	17	10	28	29	57	50
0597	38-T7	10	24	4,6	1,6	13	7	38	22	60	36
0598	39-T8	12	26	4,9	1,4	18	10	29	29	58	50