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IDADES DE DESCARTE DA VACA: EFICIÊNCIA BIOECONÔMICA E RESILIÊNCIA DO SISTEMA DE CRIA

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Orientador: Júlio Otávio Jardim Barcellos
Coorientador: Gabriel Ribas Pereira

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Idades de descarte da vaca: eficiência bioeconômica e resiliência do sistema de cria[1]

Resumo

Para expandir os conhecimentos em relação à idade ideal de descarte da vaca no rebanho de cria, foram realizados dois estudos com modelos de simulação dinâmicos e determinísticos. O primeiro comparou a eficiência bioeconômica de sistemas de cria com diferentes idades máxima de descarte da vaca, denominado de tempo de permanência (TP). Foram construídos dez cenários com vacas de descarte dos quatro (TP4) aos treze anos (TP13). A oferta de energia metabolizável (EM) considerou o suprimento total das exigências dos animais (NRC, 2000, 2016). A relação entre a produção de peso vivo (PV) total e a EM consumida determinou a eficiência biológica dos sistemas (EBio). A eficiência econômica foi representada pela relação da margem bruta (MB) e a área de produção (EEA) para os sistemas; e pela relação entre a MB e as vacas de cria (EEV) para avaliar a eficiência das vacas. Uma regressão linear simples entre a EBio, a EEA e a EEV determinou a eficiência bioeconômica. O TP4 apresentou os melhores resultados para EBio e EEA, porém a EEV foi melhor no TP13. A eficiência bioeconômica foi melhor no TP6, o que demonstra que um rebanho de cria expressa sua melhor eficiência quando o as vacas são descartadas ao atingem a idade adulta. O segundo estudo comparou o efeito de diferentes idades de descarte da vaca e de três níveis de energia na resiliência de sistemas de cria estáveis. No primeiro ano (Ano 1), considerou-se a disponibilidade de energia baixa (50%, B), média (75%, M) e alta (100%, A) 60 dias antes e depois do início da parição (120 dias) (NRC, 2000, 2016), para os rebanhos de idade máxima de descarte da vaca (tempo de permanência, TP) aos quatro (TP4B, TP4M, TP4A), seis (TP6B, TP6M, TP6A) e onze anos (TP11B, TP11M, T11A). A partir do Ano 2 a disponibilidade energética para todos os sistemas foi alta. A relação entre a venda de kg dos animais (touros, vacas e bezerros) e a área útil para a produção determinou a produtividade do sistema. A resiliência foi considerada quando os sistemas atingiram 95% da produtividade padrão (anterior à redução da disponibilidade energética). Os resultados para atingir a resiliência foram melhores nos TP6 e TP11 que necessitaram de dois anos, enquanto para os TP4 foi necessário três anos. Entretanto, o descarte de vacas mais velhas levou ao maior aumento de kg de vaca na proporção de produto vendido. Portanto, rebanhos estáveis manifestam melhores EBio e EEA quanto mais jovens forem as vacas de descarte, mas apresentam maior vulnerabilidade frente às intempéries climáticas que possam prejudicar os índices produtivos, o que retarda a resiliência. Por outro lado, o maior tempo de permanência da vaca possibilita a melhor EEV e resiliência mais rápida, porém há maior aumento da participação de kg de vaca vendidos pelo sistema em situações de desafios alimentares. Assim, o descarte de vacas próximo aos cinco anos e meio (TP6) proporciona o equilíbrio entre os indicadores de eficiência, apresenta menor tempo à resiliência e sofre alterações intermediárias na estrutura do produto vendido.

Palavras-chave: estrutura de rebanho; longevidade da vaca; resistência; restrição alimentar em vacas; reversibilidade; stayability.

[1]Tese de Doutorado em Zootecnia - Produção Animal, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil. (92 p.) março, 2020.

Cow culling ages: bioeconomic efficiency and resilience of the cow-calf system[1]

Abstract

To expand the knowledge regarding the ideal age for cow culling in the cow-calf herd, two studies were carried out with dynamic and deterministic simulation models. The first compared the bioeconomic efficiency of cow-calf systems with different maximum age for cow culling, called lifetime (LT). Ten scenarios were built with cows culling from four (LT4) to thirteen years (LT13). The supply of metabolizable energy (ME) considered the total supply of the animals' requirements (NRC, 2000, 2016). The relation between total live weight (LW) production and the consumed ME determined the biological efficiency of the systems (BioE). Economic efficiency was represented by the ratio of gross margin (GM) and production area (EEA) for the systems; and the relation between GM and cows (EEC) to assess the efficiency of cows. A simple linear regression between BioE, EEA and EEC determined bioeconomic efficiency. The LT4 presented the best results for BioE and EEA, however EEC was better in LT13. Bioeconomic efficiency was better in LT6, which shows that a cow-calf herd expresses its best efficiency when the cows reach adult age. The second study compared the effect of different ages of cow culling and of three energy levels on the resilience of stable cow-calf systems. In the first year (Year 1), was considered availability of low (50%, L), medium (75%, M) and high (100%, H) energy 60 days before and after the start of the birth (120 days) (NRC, 2000, 2016), for herds of maximum age for cow culling (lifetime, LT) at four (LT4L, LT4M, LT4H), six (LT6L, LT6M, LT6H) and eleven years (LT11L, LT11M, LT11H). From Year 2, energy availability for all systems was high. The relation between the sale of kg of animals (bulls, cows and calves) and the area used for production determined the productivity of the system. Resilience was considered when the systems reached 95% of standard productivity (prior to the reduction in energy availability). The results to achieve resilience were better in LT6 and LT11, which required two years, while for LT4 was necessary three years. However, the older cows culling led to a greater increase in kg of cow in the proportion of product sold. Therefore, stable herds show better BioE and EEA the younger the cows are culling, but they are more vulnerable to weather conditions that can damage production rates, which slows resilience. In contrast, the longer lifetime the cow allows better EEC and faster resilience, but there is a greater increase in the kg of cow sold by the system in situations of food challenges. Thus, the disposal of cows close to five and a half years (LT6) provides a balance between efficiency indicators, presents less time to resilience and undergoes intermediate changes in the structure of the product sold.

Keywords: cow longevity; cows feed restriction; herd structure; resistance; reversibility; stayability.

[1]Doctoral thesis in Animal Science, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (92 p.) March, 2020.

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Lista de Abreviaturas

A - alta energia

ADG - average daily gain

A.I. - artificial insemination

AME - available metabolizable energy

AU - animal unit

B - baixa energia

BioE - biological efficiency of the systems

$BioEC_c$ - biological efficiency of the cow

c - age group of the cow

DAR - daily accumulation rate

DMI_d - daily dry matter intake capacity

EBio - eficiência biológica dos sistemas

EEA - eficiência econômica por área de produção

EEC - eficiência econômica por vaca de cria

EHF - efficiency of harvest forage used by the animals

EM - energia metabolizável

EM_m – energia metabolizável de manutenção

FM - forage mass

GM - gross margin

H – high energy

Ha – hectare

Hd – head

I.A. – inseminação artificial

L – low energy

LT – lifetime cow in the herd

LW - live weight

$LWCWC_c$ - live weight of the cow's weaned calf

M - média energia

MB – margem bruta

ME - metabolizable energy

MEC - total metabolizable energy consumed by the system

$MECC_c$ - total metabolizable energy consumed by the cow

MEF - metabolizable energy of forages

ME_g - metabolizable energy of growth

ME_l - metabolizable energy of lactation

ME_m - metabolizable energy of maintenance

ME_y - metabolizable energy of pregnancy

MLT - maximum Lifetime

MEC_d - metabolizable energy consumed per day

PGF2a - prostaglandin

PT – produção total

PV – peso vivo

RE – restrição energética

TC - total cost

TDN - total digestible nutrients

TLWS - total live weight sold

TP – total production

TPM – tempo de permanência máximo

TR - total revenue

WGC_c - weight gain of the cow

Sumário

CAPÍTULO I

1. Introdução

A eficiência bioeconômica dos sistemas de produção é essencial para a permanência das atividades agropecuárias. Em sistemas de cria, ela é dependente da estrutura de rebanho, uma vez que sua configuração pode melhorar o aproveitamento dos recursos alimentares e maximizar a produção. Além disso, o tempo de retorno à resiliência de sistemas de cria - capacidade de retornar ao seu ao equilíbrio após sofrer distúrbios - também está associado à estrutura de rebanho.

Nesse contexto, a eficiência biológica da vaca (Baker & Carter, 1976) e bioeconômica dos sistemas de cria foram investigadas por diversos estudos ao considerar a transformação da energia metabolizável (EM) em bezerros desmamados e vacas de descarte (Lamb; Tess; Robison, 1992; Nasca et al., 2015; Walmsley et al., 2016); além do tempo de retorno à resiliência em sistemas de cria (Viet et al., 2013). No entanto, essas pesquisas não consideraram as diferentes estruturas de rebanho que podem distorcer esses resultados.

Em sistemas de produção de ruminantes, a maior parcela da EM consumida é destinada à manutenção (EM_m), que é a porção improdutiva da EM e chega a cerca de 50% da exigência total do rebanho de cria apenas para a manutenção das vacas (Ferrel & Jenkins, 1985). Isso porque há maior necessidade de energia para essa função em animais mais velhos, até que atinjam seu peso maduro (NRC, 2000), o que compromete a eficiência em transformar a energia consumida em produto. Essa variação na eficiência da EM associada à idade do animal torna este indicador relevante para a comparação da eficiência dos sistemas de produção e para o impacto econômico da variação da idade de descarte das vacas.

Tão importante quanto considerar o impacto causado pelo alto consumo da EM_m é o planejamento para disponibilizá-la ao rebanho de cria. No entanto, fatores que não estão sob o controle do gestor rural, como intempéries climáticas, podem causar déficit energético no sistema pela estacionalidade forrageira. Caso isso aconteça no pré-parto, pode levar a reduções nas taxas de prenhez, principalmente em vacas mais jovens (Richards; Spitzer; Warner, 1986; Goehring; Corah; Higgins, 1989) e de mortalidade de bezerros, enquanto no pós-parto pode reduzir as taxas de desmame e de vacas de descarte. Essas variações induzem o rebanho a reter mais novilhas, o que o torna mais jovem e com maior vulnerabilidade a novas intempéries climáticas.

O menor tempo de permanência da vaca no rebanho de cria exige uma alta renovação de novilhas, o que possibilita o melhor uso da energia para o crescimento (Brethour & Jaeger, 1989; Seidel & Whittier, 2015). Além disso, vacas de dois anos podem consumir até 19% menos EM_m do que vacas adultas (NRC, 2000). Por outro lado, sistemas mais jovens apresentam maior exigência por alimentos de melhor qualidade e, portanto, são mais vulneráveis a intempéries climáticas que influenciam diretamente na produção forrageira. Portanto, a estrutura de rebanho com alta proporção de animais jovens pode dificultar a recuperação do sistema após eventos negativos na produção.

Por outro lado, o maior tempo de permanência da vaca permite o aumento da margem econômica do sistema, pelo desmame de bezerros mais pesados e redução da reposição de novilhas (Roberts; Petersen; Funston, 2015). Além disso, esses sistemas são menos vulneráveis às indisponibilidades alimentares, o que pode antecipar a resiliência em relação aos sistemas mais jovens. Assim, as avaliações das estratégias para aumentar a produtividade e o retorno econômico da empresa, bem como menor tempo à resiliência, passam pela compreensão dessas relações, especialmente no âmbito de sistemas (Nozières; Moulin; Dedieu, 2011).

A partir disso, supõem-se que sistemas com menor tempo de permanência da vaca apresentam melhor eficiência biológica, porém, maior tempo à resiliência. Por outro lado, acredita-se que sistemas de vacas de descarte mais velhas possuem melhor eficiência econômica, além de menor tempo de retorno à resiliência.

Porém, essas hipóteses devem ser validadas por meio de análises que considerem diferentes estruturas de rebanho e suas eficiências física e econômica para identificar o tempo de permanência ideal da vaca no rebanho. Entretanto, o custo, a complexidade e o nível de controle necessário para uma análise confiável desses sistemas torna a comparação inviável por experimentação. Assim, esse estudo utiliza modelos de simulação para analisar a interação entre esses fatores dos sistemas de produção a baixo custo e de forma rápida (Naazie; Makarechian; Hudson, 1999).

2. Revisão bibliográfica

A presente revisão bibliográfica aborda os elementos essenciais de sistemas de cria de bovinos de corte, tempo de permanência da vaca no rebanho até seu descarte, resiliência de sistemas de cria e modelos de simulação para a discussão desse estudo.

2.1 Sistemas de cria de bovinos de corte

Sistemas são formados por conjuntos de fatores que trabalham coletivamente, como o mesmo objetivo (Forrester, 1968) e respondem de forma conjunta a estímulos externos. Os sistemas de bovinos de corte são caracterizados por sua complexidade (Barcellos et al., 2013), pois é necessário integrar e gerenciar uma série de fatores de produção, como: ambientais, sócio-regionais, de capital, de recursos humanos, do perfil do empresário, de mercado e de logística. Após o entendimento e a gestão de todos esses fatores em sinergia, com a visão do todo, é que se torna possível o desenvolvimento de um sistema competente e sustentável (Barcellos et al., 2002).

Entre as fases do sistema de produção de pecuária de corte, a cria é considerada a mais complexa e aquela que oferece o suporte para a atividade, pois dá início à cadeia produtiva da carne (Rovira, 2006). A fase de cria compreende a reprodução, o crescimento e o desmame dos bezerros, que pode acontecer entre seis e doze meses de idade. Os bezerros são comercializados para a fase de recria e posterior engorda; já as bezerras, que não são mantidas no sistema para reprodução, são vendidas como fêmeas de reposição. Matrizes descartadas da reprodução e touros improdutivos são normalmente vendidos para a terminação (Valle; Andreotti; Thiago,1998).

A cria tem por objetivo produzir um bezerro por vaca acasalada ao ano e sua eficiência é avaliada pela relação entre quilos de bezerro desmamados e o número de vacas submetidas à reprodução no ano anterior (Baker & Carter, 1976). No entanto, esse objetivo é complexo, pois essa é a fase mais exigente no que diz respeito ao conhecimento e administração entre as etapas de produção (Rovira, 2006). O sucesso dessa etapa depende da fertilidade do rebanho, que necessita de adequada sanidade, nutrição, fertilidade individual da vaca, fertilidade do touro, entre outros (Oliveira et al., 2006).

A alta exigência da cria é consequência da grande necessidade de energia para a manutenção das vacas em relação ao seu produto (Simeone & Beretta, 2002). Isto porque cerca de 50% da energia que um sistema consome para produzir carne é destinado apenas para a manutenção das vacas (Ferrell & Jenkins, 1985). Esse consumo energético explica a maior eficiência do abate de primíparas após o desmame do primeiro bezerro, pois minimiza a necessidade de energia que seria utilizada para o crescimento das matrizes (Bourdon & Brinks, 1987; Sell et al., 1988; Brethour & Jaeger, 1989). Portanto, rebanhos com maior número de vacas jovens podem ser mais eficientes.

2.1.1 Estrutura do rebanho de cria

A estrutura de rebanho apresenta a distribuição, numérica e em percentual, de cada categoria animal dentro do sistema de produção. A alteração de indicadores, como idade ao primeiro acasalamento, taxa de natalidade, taxa de reposição de novilhas e taxa de descarte de vacas, além da mortalidade, modificam essa estrutura e as características de produção do sistema de cria.

O aumento da participação de vacas de cria na estrutura de um rebanho é notado à medida que a idade ao primeiro acasalamento é reduzida e a natalidade aumenta. Em estudo que a idade ao primeiro acasalamento foi reduzida de 36 para 24 e 14 meses com 50% de natalidade, houve o aumento de vacas de cria em 25, 28 e 33%, respectivamente (Beretta; Lobato; Mielitz Netto, 2001). Com a elevação da natalidade para 90%, observaram uma participação de 39, 42 e 45%, respectivamente. Esse aumento de matrizes causa um incremento nos níveis de exigências nutricionais, podendo sofrer alterações ao longo do ano e melhorar a produtividade do sistema (Barcellos et al., 2013).

O aumento da taxa de reposição de novilhas leva à redução da idade média das vacas do sistema. Ao analisar três cenários com 14, 18 e 22% de reposição de novilhas, foi observada a redução da idade média das vacas do rebanho ao constatar que metade das novilhas de reposição haviam sido retiradas do sistema aos oito, cinco e quatro anos de idade, respectivamente (Roberts; Petersen; Funston, 2015). Além disso, os autores relataram que 28% das novilhas que ingressaram no sistema de menor reposição permaneceram até os 12 anos, ao passo que no sistema intermediário, apenas 15% permaneceram até essa idade.

Sistemas que possuem altos índices de prenhez e utilizam elevadas taxas de reposição de novilhas são sistemas de elevados índices de renovação e podem ter de retirar vacas prenhas do rebanho para mantê-lo estável. Por exemplo, para repor 25% de novilhas com uma taxa de prenhez de 85%, é preciso que 10% de vacas prenhas sejam retiradas do sistema, pois apenas 15% não produzirão um bezerro. Para a decisão de quais vacas devem ser retiradas do rebanho são utilizados critérios como problemas físicos, lesões, doenças, baixo padrão genético ou idade (Arthur et al., 1993; Bascom & Young, 1998; USDA, 2010). Quando a idade, geralmente pela condição da dentição, é o critério escolhido, as vacas mais velhas são retiradas do sistema. A partir disso, o maior percentual de vacas jovens no rebanho incorre no incremento da demanda por alimentos de maior qualidade (Barcellos et al., 2013). Por outro lado, o sistema se tornará mais eficiente por apresentar maior proporção de animais em crescimento, o que reduz a necessidade energética de manutenção por unidade de quilograma de peso vivo produzido (Taylor et al., 1985; Bourdon & Brinks, 1987; Ereth et al., 2000; Seidel & Whittier, 2015).

2.1.2 Eficiência bioeconômica de sistemas de cria

O conceito de eficiência pode ser facilmente confundido com produtividade devido à diferença sutil que os define, por eficiência ser derivada da própria produtividade. Enquanto a produtividade é a relação entre o produto e o insumo para gerá-lo, a eficiência é a relação entre o que foi produzido, a partir de determinado insumo, e o que poderia ter sido produzido. Isto é, a eficiência se refere ao ponto máximo produtivo que uma atividade pode chegar em detrimento de certo insumo (Coelli et al., 2005).

Estudos sobre os fatores que influenciam a eficiência da utilização de alimentos pelos animais foram realizados por Kleiber em 1936. Mais tarde, o início da década de 70 foi marcado por diversos autores que buscavam discutir a eficiência biológica e econômica da bovinocultura (Dickerson, 1970; Harris, 1970; Gregory, 1972). Posteriormente, Baker & Carter (1976) propuseram uma forma de determinar a eficiência biológica individual de uma vaca de cria, através da divisão da produtividade total por 100 kg de vaca acasalada, corroborando com Robertson (1973), que afirmou que a eficiência biológica deve ser considerada em função de unidades produtoras.

Entretanto, ao final da década de 70, Fitzhugh (1978) sugeriu que a eficiência da produção deve ser avaliada em nível de sistema e não do animal. No mesmo ano, Dickerson (1978) definiu o conceito de eficiência bioeconômica do sistema ao agregar diferentes componentes do ciclo de produção, como pastagens, clima e a genética animal. Nos anos 80, ao publicarem seus resultados de que a fase de cria consome mais de dois terços da energia exigida para a produção de carne, Ferrel & Jenkins (1985), influenciaram muitos estudos a utilizar a energia alimentar como um *input* necessário para medir a eficiência biológica do sistema de cria.

Além disso, o estudo da eficiência biológica concedeu um maior propósito para as investigações da eficiência econômica desses sistemas. Tornara-se necessário descobrir se a máxima produção zootécnica dos animais era compensada monetariamente. A partir disso, trabalhos de eficiência bioeconômica foram desenvolvidos, baseados na margem financeira do sistema (Lamb; Tess; Robison, 1992; Pang et al., 1999a). A eficiência econômica também foi abordada de diversas formas mas, ao contrário da biológica, o recurso que melhor a determina é específico em cada situação (vaca de cria ou área útil de produção).

Desde o início dos anos 90, a eficiência econômica é analisada pela relação entre o resultado econômico e o recurso mais relevante para o sistema. No caso dos sistemas de cria, a margem operacional sobre os kg de novilhos vendidos foi utilizada para demonstrar a eficiência econômica (Lamb; Tess; Robison, 1992). Na mesma década, diversos autores avaliaram esse indicador ao dividir os resultados financeiros pelo número de vacas de cria (Melton; Colette; Smith, 1993; Hirooka et al., 1998; Pang et al., 1999a, 1999b; Pang; Makarechian; Basarab, 1999; Pravia et al., 2013; Ash et al., 2015) ou pela área útil para a produção (Barbosa et al., 2010; Oaigen et al., 2011; Ruviaro et al., 2016). Portanto, a relação entre o resultado econômico de um sistema de cria e o número de vacas do rebanho ou a área útil de produção, acompanhado do indicador biológico, satisfaz os requisitos necessários para a avaliação bioeconômica de sistemas de cria submetidos a diferentes realidades.

2.1.3 Uso da energia em sistemas de cria

A energia é considerada como um fator restritivo para a vida dos animais e suas produções, nas quais pode assumir até quatro formas: energia de manutenção, energia de ganho ou crescimento, energia de gestação e energia de lactação. O consumo de cada tipo de energia por animal pode variar conforme o peso corporal, raça, sexo, idade, estado fisiológico e estado nutricional do animal.

A distribuição da utilização da energia no sistema de cria depende de aspectos como a estrutura de rebanho, que pode variar em números de animais em crescimento, idade ao primeiro acasalamento das fêmeas e idade de descarte das vacas, entre outros. Como mencionado anteriormente, metade da energia consumida em sistemas de bovinos de corte é destinada para a manutenção das vacas (Ferrel & Jenkins, 1985), o restante para manutenção de novilhas de reposição e bezerros (20%), lactação e gestação (14%) e o crescimento e terminação de bezerros 16% (Figura 1).

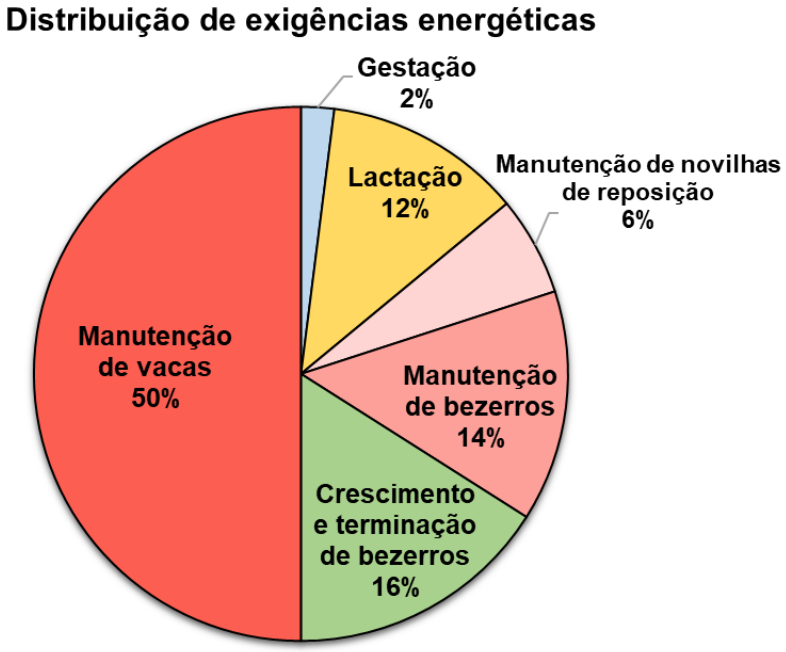

Figura 1. Representação da distribuição da energia exigida pelos diferentes processos fisiológicos em produção de bovinos de corte.

Adaptado de Seidel & Whittier, 2015.

Essa diferença no consumo de energia para a manutenção do rebanho de cria pode variar de acordo com a idade média das vacas, porque a demanda de energia para manutenção é maior em animais mais pesados, que produzem bezerros mais pesados ao nascimento e possuem maior capacidade de produção de leite (Brody, 1945; Hansen et al., 1982; Tyrrell & Reynolds, 1989; Montaño-Bermudez; Nielsen; Deutscher, 1990). Com isso, esta diferença de energia consumida para a manutenção pode chegar a 20% entre vacas de dois e cinco anos – considerando o mesmo peso maduro, em gestação e em lactação (NRC, 2000). Portanto, o maior número de vacas adultas impõe ao sistema uma maior demanda de energia para funções de manutenção. Por outro lado, o maior número de vacas jovens aumenta o consumo da energia de crescimento, uma vez que mais animais necessitam dessa energia.

A exigência energética para a gestação está relacionada ao crescimento fetal e ao peso de nascimento do bezerro, enquanto a energia de lactação está associada à capacidade de produção de leite da vaca. Portanto, vacas de dois anos exigem menos energia para a gestação e lactação, pois produzem um bezerro 8% mais leve do que vacas de peso maduro e apresentam uma capacidade de lactação de 26% menor do que vacas de quatro anos (Butson & Berg, 1984; Clutter & Nielson, 1987; Gregory et al., 1990). A partir disso, fica claro que a exigência energética de manutenção em vacas adultas aumenta direta (quilogramas de peso vivo) e indiretamente (produção de bezerro e leite) em relação às vacas mais jovens que ainda estão em crescimento.

Em pesquisa desenvolvida com um sistema de cria *Bos taurus*, com idade ao primeiro acasalamento aos 14 meses, apresentou variação de 40 a 45 Mcal de energia metabolizável por quilograma de bezerro produzido (Lamb; Tess; Robison, 1992). Em estudo semelhante, com rebanhos ao primeiro acasalamento aos 14 e 36 meses, foi relatada a necessidade de 46 e 102 Mcal de energia metabolizável para a produção de um quilograma de bezerro (Beretta; Lobato; Mielitz Netto, 2001). Os autores atribuíram a redução da necessidade energética por unidade de produto no rebanho de vacas jovens, devido à ausência de categorias improdutivas no sistema de produção, liberando áreas para outras categorias.

A partir disso, torna-se mais fácil entender por que a estrutura de rebanho em sistemas de cria pode apresentar grandes diferenças em eficiência no uso da energia do alimento. Nesse sentido, Seidel & Whittier (2015) propuseram um rebanho formado apenas por novilhas, as quais após o desmame seriam vendidas para abate ou comercializadas para reposição, uma vez que ainda teriam alto valor de comercialização. No entanto, os autores deixaram claro que o rebanho seria incapaz de manter sua estrutura, por não desmamar 100% de bezerras que deveriam emprenhar na estação de acasalamento subsequente. São questões como essas que reforçam o objetivo desse estudo de avaliar o impacto do tempo de permanência das vacas sobre a eficiência bioeconômica do sistema de cria.

2.1.4 Tempo de permanência da vaca em sistemas de cria

Muitas são as razões pelas quais as vacas são descartadas de um rebanho de cria: infertilidade, aborto, baixa habilidade materna, problemas físicos, doenças, lesões, baixa produtividade, problemas de dentição, idade e redução do rebanho (Greer; Whitman; Woodward, 1980; Rohrer et al., 1988; Arthur et al., 1993; Bascom & Young, 1998; USDA, 2010). Depois de perdas reprodutivas, o descarte por idade é a maior razão para uma matriz ser encaminhada para abate (USDA, 2010) e está indiretamente envolvida em todos os outros fatores que podem levar uma vaca a ser descartada.

As vacas que são retiradas do sistema por atingirem a idade máxima indicam o tempo de permanência da vaca no rebanho (TP) e, por conseguinte, elevam a idade média do rebanho e está relacionado à produtividade e eficiência do sistema de cria e seus ganhos genéticos. Esse assunto foi amplamente discutido quanto aos seus impactos na genética de bovinos de corte (Martin et al., 1992; Jamrozik et al., 2013; Santana et al., 2013; Paterno et al., 2017), mas poucos discutem os efeitos do tempo de permanência da vaca sobre a produtividade (Arthur et al., 1993; Roberts; Petersen; Funston, 2015) e inexistem trabalhos relacionados à eficiência.

A eficiência biológica do sistema de cria é dependente do TP, porque as vacas adultas podem desmamar bezerros até 17% mais pesados do que vacas de dois anos (Rumpf & Van Vleck, 2004). Por outro lado, possuem um peso até 22% maior do que fêmeas que ainda não atingiram o seu peso maduro. Por essa razão, a estrutura do rebanho de cria é fundamental na produção e no consumo de energia pelo par (vaca e bezerro) ao final de um ciclo produtivo. Portanto, sua modificação, através da estrutura etária, altera a eficiência biológica do sistema.

Em estudo que avaliou diferentes fatores capazes de interferir na idade média de sistemas de cria, Rogers et al. (2004) observaram que as vacas que apresentaram dificuldades ao parto tinham 58% mais chances de serem descartadas do rebanho. Em consonância, Stockton et al. (2014) afirmaram que a dificuldade ao parto em novilhas pode reduzir até 11% das taxas de repetição de prenhez. Além disso, as chances de descarte podem aumentar com a redução do peso corporal ao desmame (Rogers et al., 2004).

Nesse sentido, é possível perceber que a variação do TP pode apresentar diferentes resultados biológicos no sistema de cria, o que refletirá diretamente em seus resultados econômicos, pois como comentado anteriormente, vacas adultas são capazes de desmamar bezerros mais pesados do que vacas jovens (NRC, 2000; 2016), permitindo que a atividade aumente sua receita. Por outro lado, a redução de quilogramas de bezerros produzidos por vacas jovens pode ser compensada pelo aumento de quilogramas de vacas descartadas do rebanho (Roberts; Petersen; Funston, 2015).

Portanto, é de suma importância que, além da produtividade e dos quilogramas comercializados, a necessidade energética e o custo de produção do sistema também sejam determinados. Dessa forma, é possível gerar indicadores biológicos e econômicos para determinar a melhor eficiência bioeconômica do sistema de cria.

2.2 Resiliência na produção animal

A teoria da resiliência foi proposta há quase cinco décadas pelo ecologista Holling (1973). Desde então, muitas definições foram desenvolvidas (Grimm & Wissel, 1997; Neubert & Casweall, 1997) e, atualmente, a resiliência é definida como a capacidade que um sistema apresenta de retornar ao equilíbrio ou estado estacionário (de estabilidade) após um distúrbio (Tilman & Downing, 1994; Ives, 1995; Mittelbach et al., 1995; Neubert & Caswell, 1997).

A resiliência foi definida de duas formas diferentes e com reflexões distintas sobre o aspecto da estabilidade. Como a estabilidade foi definida pela persistência de um sistema em estado de equilíbrio ou próximo disso (Holling,1973), a resiliência é manifestada em sua ausência. No entanto, há diferentes pressupostos referentes às variações de equilíbrios que um sistema pode apresentar (únicos ou múltiplos), e isso levou a resiliência a diversos significados (Holling, 1996), como por exemplo a resiliência de equilíbrio global e a resiliência de equilíbrio múltiplo.

A resiliência de equilíbrio global aceita a existência de apenas um estado estável (em equilíbrio), e a medida da resiliência é dada pela distância que o sistema se afastou do equilíbrio e o tempo que necessitou para retornar (Ludwig; Walker; Holling, 1996). Essa definição é comumente utilizada pelas áreas da engenharia, física, matemática, entre outras. Em contraste, a resiliência de equilíbrio múltiplo, também conhecida como ecológica, admite mais de um estado estável e é medida pela magnitude da perturbação que o sistema é capaz de absorver antes de sair do equilíbrio.

Apesar de as duas definições para a resiliência serem pragmáticas quanto às suas aceitações, um sistema de cria de bovinos de corte que é puramente biológico, mas que possui um gerenciamento humano e é manipulado para atingir objetivos específicos, pode abranger ambas. Isto é, um sistema que possui uma organização de faixas etárias de animais em sua estrutura pode passar por uma intempérie climática e ter seus índices produtivos alterados devido à mudança dessas faixas etárias. A partir disso, o gestor pode optar em permitir um novo equilíbrio do sistema com novos patamares produtivos (resiliência ecológica), ou não aceitar a nova estrutura e manipular o sistema até que retorne para a estabilidade antes da intempérie climática ocorrer (resiliência global).

No final dos anos 90, foi sugerido que a biodiversidade permite uma resiliência de escala cruzada (Peterson; Allen; Holling, 1998). Para os autores, um sistema constituído de diversas espécies em equilíbrio é fortalecido pela presença constante de todos os agentes do sistema. A perda de algumas espécies de menor número inicialmente não traz grandes prejuízos para o sistema, mesmo que ocorram alterações em padrões e controles. No entanto, a presença de um maior número de espécies, que são críticas para a sobrevivência do sistema, não é o bastante para mantê-lo estável. Isto porque, a vulnerabilidade às perturbações, que antes seriam absorvidas sem alterações de função, padrão e controles, aumenta gradualmente conforme diminui a biodiversidade (Gunderson et al., 2000).

A resiliência cruzada pode ser utilizada para explicar a vulnerabilidade que rebanhos de cria formados por vacas jovens apresentam frente a intempéries climáticas, como a baixa pluviosidade. Os períodos de secas induzem as pastagens à estacionalidade e a disponibilidade de alimento para o rebanho é reduzida, o que pode comprometer os índices reprodutivos e reduzir a produção, perdendo estabilidade. Além disso, ao não produzir um bezerro, a vaca é descartada do rebanho, o que em larga escala desorganiza a estrutura do sistema. Como as vacas mais jovens sofrem as maiores quedas nas taxas reprodutivas em situações de crises nutricionais (Corah et al., 1975; Goehring; Corah; Higgins, 1989), rebanhos mais jovens tendem a ser mais vulneráveis à perda de estabilidade.

Portanto, ao comparar as faixas etárias de vacas de um sistema de cria com as espécies do sistema de resiliência de escala cruzada, percebe-se que rebanhos formados por poucas faixas etárias de vacas jovens estão mais expostos ao desequilíbrio e à desorganização pela redução da produção. Isso porque as vacas mais velhas, que suportam melhor intempéries climáticas, não estão presentes. Além disso, quando esses rebanhos entram em desequilíbrio, também ficam mais expostos a uma nova intempérie climática de menor intensidade.

A maior vulnerabilidade ao desequilíbrio sugere a necessidade de um maior tempo de retorno à resiliência que rebanhos jovens apresentam após um distúrbio. Isso porque a desorganização estrutural ocorre em maior escala em sistemas com menor diversidade. Apesar de, inicialmente, os transtornos parecerem apenas biológicos, há um grande prejuízo econômico com a demora em retornar à resiliência em sistemas comerciais. Afinal, enquanto não há estabilidade no rebanho, a produção é variável, com maiores probabilidades de resultar em redução da margem econômica. Portanto, para minimizar as perdas produtivas a resiliência deve ser atingida o mais rápido possível.

Em estudo com rebanho de cria submetidos a reduções na taxa de prenhez e de mortalidade de bezerros, foi encontrada a necessidade de dois a três anos para o retorno à resiliência, e quatro anos em reduções de maior intensidade (Viet al., 2013). Nesse estudo, um dos objetivos foi identificar o tempo de retorno à resiliência frente às diferentes intensidades de redução reprodutiva e de sobrevivência de bezerros, porém, em um mesmo rebanho.

Não existem trabalhos que avaliem a resiliência em diferentes estruturas de rebanhos, o que compromete a determinação de qual a melhor estratégia na formação de um sistema para diferentes realidades geográficas, climáticas e de mercado. Portanto, são necessários estudos que respondam qual a melhor idade do rebanho para o retorno mais rápido à resiliência após intempéries climáticas que resultem em diferentes níveis de energia disponível para o rebanho. Para isso, a resiliência pode ser considerada pelo retorno ou aproximação à estabilidade produtiva padrão do sistema anterior à crise.

2.3 Modelos de simulação

Modelos de simulação são ferramentas que analisam as interações entre os múltiplos fatores existentes em sistemas de produção (Diaz-Solis et al., 2006). Isto é, são capazes de predizer, de forma aproximada, o impacto que uma alteração ou implantação de uma nova abordagem pode causar no sistema. Para Banks (1998), a simulação é a reprodução de um processo ou sistema que retrata a realidade no tempo. Law (2014) define a simulação como a representação das relações de um sistema, por meio da matemática e/ou lógica, que compõem um modelo para compreender o comportamento do sistema ou prever um novo comportamento.

Para a elaboração de um modelo matemático é preciso observar um sistema, explicar as observações através de uma hipótese, realizar simulações para predizer o comportamento do sistema e testar a validade das hipóteses através da experimentação (Dourado-Neto et al., 1998). Porém, não é possível avaliar a modelagem como totalmente correta, pois nenhum modelo representa completamente a realidade, podendo não haver um modelo totalmente válido. Ainda assim, modelos de simulação permitem vantagens como: redução ou aumento do tempo do estudo, utilizar diferentes níveis de pressão sobre uma população de qualquer espécie e tamanho, testar hipóteses sem incorrer em custos e impactos significativos no mundo real e aproximar a pesquisa e a extensão, além de desenvolvê-las com maior rapidez (Hirooka; Groen; Hillers, 2010; Nitu; Burlacu; David, 2010).

Para atingir essa versatilidade a simulação passou por um longo processo de desenvolvimento marcado por três períodos (Goldsman; Nance; Wilson, 2010). O primeiro (1877 a 1945) foi iniciado pelo francês Georges Buffon que utilizou a aleatoriedade para tomadas de decisão, considerado como o precursor do método de Monte Carlo. Muitas décadas depois (de 1945 a 1970), talvez o passo mais importante para o rápido desenvolvimento da simulação tenha ocorrido com o método de Monte Carlo resolvendo complexidades criadas pelo primeiro computador digital eletrônico e a bomba de hidrogênio. Com o maior acesso aos computadores, pesquisadores iniciaram uma alta produção de ferramentas de simulação para a pesquisa. Finalmente, a partir da década seguinte (1970 a 1982), houve a expansão de diferentes linguagens e métodos de simulação, que permitiram importantes melhorias na área da pesquisa e do ensino com o uso da simulação até os dias atuais.

2.3.1 Classificação e tipos de modelos

Os modelos podem ser classificados de três formas: conceituais, que descrevem o sistema por meio de teorias, *frameworks* ou gráficos; físicos, geralmente expressos por maquetes; e matemáticos, que descrevem o sistema por fórmulas matemáticas, em que os dados de entrada geram resultados de saídas (Acock & Acock, 1991). Os modelos matemáticos se dividem em dois tipos: estáticos/dinâmicos e estocásticos/determinísticos. Além disso, esses dois tipos podem ser mesclados em estático determinístico, estático estocástico, dinâmico determinístico e dinâmico estocástico.

Estáticos ou dinâmicos são definidos pelo comportamento do tempo. Os modelos estáticos não consideram o tempo como variável, portanto, não têm a capacidade de simular as alterações em um sistema ou prever seus resultados ao longo do tempo. Apesar desse atributo tornar os modelos estáticos menos atrativos para os sistemas agropecuários, diversas pesquisas e modelos consagrados foram realizados ao utilizá-lo (INRA, 1989; Malone & Melstrom, 2020; Peng, 2020).

Por outro lado, os modelos dinâmicos consideram o tempo como varável e têm suas saídas afetadas por ele. Esses modelos são capazes de predizer o efeito acumulativo no sistema causado por diferentes pressupostos, o que aproxima suas saídas aos eventos observados no mundo real, principalmente em sistemas biológicos. Essa característica possibilita seu amplo uso na agropecuária, por exemplo, para expressar os resultados de modelagem no crescimento de forrageiras e ganho de peso animal (Pang et al., 1999a; Lynch et al., 2019; Strullu et al., 2020).

Determinísticos/estocásticos são definidos pela aleatoriedade dos parâmetros de entrada. Os modelos determinísticos geram resultados a partir de entradas fixas, isto é, dados que não podem variar em distribuições de probabilidades. Apesar de não utilizar a entrada aleatória de dados, o modelo determinístico é o mais utilizado em sistemas de produção animal (Pettigrew, 2016). Em contraste, modelos estocásticos consideram as probabilidades e, portanto, também são conhecidos como probabilísticos. Isto é, os parâmetros de entrada podem assumir uma característica de variável aleatória, em que apenas uma é suficiente para tornar o modelo estocástico (Spreen et al., 2019). Nesse tipo de modelo, execuções repetidas sobre os dados aleatórios são exigidas para gerar os resultados, o que possibilita resultados repetidos necessários para análises estatísticas.

2.3.2 Modelos de simulação em bovinos de corte

Apesar de Arcus (1963) ter introduzido a simulação para o uso na agropecuária com estudo de pastejo em meados do século XX, pesquisadores já utilizavam dados publicados para tentar prever comportamentos de plantas e animais desde o início do século passado. Contudo, foi após a introdução dos sistemas dinâmicos nos anos 60 que houve um aumento significativo da pesquisa voltada para a produção animal. Na década seguinte, os modelos ficaram mais complexos com o uso de multivariáveis como produção de pastagens, nutrição e reprodução. Eles foram a desenvolvidos com a Programação Linear para bovinos de corte (Wilton et al., 1974) e com o modelo determinístico Sistemas de Produção de Gado Texas A&M (Sanders e Cartwright, 1979).

Entre os anos de 1980 e 1990 a diversidade de modelos e objetos de pesquisa cresceu em grande escala, com modelos determinísticos e dinâmicos abordando assuntos relacionados a bovinos de corte como desempenho individual e de sistema, reprodução, crescimento, mortalidade, descarte de vacas, nutrição, produção de leite, produtividade, idade do rebanho (Loewer Jr et al.,1980; Fox & Black, 1984; Bourdon & Brinks, 1987; Fox; Sniffen; O'connor, 1988). Na década seguinte, os modelos de simulação em sistemas de cria que avaliaram a eficiência biológica (Green et al., 1991) e a eficiência bioeconômica (Lamb; Tess; Robison, 1992; Pang et al., 1999a) ganharam destaque.

Desde sua introdução em sistemas de bovinos de corte, os modelos de simulação continuam em expansão e, nos últimos vinte anos o seu crescimento é notório, com cada vez mais pesquisadores aderindo a essa ferramenta. No entanto, algumas perguntas ainda devem ser respondidas, como aquelas que dizem respeito à idade de descarte da vaca, uma vez que, as consequências causadas na eficiência bioeconômica e na resiliência de sistemas de cria pela idade máxima da vaca no rebanho, permanecem sem resposta. Nesse sentido, ainda se questiona: (i) Qual a idade ideal de descarte da vaca para a atingir a melhor eficiência bioeconômica em sistemas de cria? e (ii) Qual a idade ideal de descarte da vaca para o retorno mais rápido à resiliência em diferentes níveis de disponibilidade energética? Para esses esclarecimentos, são necessárias ferramentas como os modelos de simulação que relacionam perspectivas biológicas, produtivas e econômicas, de modo que possam ser avaliadas (Diaz-Solis et al., 2006) propriedades que satisfazem as necessidades deste estudo.

3. Hipóteses

1) A menor idade da vaca ao descarte permite ao sistema de cria a melhor eficiência biológica, porém, uma menor eficiência econômica.
2) A maior idade da vaca ao descarte possibilita ao sistema de cria o menor tempo à resiliência após uma intempérie climática de curta duração.

4. Objetivo geral

1) Desenvolver um modelo de simulação capaz de predizer resultados biológicos e econômicos de sistemas de cria com diferentes idades da vaca de descarte do rebanho.

4.1 Objetivos específicos

1) Predizer qual a idade da vaca de descarte para a melhor eficiência bioeconômica em sistemas de cria.
2) Predizer qual a idade ideal da vaca de descarte para o menor tempo de retorno à resiliência em sistemas de cria submetidos a diferentes níveis de disponibilidade energética.

CAPÍTULO II

Article prepared according to the norms of the Agricultural Systems (Appendix)

Efficiency in cow-calf systems with different ages of cow culling

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Abstract: The bioeconomic efficiency of cow-calf systems was compared by a deterministic dynamic simulation. The simulation model considered stable cow-calf systems differentiated by the maximum age for culling cows, lifetime (LT), culled at four (LT4); five (LT5); six (LT6); seven (LT7); eight (LT8); nine (LT9); ten (LT10); eleven (LT11); twelve (LT12) and thirteen years (LT13) old. The necessary supply of metabolizable energy (ME) for the herd was established as natural grasslands, cultivated pasture in the winter/spring, and pre-dried pasture produced by the system. The biological efficiency of the systems (BioE) was considered the ratio between the production of total live weight (LW) and the ME consumed over one production cycle. Economic efficiency was determined by the ratio between gross margin (GM) and production area (EEA); and the ratio between GM and number of cows (EEC). Bioeconomic efficiency was determined by a simple linear regression between BioE, EEA, and EEC. The efficiency of the animal unit, considering BioE and EEA were better in LT4, while EEC was better in LT13. In determining the bioeconomic efficiency of the systems, the best results were found in LT6, which suggests that the best efficiency of a cow-calf herd is reached when the adult age and mature weight of the cow are reached, and there is no more energy used for growing. The results indicate that stable cow-calf herds express their best BioE and EEA when the cow culling age is lower. However, EEC depends on cows that remain in the herd as long as possible. The culling age of cow that balances these biological and economic indicators is reached around five and half years.

Keywords: herd structure, longevity, feed restriction in cows, stayability.

1. Introduction

The economic viability of cow-calf systems is closely associated with the biological efficiency of cows. Therefore, to achieve satisfactory results in the activity, the herd must be structured to reach the highest possible productive capacity of these animals when transforming food resources into a commercialized product. With this purpose, research has measured the biological efficiency of the cow-calf system through the use of metabolizable energy (ME) for calf production (Lamb et al., 1992; Walmsley et al., 2016). However, these studies evaluated the individual efficiency of cows and did not consider the efficiency of the cow-calf systems, which can distort the results of these analyzes.

When analyzing ME, the impact of the metabolizable energy for the maintenance (ME_m) of the production systems must be considered, which is the unproductive portion of the ME and represents about 50% of the total herd requirement only for cow maintenance (Ferrel & Jenkins, 1985). This is because, the older the animals, the more energy they need for maintenance until they reach their mature weight (NRC, 2000), which makes them less efficient in transforming the energy consumed into muscle, hence, meat products. This difference in the use of ME makes this indicator relevant for efficiency analysis of production systems, as well as the economic impact of the variation in the culling age of cows.

When considering cow-calf systems, the shorter lifetime cow in the herd demands high heifer replacement , which allows better utilization of the energy used for growth (Brethour & Jaeger, 1989; Seidel & Whittier, 2015). In addition, cows that reach mature weight consume about 25% more energy for maintenance than two-year-old cows (NRC, 2000). In contrast, when the productive lifetime of cows is longer, heavier calves are obtained at weaning, and there is a reduction in the heifer replacement rate (Roberts et al., 2015), which positively impacts the margin of the cow-calf system. Thus, understanding these relations, especially considering production systems, allows farmers to assess which is the best strategy to increase the productivity of their operations.

In this context, in production systems, the herd structure is a complex issue and must consider the ideal age for cow culling (lifetime). Although some research indicates that the most efficient systems culled primiparous cows soon after weaning a calf (Taylor et al., 1985; Bourdon & Brinks, 1987; Ereth et al., 2000), this system could not be maintained because it is not able to produce the necessary number of heifers to replace the culled cows and ensure herd stability (Seidel & Whittier, 2015). Nevertheless, this hypothesis must be scientifically validated, considering the different herd structures and bioeconomic efficiency to identify the ideal cow lifetime in the herd.

In addition, research that seeks to increase animal production efficiency contributes to the strategic use of natural resources and helps both to reduce the negative impact of production on the environment (Rotz et al., 2013) and to the image of beef industry. However, comparison through experimentation becomes impracticable due to the cost, complexity, and level of control required by these systems for a reliable analysis. In contrast, the simulation models analyze the interaction between the production system factors quickly and at low cost (Naazie et al., 1999). In this sense, this study identifies the ideal cow lifetime in the herd until its culling for the best bioeconomic efficiency of cow-calf systems.

2. Methods

2.1 Model overview

A deterministic dynamic model was constructed to compare the bioeconomic efficiency of cow-calf systems programmed in Microsoft Excel spreadsheets. The input parameters were collected from scientific articles published in relevant journals and the technical coefficients and assumptions of herd evolution typical of cow-calf systems in natural grasslands (Feuz & Skold, 1990). To determine the necessary metabolizable energy (ME) for animal growth and pasture energy availability, the animals' daily requirements were also considered.

Ten production system scenarios were built with herds of 1,000 British breed cows. The criteria for differentiating the systems was the maximum age at which the cows were culled, called lifetime (LT), considered at four (LT4); five (LT5); six (LT6); seven (LT7); eight (LT8); nine (LT9); ten (LT10); eleven (LT11); twelve (LT12); and thirteen years old (LT13). To maintain the discrete nature of the variables, the maximum age for culling cows in the system was considered after the weaning of its last calf (e.g., 10.5-year-old cows for the LT11).

To compare the systems, the following parameters were used: 1. Stable herd structure, with the distribution effect of the age groups of cows and bulls based on zootechnical indicators (Figure 1); 2. Body condition score 3 on a scale of 1 (very thin) to 5 (very fat) (Houghton et al., 1990); 3. Mineral salt offer (specifications in the supplementary information 1) in the order of 80 g/450 kg of live weight (LW) per day for all cows; 4. Vaccination against clostridiosis, reproductive diseases, foot-and-mouth disease, brucellosis, in addition, antiparasitic treatments, according to typical proceedings and legal requirements for animal welfare and sanitation.

Model inputs	Value	Reference
Mature cow weight at 5 years (kg)	480.0	
Calving rate (%)		
2-year-old cows	88	Rumpf and Van Vleck, 2004; Roberts et al., 2015
3-year-old cows	87	
Cows above 3 years old	88	
Birth weight (kg)		
Calf of 2-year-old cow	35.0	Gregory et al., 1990
Calf of 3-year-old cow	36.1	
Calf of 4-year-old cow	37.2	
Calf of cow above 4 years	38.0	NRC, 2000
Peak milk production (kg)		
2-year-old cows	5.92	Hansen et al., 1982; Butson and Berg, 1984a, 1984b; Cluter and Nielson, 1987; Rovira, 1996
3-year-old cows	7.04	
Cows above 3 years old	8.00	
Average daily gain (ADG)(kg)		
Calf of 2-year-old cow	0.633	AFRC, 1993; Gregory et al., 1990; Rumpf and Van Vleck, 2004; Roberts et al., 2015
Calf of 3-year-old cow	0.656	
Calf of 4-year-old cow	0.703	
Calf of 5 to 9-year-old cow	0.770	
Calf of 10-year-old cow	0.763	
Calf of 11-year-old cow	0.753	
Calf of 12 and 13-year-old cow	0.733	
From weaning to 12 months	0.800	NRC, 2000
1-year-old cows (13 to 24 month)	0.267	Gregory et al., 1992
2-year-old cows	0.160	
3 and 4-year-old cows	0.053	Fox et al., 1992
11-year-old cows	- 0.008	Roberts et a., 2015
12 and 13-year-old cows	- 0.009	
Mortality rate (%)		
Calf of 2-year-old cow	5	Pang et al., 1999
Calf of 3-year-old cow	2	
From weaning to 12 months	3	
Cows	2	

Figure 1. Assumptions of simulation model for the efficiency of cow-calf systems according to lifetime cows.

The model was developed by the interaction between the dynamics of cow-calf herd structure, animal energy necessity, energy production by grasslands, and monetary flow of the production system. For this, the submodels were developed: herd structure, energy requirement, forage production, and financial results (Figure 2).

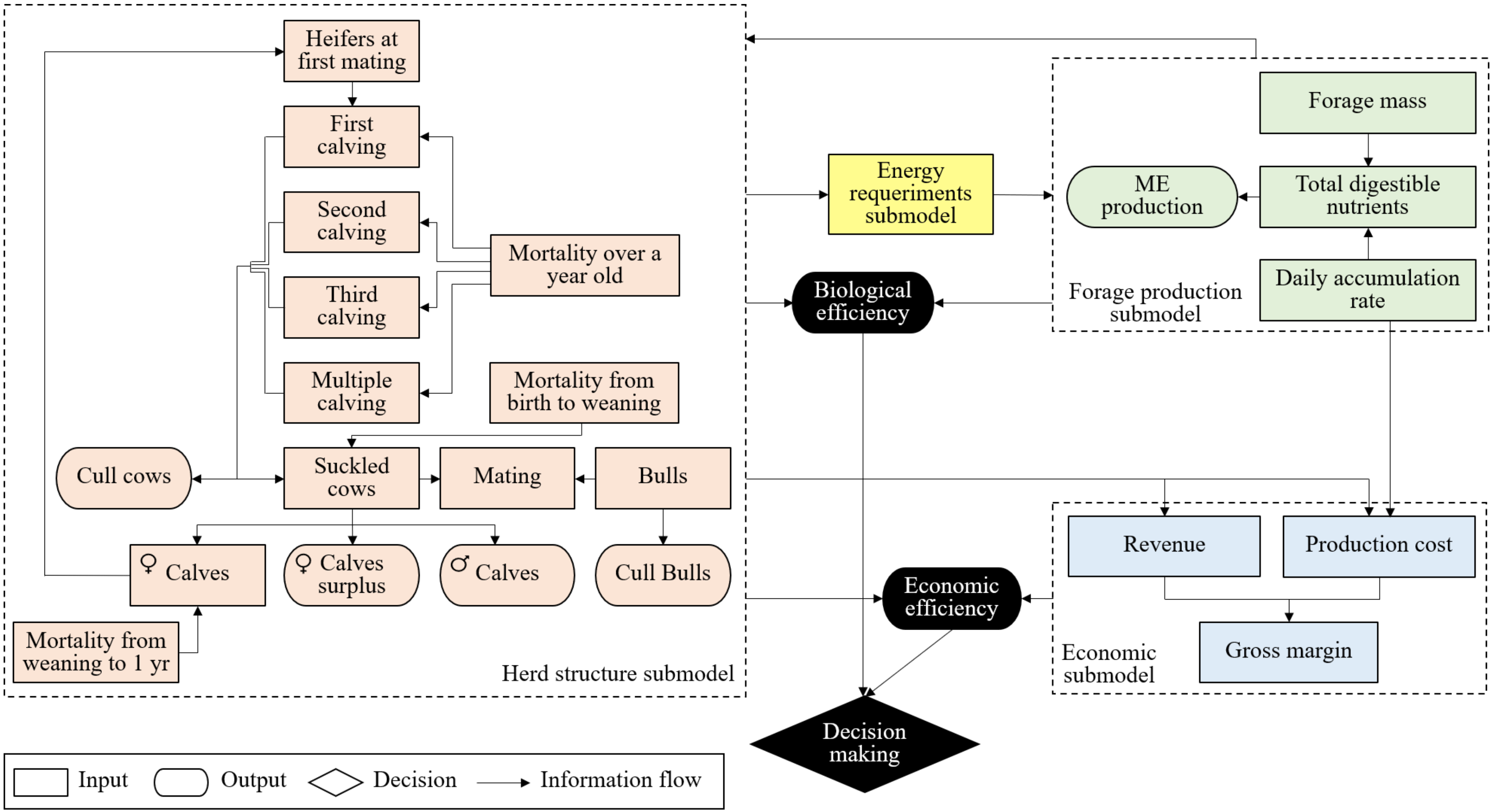

Figure 2. Simplified flowchart of the proposed conceptual model for cow-calf systems with different lifetime cows.

2.2 *Herd structure submodel*

The breeding season was considered from November 1st to January 29th (90 days). The initial mating age considered for heifers was 14 months and for bulls at two years. In this model, bulls were purchased at two years, used for six breeding seasons until seven years old, and subsequently sold with an annual culling rate of 20%. Cows at two years or more were exposed to natural breeding under the ratio of one bull for every 25 females. It has been established that heifers were artificially inseminated (A.I.) at 14 months with a synchronization program based on prostaglandin administrations (PGF2a), considering 1.6 A.I. by heifers (Dunn et al., 1969; Goehring et al., 1989). The calving season was divided into four periods of 21 days each, from August 16th to November 18th (Pang et al., 1999).

The proportion of cows in each age group varied according to the maximum age of culling and the calving, weaning, and mortality rates. Cows that did not calve a calf were culled at the end of calving season. Those that did not wean their calves or reached the arbitrated LT for each system were culled at weaning on April 1 (Figure 3). The calving and weaning rates were represented by the number of cows that calved and weaned a calf, respectively, in relation to the number of cows subjected to mating in the previous season.

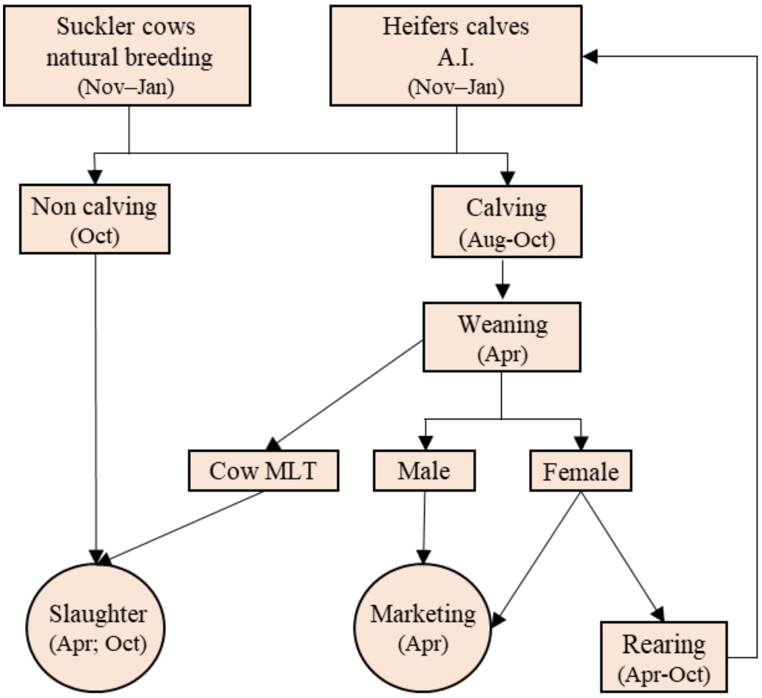

Figure 3. Cow-calf system flowchart (A.I.: Artificial Insemination; MLT: Maximum Lifetime).

The heifer replacement considered only those produced in the system itself to keep the herd with a constant number of cows, without external purchases. When the number of heifers produced did not reach the minimum necessary for replacement, the system was not simulated, since it would not remain sustainable. For this reason, LT4 was the youngest LT simulated, as culling cows under four years old would cause a gradual reduction of the system until it became unviable. Heifer retention was performed at weaning, and the selection of the heaviest heifer was used as a criterion.

Female calves that did not recompose the system and male calves were sold immediately after weaning. The total production (TP) of the scenarios was calculated from the sum of all of the kg sold in live weight of each category, while the productivity (kg/ha) was determined from the relation between TP and the production area, as described by Nasca et al. (2015). For all systems, the same weight of the animals was considered, within each age group, both at the time of sale and for the animals that remained in the herd.

2.3 Energy requirements submodel

The energy requirement submodel evaluated the ME needs for calves, cows, and bulls, considering the age group and the physiological state in which each animal is in the productive cycle; maintenance (ME_m), growth (ME_g), lactation (ME_l), pregnancy (ME_y); according to the previously defined calving periods. The modeling considered the availability of 100% of the energy necessary for the animals to reach the productive, individual, and herd indexes, according to the dynamic physiological parameters of each animal age group (AFRC, 1993; NRC, 2000; NRC, 2016). Biological efficiency, by age group of the cow ($BioEV_v$), was defined by Equation 1.

$$BioEC_c = \frac{MECC_c}{(WGC_c + LWCWC_c)}$$

(Equation 1)

in which, $BioEC_c$ is the biological efficiency of the cow; $MECC_c$ is the total metabolizable energy consumed by the cow; WGC_c is the weight gain of the cow; $LWCWC_c$ is the live weight of the cow's weaned calf; c is the age group of the cow.

The BioE (Equation 2) of the different simulated systems was also evaluated from the relationship between the total ME consumed by the system and the kg sold of slaughtered bulls and cows, in addition to the kg of calves (Lamb et al., 1992; Walmsley et al., 2016).

$$BioE_t = \frac{MEC_t}{TLWS_t}$$

(Equation 2)

in which, BioE is the biological efficiency of the system; MEC is the total metabolizable energy consumed by the system; and TLWS is the total live weight sold; t is the maximum lifetime cow (LT).

2.4 Forage production submodel

This submodel was used to calculate the animal load capacity of each cow-calf system. The metabolizable energy of forages (MEF; equation 3) is estimated from forage production, through the daily accumulation rate (DAR), forage mass (FM), grazing rate, and total digestible nutrients (TDN).

$$MEF = TDN \text{ x } 4.4 \text{ x } 0.82$$

(Equation 3)

in which MEF is the metabolizable energy of forage; TDN is the total digestible nutrient; 4.4 is the conversion constant from TDN to digestible energy; and 0.82 is the conversion constant of digestible energy for ME (NRC, 2000).

Thus, the model simulates the monthly variation in ME production in response to the demand for ME from animals in the herd. Therefore, the model was built to adjust the sizing of the production area with the assumption that in the months with feed surplus there would be storage through pasture conservation, in the form of pre-dried, to be supplied in periods of feed deficit. It was assumed as a feed surplus when the pasture produced more ME than the animals required (May to August). The feed deficit was considered when pasture production did not have the capacity to supply animals' ME necessity (September to March). Forage storage was considered only for cultivated oat pastures (*Avena strigosa*) in consortium with ryegrass (*Lolium multiflorum*), as the scarcity of natural grasslands surplus and the high cost of this hay discourage the practice in the region.

The values for the calculation of ME production used to build this model were based on data from natural grasslands typical of the region (Carvalho et al., 2017) and from scientific research on cultivated oat/ryegrass pastures (Restle et al., 1999; Roso et al., 1999; Piazzetta et al., 2009) from FM and DAR in the range of two standard deviations from the mean. While natural grasslands were used over the year, oat pasture (April to August) with ryegrass (May to October) was used from April to October.

To determine which age groups of calves should receive natural grassland or oats/ryegrass, the daily dry matter intake capacity (DMI_d) was considered in the different physiological conditions of the animals (NRC, 2016). To calculate the metabolizable energy consumed per day (MEC_d), Equation 4 was used:

$$MEC_t = DMI_t \text{ x } MEF$$

(Equation 4)

in which, MEC_d is the metabolizable energy consumed per day; DMI_t is the daily dry matter intake; and MEF is the metabolizable energy of forage; t is the number of days.

The available metabolizable energy (AME) per hectare was determined from Equation 5:

$$AME = EMF \text{ x } (MF + TAD_t) \text{ x } ECF$$

(Equation 5)

in which, AME is the metabolizable energy available per hectare; MEF is the metabolizable energy of forage; FM is the forage mass per hectare; DAR is the daily accumulation rate (Silveira, 2011); t is the number of days; and EHF is the efficiency of harvest forage used by the animals (Carvalho et al., 2017).

Thus, the average AME of natural grasslands, in 12 months of the year, and of oat/ryegrass consortium pasture, in seven months of production, obtained average values of 364 Mcal/ha and 1,744 Mcal/ha, respectively. Considering the energy requirements of the systems and the energy availability of the pastures (Figure 4), the feed base of each category and age group of animals in the different systems was determined.

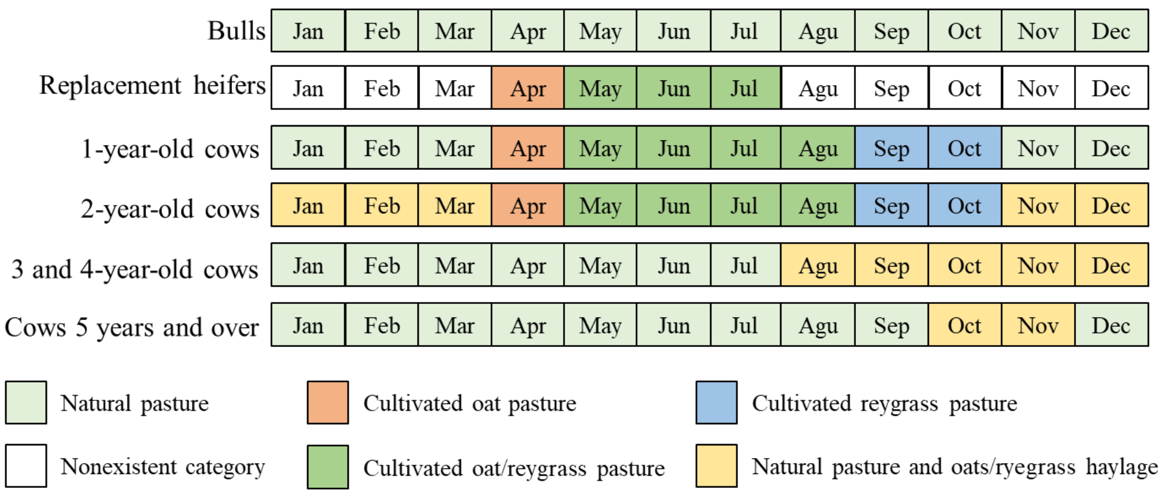

Figure 4. Monthly feed composition provided for each age group of cows and category of cow-calf systems.

2.5 *Economic submodel*

The economic submodel measured the economic efficiency per area (EEA) and per cow (EEC) in the different scenarios, through the gross margin (GM), which was calculated by the difference between revenue and production cost (fixed and variable) and later divided by the number of hectares and the number of cows exposed to breeding in the previous year (Equations 6 and 7).

$$EEA = \frac{GM}{hectares}$$

$$EEC = \frac{GM}{number\ of\ cows\ exposed\ to\ breeding\ in\ the\ previous\ year}$$

(Equations 6 and 7)

Total revenue was estimated by the sum of the total sale of LW kg of weaned male calves, weaned female calves not used for replacement, and culled cows and bulls. The prices were based on the regional average of the last five years (ESALQ, 2019; NESPro, 2019) that also agrees with the current market conditions in the country. Therefore, the selling price used per kg of LW for male and female calves was US$ 1.58 and US$ 1.45, respectively, for cows sold at the end of calving US$ 1.15, for cows sold at the end of weaning US$ 1.08, and for cull bulls US$ 1.15.

The fixed costs considered in the model were those that do not change with the variation of production in the cow-calf system in a productive cycle, while the variable costs were those that show variability in the increase or decrease in production. All costs were considered in accordance with market prices and subsequently corrected by the General Price Index-Internal Availability *(índice geral de preços-disponibilidade interna - IGP-DI)* for the average of the last five years. The values used are representative of a property of 1,000 cows located in southern Brazil with the tax values varying proportionally to the production area. The model did not consider opportunity costs for land and capital, as they are not parameters usually used by farmers in Brazil.

To evaluate the relation between BioE and EEA and between BioE and EEC, simple linear regression models were performed using the SPSS 20.0 software (IBM, 2015), considering a significance level of 95%. The adjusted trend lines were plotted on a dual-axis graph to determine the balance between the two efficiencies. Hence, it was possible to identify the lifetime cow in the herd that resulted in the best bioeconomic efficiency.

For all models, a manual check of the input parameters and the results obtained were performed to detect distortions and possible typing errors. In addition, careful validation based on scientific references was carried out to ensure the model's representativeness.

3. Results

3.1 Herd structure submodel

The herd composition, the number of heifers retained for replacement, and the number of calves weaned varied in the different cow-calf systems according to each LT (Table 1). The results showed that the reduction in the culling age cow requires a higher replacement of heifers. The LT4 obtained a higher replacement of heifers than LT6 (47.7%), LT8 (83.3%) and LT13 (145.5%).

Table 1. Herd structure (%) of 10 cow-calf systems (1,000 cows) with different lifetime cow (LT).

Category	LT4	LT5	LT6	LT7	LT8	LT9	LT10	LT11	LT12	LT13
2-year-old bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
3-year-old bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
4-year-old bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
5-year-old bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
6-year-old bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
1-year-old cows	17.02	14.02	12.12	10.85	9.92	9.23	8.70	8.28	7.94	7.66
2-year-old cows	14.98	12.33	10.68	9.55	8.73	8.12	7.65	7.28	6.98	6.74
3-year-old cows	13.03	10.72	9.29	8.30	7.60	7.07	6.66	6.34	6.08	5.87
4-year-old cows	-	9.44	8.17	7.31	6.69	6.23	5.86	5.58	5.35	5.16
5-year-old cows	-	-	7.18	6.43	5.88	5.47	5.16	4.91	4.71	4.54
6-year-old cows	-	-	-	5.66	5.18	4.82	4.54	4.32	4.13	4.00
7-year-old cows	-	-	-	-	4.56	4.24	3.99	3.80	3.64	3.52
8-year-old cows	-	-	-	-	-	3.74	3.51	3.34	3.21	3.10
9-year-old cows	-	-	-	-	-	-	3.09	2.94	2.81	2.72
10-year-old cows	-	-	-	-	-	-	-	2.59	2.48	2.40
11-year-old cows	-	-	-	-	-	-	-	-	2.19	2.10
12-year-old cows	-	-	-	-	-	-	-	-	-	1.86
Cull bulls	0.19	0.22	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28
Cull cows	16.12	13.09	11.18	9.88	8.94	8.25	7.71	7.29	6.95	6.67
Replacement heifers	17.02	14.02	12.12	10.85	9.92	9.23	8.70	8.28	7.94	7.66
Male calves	19.15	19.84	20.28	20.57	20.79	20.95	21.07	21.17	21.25	21.31
Female calves	1.55	5.22	7.54	9.10	10.23	11.09	11.74	12.26	12.66	13.01
Total	100	100	100	100	100	100	100	100	100	100

The systems also varied concerning the weaning rate, the number of animals sold, the average weight per category, the total kg sold, and their distribution by category (Table 2). Systems that culled older cows had a higher rate and weight at weaning than those that culled younger cows. However, production per animal was higher in the younger culled cow systems.

Table 2. Weaning rate, number and average weight per animal sold and weight of calves at weaning in 10 cow-calf systems with different lifetime cow (LT).

Systems	**Weaning rate**	**Bulls**	**Cows**	**Male calves**	**Female calves**	**Total**
	%	Head (Kg/hd)	Head (Kg/hd)	Head (Kg/hd)	Head (Kg/hd)	Head (Kg/hd)
LT4	85.0	5 (768)	358 (457)	425 (185)	34 (150)	821 (306)
LT5	85.3	5 (768)	281 (463)	427 (190)	112 (163)	825 (283)
LT6	85.5	6 (768)	236 (462)	427 (192)	159 (167)	828 (268)
LT7	85.6	6 (768)	206 (462)	428 (194)	189 (173)	829 (260)
LT8	85.6	6 (768)	184 (462)	428 (195)	211 (177)	829 (254)
LT9	85.7	6 (768)	169 (462)	428 (196)	227 (180)	830 (250)
LT10	85.7	7 (768)	157 (462)	429 (197)	239 (181)	832 (246)
LT11	85.8	7 (768)	148 (461)	429 (197)	248 (182)	832 (244)
LT12	85.8	7 (768)	140 (460)	429 (197)	256 (183)	832 (242)
LT13	85.8	7 (768)	134 (459)	429 (197)	262 (183)	832 (240)

Note: the weaning weight is represented by the average weight of male calves sold. Kg/hd: kilograms/head.

Systems that remained with their cows for longer, sold more male and female calves and with a higher average weight in both categories. In contrast, herds that culled younger cows, sold lighter cows, but in higher quantities. In addition, the younger the culled cow was, the higher the TP was, even with the lowest number of animals sold. The LT4 showed a 7.1% superiority in kg sold over LT5 due to the higher number of cows sold by age limit. This was the biggest difference between sequential scenarios, similar to the variation found between LT7 and LT13.

3.2 Energy requirements submodel

The largest MECC was found in four-year-old cows and the lowest in two-year-old cows. Mature weight cows were the ones that used more ME for maintenance functions (74%), while two-year-old cows the ones used less (66%). In contrast, two-year-old cows demanded a higher proportion of ME_g (14%) than other cows in the herd.

In relation to the systems, the MEC was higher in younger cows, with a 10.8% superiority of LT4 over LT13. However, systems that remained with eleven-to-thirteen-year-old cows did not vary in relation to the use of MEC. Although LT4 used 4.7% more ME_m than LT13, this energy presented a greater proportion of the total consumption in LT13 (Figure 5). However, for ME_g, it was not the same, as the LT4 consumed 108.4% more of this energy than the LT13 and was the one that presented the highest proportion of consumption among the systems.

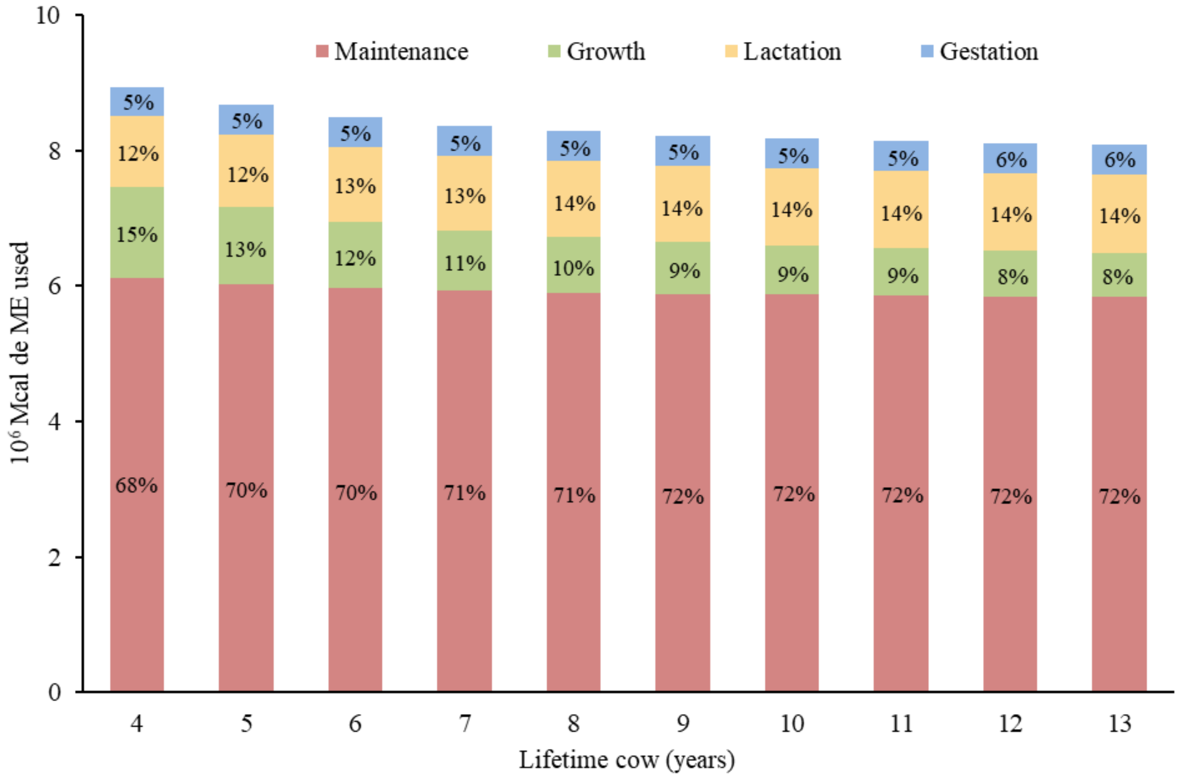

Figure 5. Total metabolizable energy (ME) used in 10 cow-calf systems with different lifetime cow (years) and their respective distribution of ME for maintenance, growth, lactation and gestation. The number in % represents the ME assigned to the function.

The BioEC was 21.6% higher in two-year-old cows than twelve-year-old cows, as they needed 33.5 Mcal of ME to produce one kg of LW while the older 40.8 Mcal of ME. In systems, the best BioE was LT4 with a 12.3% superiority over LT13, due to the need for 35.7 Mcal of ME to produce one kg of LW in the smallest LT and 40.7 Mcal of ME in the largest (Figure 6). The LT11 presented BioE only 1% higher than LT13, which demonstrates the proximity between the systems and the formation of a plateau when the cows are culled after ten years old.

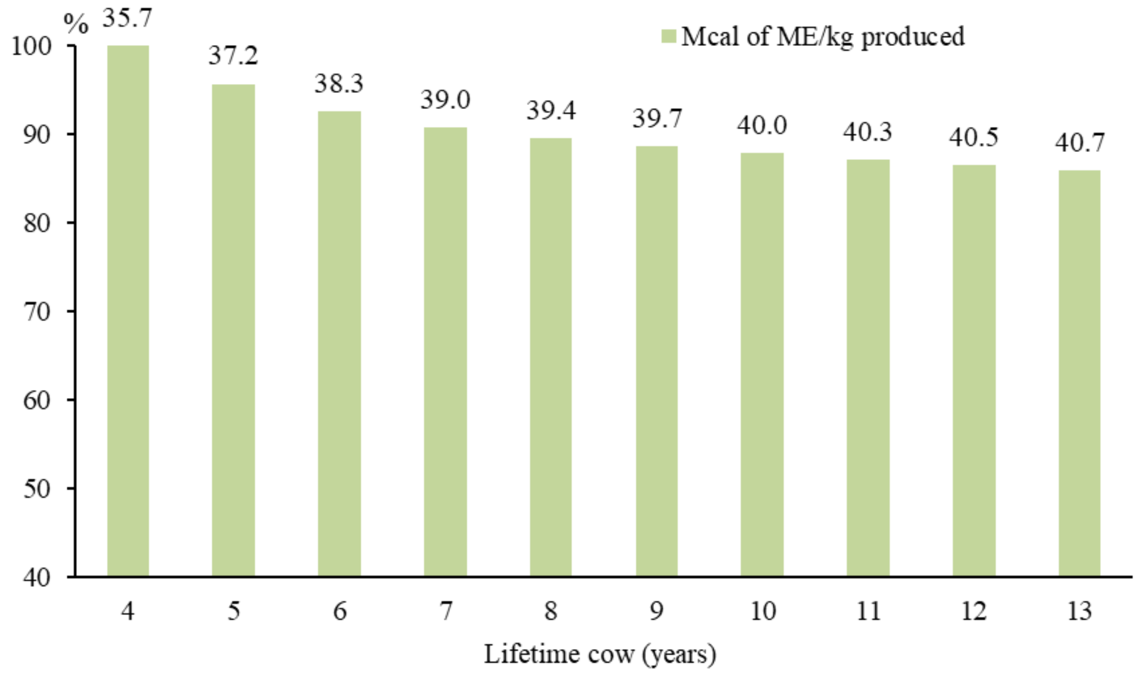

Figure 6. Biological efficiency: Mcal of metabolizable energy (ME; values over the bars) consumed per kg produced represent in 10 cow-calf system with different lifetime cow (LT). The LT4 is the most efficient among all LT, therefore it was represented with 100%.

3.3 Forage production submodel

Systems that culled younger cows required less production area and had a higher proportion of cultivated pasture compared to systems that culled older cows (Table 3). The LT4 used a production area 23% smaller than LT13, but it needed a 144% larger area of oat/ryegrass pasture.

Table 3. Total production area, natural grasslands, oat/ryegrass pasture, animal unit per hectare (AU - 450 kg), and productivity in 10 cow-calf systems with different lifetime cow (LT).

	LT4	**LT5**	**LT6**	**LT7**	**LT8**	**LT9**	**LT10**	**LT11**	**LT12**	**LT13**
Total production area (ha)	1,210	1,307	1,363	1,400	1,427	1,446	1,461	1,472	1,481	1,489
Natural grasslands (%)	70.70	78.27	82.33	84.82	86.50	87.70	88.59	89.27	89.81	90.24
Oat/ryegrass pasture (%)	29.30	21.73	17.67	15.18	13.50	12.30	11.41	10.73	10.19	9.76
Animal unit (AU/ha)	1.05	0.96	0.92	0.89	0.87	0.85	0.84	0.84	0.83	0.82
Productivity (kg/ha)	207	178	163	153	147	143	140	137	135	133

As the culling age of cows was reduced, there was an increase in stocking and productivity of the systems. The LT4 obtained higher stocking and productivity of 28 and 55.6%, respectively, in relation to LT13. Ergo, the older the cows were culled, the smaller was the difference between the sequential systems of only 1% from LT11.

3.4 Economic submodel

The lower the LT, the higher was the total revenue (TR) of the cow-calf system (Figure 7). The systems of cows culled older showed the composition of their TR predominantly by male and female calves, representing 73.6% in LT13 (Table 4). In contrast, systems with younger culled cows showed greater participation of cows and bulls in the TR, with LT4 reaching 59%. Despite the increase in TR with the reduction in the culling age of cows, the production costs increased considerably, mainly for feed, which caused a decrease in GM.

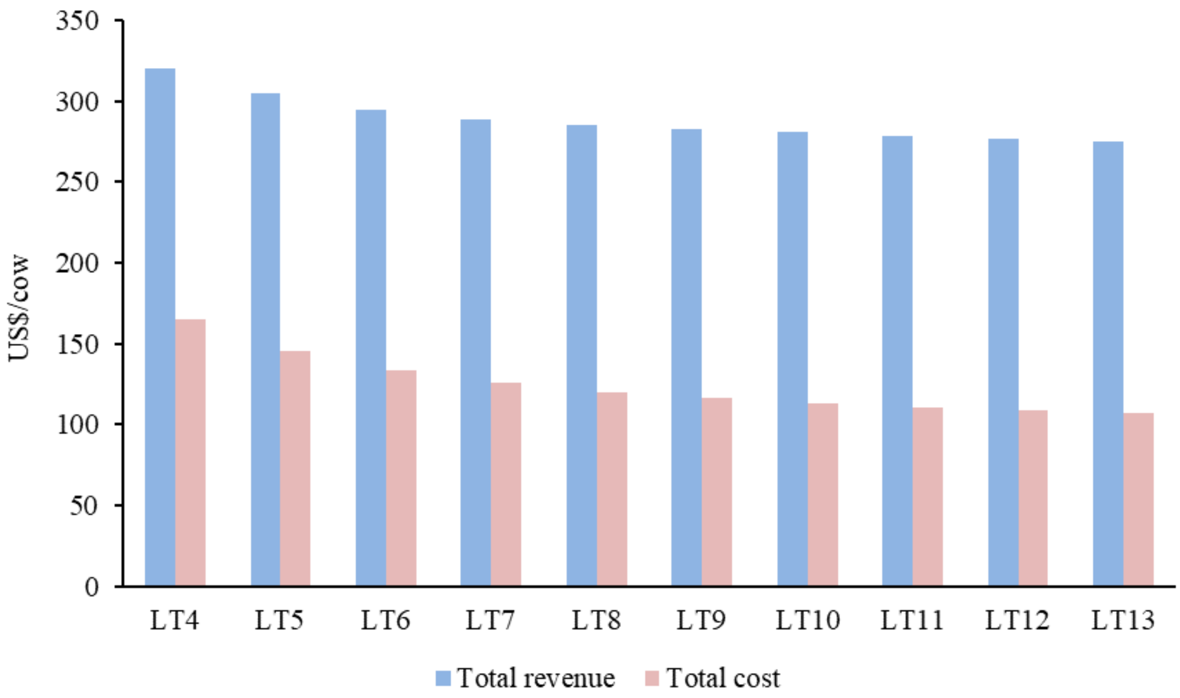

Figure 7. Total revenue (TR) and total cost (TC) per cow in 10 cow-calf systems with different lifetime cow (LT; years).

The cost of LT4 was higher than LT8 (37%) and LT13 (53.8%). The greater participation in production costs in all systems was related to the production of cultivated oat/ryegrass pasture for younger females. In addition to pasture, the items that impacted the costs in LT4 to LT6 the most were mineral salt, labor, and the purchase of bulls, presented in order of importance. From the LT7, labor became the second-highest cost and mineral salt the third.

The EEC was directly proportional to the increase in the cow culling age ($r^2 = 0.96$; $p < 0.001$), with the LT13 presenting an EEC 8.4% higher than the LT4, but only 2% higher than the LT8 (Figure 8). For the EEA, the results were contrary, with the superiority of the systems that culled younger cows ($r^2 = 0.97$; $p < 0.001$). Among the 10 cow-calf systems, LT4 had a better EEA than LT5 (5.4%), LT6 (8.7%), and LT13 (13.4%). It is noted that the EEC obtained more regularity among the systems, since, from LT10 (US$ 161.67) to LT13 (US$ 168.40), the variation was 0.4%, while the EEA varied 1.5% between those same systems.

Table 4. Composition of revenue and costs of production and gross margin of 10 cow-calf systems with different lifetime cow (LT).

Item	LT4	LT5	LT6	LT7	LT8	LT9	LT10	LT11	LT12	LT13
Revenues (%)										
Bulls	1.14	1.35	1.49	1.58	1.64	1.69	1.72	1.76	1.78	1.80
Cows	57.82	48.06	41.43	36.69	33.19	30.55	28.52	26.92	25.61	24.55
Male calves	38.69	41.89	44.00	45.32	46.20	46.87	47.38	47.82	48.17	48.46
Female calves	2.34	8.70	13.08	16.41	18.97	20.89	22.38	23.51	24.44	25.18
Total	100	100	100	100	100	100	100	100	100	100
Costs (%)										
Fixed										
Accounting	0.14	0.16	0.17	0.18	0.19	0.20	0.20	0.21	0.21	0.21
Electricity	0.58	0.66	0.72	0.77	0.80	0.83	0.85	0.87	0.89	0.90
Taxes	2.41	2.94	3.35	3.65	3.89	4.08	4.24	4.36	4.47	4.56
Maintenance	1.02	1.17	1.29	1.37	1.44	1.50	1.54	1.58	1.61	1.63
Labor	12.16	13.76	14.99	15.92	16.65	17.24	17.71	18.10	18.42	18.69
Insurance	0.62	0.70	0.76	0.81	0.85	0.88	0.90	0.92	0.94	0.95
Variables										
Purchase bulls	5.01	6.38	7.40	8.18	8.78	9.27	9.66	9.99	10.26	10.48
Oat/ryegrass	50.54	45.81	42.33	39.68	37.60	35.95	34.61	33.52	32.61	31.85
Fuel*	2.86	2.59	2.39	2.24	2.13	2.03	1.96	1.90	1.84	1.80
Veterinarian**	0.93	0.84	0.77	0.72	0.69	0.66	0.63	0.61	0.59	0.58
Pre-dried	3.59	3.70	3.63	3.58	3.55	3.52	3.49	3.47	3.46	3.44
Reproduction	3.44	3.14	2.93	2.77	2.64	2.54	2.46	2.39	2.34	2.29
Mineral salt	13.05	14.22	15.12	15.81	16.34	16.76	17.10	17.38	17.61	17.80
Animal health	3.67	3.94	4.16	4.32	4.45	4.55	4.63	4.70	4.75	4.80
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

*Fuel costs were measured for maintaining cultivated pasture.
**The disbursement to the veterinarian was calculated as a cost of cesarean section on 5% of calving from females from 22 to 24 months of age (Tozer et al., 2002).

The higher presence of young cows in the systems also required greater investment in high-cost resources, while the presence of older cows used lower-cost resources, such as natural grasslands instead of cultivated pasture. Even with the lowest biological efficiency, the older cow systems are more economically efficient. The regression demonstrated that the bioeconomic efficiency in herds of calves that have their energy requirements met is reached when culling cows is close to six years. Therefore, among the simulated scenarios, LT6 was the one with the best efficiency when considering BioE, EEC, and EEA.

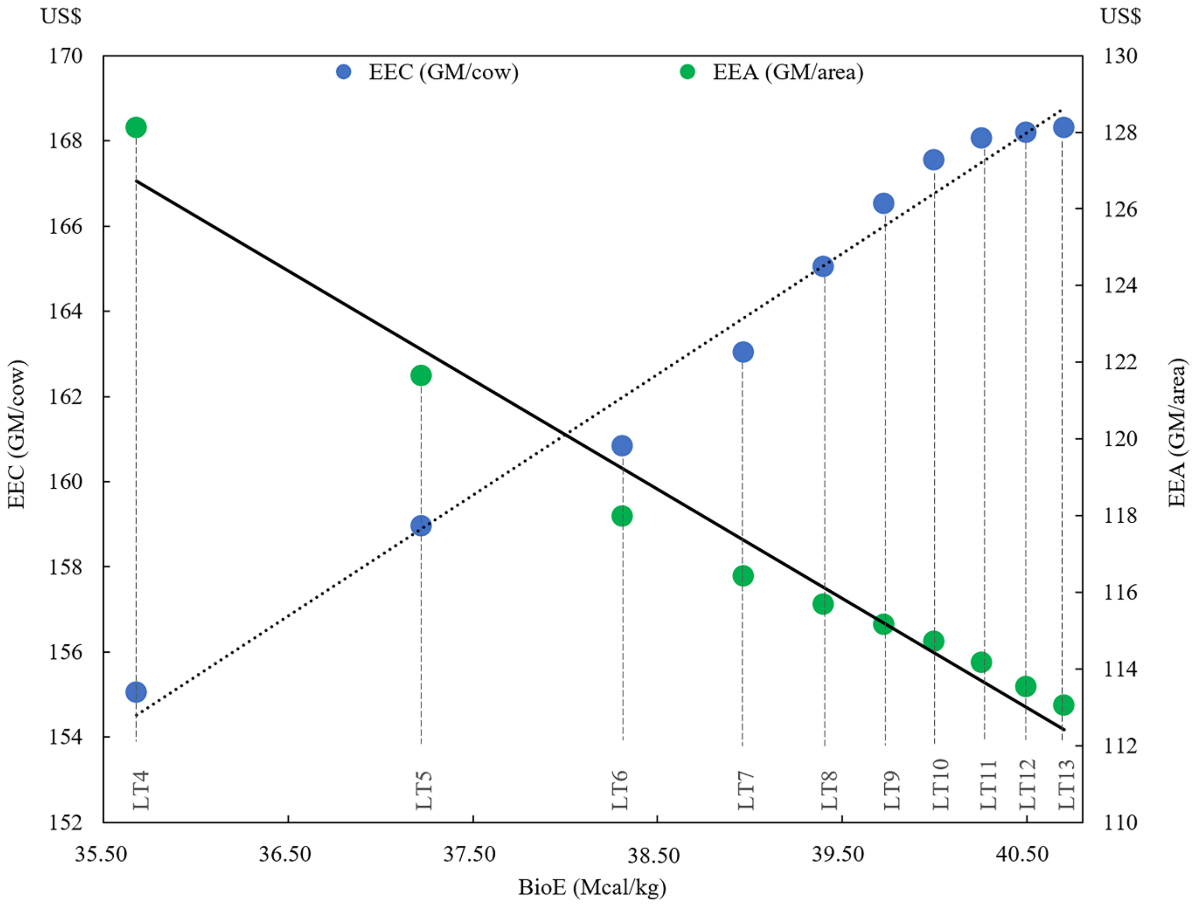

Figure 8. Linear regression of biological efficiency (BioE), economic efficiency per cow (EEC) (r2 = 0.96; p <0.001) and economic efficiency per area (EEA) (r^2 = 0.97; p <0.001) of 10 cow-calf systems with different lifetime cow (LT). Crossing point of the straight lines is the optimum point between biological and economic efficiencies.

4. Discussion

The proposed model served its purpose because it was able to satisfactorily represent a real system and was validated by performance checks and evaluations (Dent & Blackie, 1979). The herd structure submodel validated experimental data and logic (Lamb et al., 1992; Pang et al., 1999; Roberts et al., 2015; Seidel & Whittier, 2015) for its construction. The results found demonstrate coherence from the submodel entries, maintaining the appropriate proportions between the cows' age groups in each system. In comparison with the participation of each age group of cows at calving in other similar studies (Roberts et al., 2015; Lamb et al., 1992), the herd structure results were similar (Table 5). In addition, the herd structure has been verified and tested to ensure credible results.

Table 5. Percentage of cows at calving by age groups in a cow-calf herd.

Cow age (years)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
					Age group of cows at calving (%)						
Lamb et al., 1992	18	15	13				54				-
Roberts et al., 2015	17	15	13	11	10	9	8	6	5	3	3
Model	16	14	12	11	10	8	7	7	6	5	4

Data based on Angus cows; 87.5% average calving rate; 18% heifer replacement; 2% of cow mortality; 5% mortality of calves of 2-year-old cow; 2% mortality of calves of cows above 2 years old; twelve years of lifetime cow in the herd.

The culling of 50% of replacement heifers in up to five years also demonstrates the consistency of the submodel, as similar results have been reported in research that culled half of the heifers retained for replacement between four and five years after their insertion in the cow-calf herd (Schons et al., 1985; Tanida et al., 1988; Roberts et al., 2015). The greater number of replacement heifers presented in the lower LT systems is justified by the shorter lifetime cow in the herd. For the system to maintain its structure and to be stable, the number of replacement females must be the same as that of culled females, regardless of the reason for culling, infertility, low maternal ability, unsatisfactory racial standard, or age (Roberts et al., 2015; Seidel & Whittier, 2015).

Most of the equations inserted in the energy requirement submodel have been independently validated (AFRC, 1993; NRC, 2000; NRC, 2016). The exposed results were also relevant, since the consumption of 8,136 Mcal of ME/cow/year in LT11 agree with the results of Lamb et al. (1992).

The lower age of culling cows also increases the number of culled cows, even with the production of a calf. The high concentration of cows in lower age groups increases the number of cows of the last calving that are necessarily culled at weaning. Despite culling a larger number of cows, the total number of animals in the herd increases, as for each culled cow, a heifer is retained for replacement. As a result, in addition to more cows from the last calving from weaning to calving, there are also more heifers from weaning to the next reproductive period. Therefore, the younger culling age increases the number of animals in the herd and consequently leads these systems to present a higher ECM, as well as ME_m.

Another factor that accentuates the energy consumption of the herd is that the lowest LT systems have the highest number of four-year-old cows, and they are the ones that have the highest MECC among all the age groups. Even if they consume less ME_m and ME_y than mature cows, they still require ME_g to grow 4% of their live weight (Fox et al., 1992). The ME_m variations in the different systems demonstrate the coherence of the results regarding energy distribution of 68% (LT4) to 72% (LT13), as established by the classic literature of 70% (Ferrel

& Jenkins, 1985). After all, although lower LT systems consume the largest volume of ME_m, it was the higher LT systems that used most of the energy for this function, since it presents more mature animals.

These findings are essential to the rural manager who intends to reduce the culling age of cows to increase the number of cows in the system without increasing the area, as he believes that replacing a mature cow with a young cow will reduce feed consumption by the herd. In fact, at the beginning of the reproductive life, the cow consumes less ME than an adult cow. However, greater cow culling will raise the system requirement overall. Therefore, it is essential that the rural manager understands the implications imposed by this change when making decisions that influence the herd dynamics.

The reduction in the culling age of cow also increases the number of animals growing in the herd, since in LT4 and LT5 systems, only bulls from five to seven years old have reached mature weight. The greater presence of young animals in the herd justifies the superiority of ME_g consumption in these systems, given that in the first year of life, the animals allocate the greatest amount of ECM for growth functions (NRC, 2000). So, in addition to a greater number of animals to feed, these systems have the challenge of meeting the energy requirements of more demanding animals and, for this, it is necessary to invest more in better quality feed that has a higher cost.

The increase in production cost per cow and per system, as the LT decreases, is due to the high disbursement for cultivated pastures that have elevated implantation and maintenance costs. Even with the high cost, cultivated pastures are an indispensable strategy to meet the energy requirements of low LT systems and avoid culling cows due to reproductive failures or calving difficulties (Rogers et al., 2004; Stockton et al., 2014), mainly for young cows. Although only 10% of the total area of LT13 consists of oat/ryegrass pasture (144 ha), this was also the most representative item for this system. This is because feed costs are among the most onerous for beef cattle production systems (Bouquet et al., 2010; Aby et al., 2012ab). Hence, it is important to clarify that the increase in the number of animals, as the LT decreases, also contributes to the increase in costs, as there is a need for a greater feed supply.

Systems that remained with their cows for longer are composed of a larger number of mature cows, due to a greater number of age groups and, consequently, less culling by age. As mature cows are the ones that most require ME_m and ME_y (NRC, 2000), they demand that these systems use the highest proportion of ME for these functions. The same premise is valid for ME_l, with the proviso that cows at four years already consume the same amount of this energy as mature cows (NRC, 2000). As these systems cull fewer cows by age, it is also necessary to retain fewer female calves for rearing and later replacement, so the larger LT allows for selling more female calves than the smaller LT.

It is important to highlight that this performance is only possible in systems with high weaning rates and that have a feed availability compatible with the herd requirements. Otherwise, all female calves will be retained for replacement, and there will be no surplus for sale. In a study also carried out in cow-calf systems with different heifer replacement rates, the herd with the least replacement also showed a higher surplus of female calves for sale (Roberts et al., 2015). The authors justified this result with the lesser necessity to retain female calves to keep the system stable.

In contrast, the reduction in the culling age of cows in stable systems allows the increase of LW for commercialization (Seidel & Whittier, 2015). This is due to the higher average weight per animal sold in the system because, the shorter the lifetime cow, the greater the proportion of cull cows sold, which are heavier than weaned calves. It was these circumstances that allowed LT4 to achieve superiority of TLWS because, despite being the system that sold the least weaned calves, it was the one that sold the most cull cows and, consequently, obtained the highest TR. Therefore, the lower LW sale of weaned calves is offset by the higher sale of culled cows (Roberts et al., 2015). In this simulation, it is clear that the higher TR, due to higher productivity, is accompanied by higher production costs in systems with lower LT. This is due to the high system intensification to meet the energy requirements of the animals, which agrees with other *in loco* studies (Aby et al., 2012b; Anderson et al., 2013).

The inverse relation between TR and LT is caused by the increase in cull cows. The sale of a high number of animals in this category can improve the economic results of cow-calf systems (Turner et al., 2013) without compromising the herd structure, as long as the reproductive indices are adequate. This strategy can damage herd structure henceforth if there is inadequate heifer replacement. In practical terms, systems with a weaning rate below 65% cannot cull all cows that failed to wean a calf. After all, in addition to the challenge of a high energy supply for growing animals and increased production costs, the systems will not be able to replace the number of heifers needed.

Furthermore, considering that a significant number of farmers sold cows in reproductive age in past times of crisis, the state herds structure in the following years was also impacted, compromising the competitiveness of the entire beef supply chain (IBGE, 2018). Moreover, the relationship between revenue and TLWS, although direct, is not proportional because, the selling price of animals varies according to the category and must be considered in the selection of the best LT for the system, according to fluctuations and market trends.

In Brazil, the slaughter of females represents, on average, 41% of the total number of cattle slaughtered in the last year (IBGE, 2018), while in the analyzed region, the historical average is 48% (NESPro, 2018). The reasons for this high participation are the reproductive failures, culling age or strategies to increase the revenue of the systems, since, on average, the kg price of the cull cows is about 70% of the calf kg (ESALQ, 2019; NESPro, 2019), which contributes to cow-calf systems to remain competitive.

However, in other countries such as the USA, this ratio average is only 36%, with the price of cull cow kg at only 30% of calf's kg (USDA, 2019a), which discourages rural managers from increasing a system's revenue with the sale of cull cows. Therefore, the total number of kilograms sold becomes more important than the price received, since the market must be understood for the system to achieve the best economic results. In this sense, the simulations performed by this model allow the analysis of cow-calf systems and their market to assist in decision-making regarding the configurations of the herd for better efficiency.

The best BioEC presented by the two-year-old cow is a consequence of the lower proportion of ME for the maintenance function and the greater part for the production functions (ME_g, ME_l e ME_y) (NRC, 2000). Whereas, after a cow reaches ten years, it begins a gradual weight loss (Roberts et al., 2015), which also decreases the BioEC. This process of converting energy into a marketable product explains the best BioE presented by the systems with the lowest LT and confirms the hypothesis that younger cow herds are more efficient. Seidel and Whittier (2015) found the best efficiency in cow-calf systems when culling cows at 2.5 years old (LT3), after the first calf. However, this system is not supported, as it is unable to produce the necessary number of replacement heifers for the next productive cycle. Therefore, the best BioE of the herd is dependent on the highest proportion of two-year-old cows.

Although BioE was better at LT4, these systems face challenges such as high feed costs, making this LT the worst in EEC. Aside from this, the management of these herds has high operational complexity, and management failures can compromise calve production in the next cycle if the high energy requirements are not met. These results were similar to other studies, which observed a reduction in the difference in efficiency between sequential systems as the cow culling age increased. This is because there was an increase in nutrient demand and a reduction in kg production due to the greater number of mature cows (Taylor et al., 1985; Naazie et al., 1999).

Because of the lower costs, GM was higher in larger LT, which also gave to LT13 the best EEC. However, despite the smaller GM, the systems that culled younger cows had much smaller production areas, which gave these systems the best efficiency per area (EEA).

Therefore, when considering economic efficiency from an individual point of view, the system that kept its cows longer, was more economically efficient despite being less productive and biologically efficient. However, from the land-use point of view, those that remained less time with their calves were biologically and economically more efficient. Consequently, the system with the ideal bioeconomic efficiency is the LT6, which culled cows at about 5.5 years old.

Although the model is based on the particularities of Brazilian production, with a predominance in grassland production, the GM per cow among the systems (US$ 155.05 to US$ 168.30) is similar to that found in countries with developed production, such as the USA, whose average GM per cow over the past ten years was about US$ 147.61 (USDA, 2019b). This confirms that the model presents consistency and is reliable to simulate cow-calf systems in different realities and markets, being appropriate to predict its economic results.

Additionally, even if the land costs have not been considered in this model, it is an important factor in farmers' decisions for the level of investments in the system. The increase in the cost of land requires intensification of production through the improvement of productive indexes so that the system remains economically viable. In breeding systems, this is observed when there is an increase in productivity, as the proportion of young cows increases in the herd due to better quality forages. Therefore, expensive land is proper for young cow production that justifies the high investment in production. In contrast, low-priced land is generally characterized by low nutritional feed or by the impossibility of cropping, which can lead to a reduction in technological investment (Barros et al., 2002; Lampert et al., 2012). Such lands are neglected by herds with a higher proportion of adult cows that have the capacity to extract the nutrients necessary for the production of lower quality feed.

Therefore, it is clear that the culling age of cows is not imperative concerning the bioeconomic efficiency of cow-calf systems, but rather a tool for decision-making, since natural resources can directly impact the herd characteristics. Aside from this, bioeconomic efficiency is dependent on the market in which the system is inserted, and this model can predict which are the best configurations or changes that rural managers should consider for this decision-making.

5. Conclusion

Understanding and adjusting the lifetime cow in the herd is fundamental to the bioeconomic efficiency of cow-calf systems due to the modifications it causes in herd structure. This is because a larger number of young cows can improve the productivity and revenue of the system, but it also presents greater operational complexity and production cost than systems that keep older cows.

Even so, the shorter lifetime cow enables the increase of biological and economic efficiency when the production area is the primary resource of the system to generate the economic result. Nevertheless, the longer lifetime cow offers greater economic efficiency when the cow is the most relevant resource, even if the biological efficiency is lower. Hence, systems with younger cows are indicated for regions that allow production intensification and pay more for cull cow, while systems with older cows should be used where it is difficult to intensify and/or commercialize the cull cow profitably.

Therefore, it is not only the cow culling age that will define the best bioeconomic result of the system but also the capacity of the rural manager to understand his production system and to plan the cows' lifetime according to the opportunities that his system its capable of. Finally, the farmers also should consider and analyze the market to provide the product demanded by the customer and achieve the highest efficiency.

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8. Supplementary information

8.1 Supplementary information 1. Mineral supplement for reproductive period.

Nutrient	Unit	Concentration*
Calcium	g (min/max)	130/140
Phosphor	g (min)	90
Sulfur	g (min)	18
Sodium	g (min)	57
Manganese	mg (min)	2160
Zinc	mg (min)	5800
Cobalt	mg (min)	110
Copper	mg (min)	1750
Iodine	mg (min)	94
Selenium	mg (min)	31
Iron	mg (min)	280
Fluorine	mg (max)	890
Crude Protein	g (min)	210
NPN - Protein Equivalent	g (max)	150
Total digestive nutrient	g (min)	150

*Guarantee levels/kg of product.

CAPÍTULO III

Artigo preparado de acordo com as normas da revista Agricultural Systems (Apêndice)

Age of cow culling and availability of energy in the resilience of the cow-calf systems

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Abstract: The resilience of beef cattle production systems was compared by deterministic dynamic simulation. The model considered cow-calf systems initially stable and differentiated by two assumptions: A) energy availability for all animals in the system in the first year of production (Year 1) at 50% (low, L), 75% (medium, M) and 100% (high, H) according to the NRC (2000; 2016). This was restricted to 60 days before and 60 days after birth (120 days); and B) the maximum age of the cull cow, called lifetime (LT), considered at four (LT4L, LT4M, LT4H), six (LT6L, LT6M, LT6H) and eleven years (LT11L, LT11M, LT11H). From the second year, availability returned to meet the energy requirements (H) of all animals in the systems. The availability of energy for the herd was simulated in natural pasture and pasture cultivated in the winter/spring produced by the system. The productivity of the systems was determined as the relation between the sale of kilograms of bulls, cows and calves and the area used for production over a productive cycle. The system was considered resilient when 95% of the system's standard productivity was reached (prior to energy restriction). The results of time required to return to stability were better (two years) in the LT6 and LT11 systems, while LT4 required three years. However, the older the cow is hen culled, the greater the change in the composition of the product sold by the system. The availability of energy did not directly influence resilience over time. Herds that culled females before reaching adult age are less resilient after adversities such as changes in climate or of any nature that interfere with reproductive rates. In contrast, the later the cow is culled, the greater the change in the system's sales structure.

Key words: cow longevity; feed restriction; herd structure; resistance; reversibility.

1. Introduction

Cow-calf systems have been shown to be resilient (Viet et al., 2013), that is, they have the ability to return to normality after suffering disturbances related to climate change, feed availability or market alterations, especially in terms of herd structure. The decision regarding the strategy to be adopted to minimize the consequences of these disturbances must consider production objectives, structural and environmental resources, in addition to the type, frequency and intensity of the disturbances (Nozières et al., 2011). However, the difficulty in returning to the condition prior to adversity is related to the changes that occur in herd structure. This is because, to reach the prior standard of the system, it is first necessary to reorganize or recover production indexes.

Forage growth and production in cow-calf systems are subject to climatic events, such as poor distribution or scarcity of rain, which results in fluctuations in the availability of energy for the herd or even by arbitrary changes in stocking rates. This energy deficit, when it occurs in the prepartum period, can increase postpartum anestrus, decrease pregnancy rates and increase calf mortality (Richards et al., 1986; Goehring et al., 1989). In the postpartum period, variations occur in the rates of weaning and cows culled in the following years. As a result, there are changes in the herd structure due to the increase in heifer replacement, mainly because of lower pregnancy, which leads to a reduction in the average age of the herd and greater vulnerability of the system to new disturbances.

It is assumed that herds culling younger cows may be the more affected by the reduction in nutrient availability and, for this reason, may need more time to return to a stable state. Systems whereby cows have lower longevity in the herd have the highest proportion of young females (Seidel and Whittier, 2015), and these have the lowest pregnancy rates in situations of energy restriction in the pre and/or postpartum period (Bellows and Short, 1978; Goehring et al., 1989). However, the age of the cull cow and the availability of energy in the resilience of cow-calf systems have not yet been evaluated and should be validated through analyzes that consider different herd structures.

The cost, complexity and level of control required for an analysis *in loco* of these systems makes comparison impossible through experimentation. In contrast, simulation models can be used to analyze the interaction between the factors of the production systems, at low cost and quickly (Viet et al., 2013). This study identifies the time needed for cow-calf systems to reach resilience using different cow longevities and when submitted to different availability of energy in pre- and postpartum periods.

2. Methods

2.1 Model overview

The time until return to a resilient state of cow-calf systems of beef cattle was compared using a deterministic dynamic model, after energy restriction (ER), common when facing climatic adversities, in the pre- and post-partum period. The model was designed using Microsoft Excel spreadsheets and the input data were obtained from relevant scientific articles. These included technical coefficients and assumptions for the evolution of typical herds (Feuz and Skold, 1990) from cow-calf systems in exclusively rangeland systems.

The model was developed with stable production systems of 1,000 British breeding cows with a mature weight of 480 kg. The differentiation criteria of the systems were: the level of metabolizable energy (ME) offered to all animals in the system only in the first year of production (Year 1), considering availability of 50% (low energy, L), 75% (medium energy, M) and 100% (high energy, H), for 120 days (60 days pre and 60 days postpartum), according to NRC recommendations (2000; 2016). The age of the cull cow, called lifetime in the herd (LT), was considered at four (LT4L, LT4M, LT4H), six (LT6L, LT6M, LT6H) and eleven years (LT11L, LT11M, LT11H), which resulted in nine scenarios. From Year 2 (post energy restriction), availability returned to meet the energy requirements (high energy) for all animals in each system.

To compare the systems, the following model assumptions were used: stable herd structure in year zero (Year 0; pre-restriction), with distribution of the age groups of bulls and cows based on technical indicators under high energy availability and scale of 1 (very thin) to 5 (very fat) for Body Condition Score (Houghton et al., 1990); variations in technical indicators in Year 1 (Table 1); stability obtained when productivity reached 95% of the system standard (pre-restriction); resilience considered when herd returned more quickly to pre-restriction state.

Table 1. Assumptions of simulation model of the cow-calf systems according to lifetime cows and level of energy supply to animals in Year 1.

Year 1	Low energy (LE)	Medium energy (ME)	High energy (HE)	Reference
Calving rate (%)				
2-year-old cows	88	88	88	
3-year-old cows	87	87	87	1, 2
4-year-old cows	88	88	88	
Cows above 4 years old	88	88	88	
Pregnancy rate (%)				
1-year-old cows (13 to 24 months)	46	73	92	

2-year-old cows	53	78	91	
3-year-old cows	64	79	92	
4-year-old cows	68	79	92	
Cows above 4 years old	68	79	92	
Birth weight (kg)				
Calf of 2-year-old cow	31.4	33.3	35.0	
Calf of 3-year-old cow	32.3	34.5	36.1	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Calf of 4-year-old cow	32.8	35.1	37.2	
Calf of cow above 4 years	33.5	35.8	38.0	
Mortality rate (%)				
Calf of 2-year-old cow	10	7	5	
Calf of 3-year-old cow	5	2	2	3, 5, 6, 14
From weaning to 12 months	3	3	3	
Cows	2	2	2	

Low, Medium and High: 50%, 75% and 100% of the animals' metabolizable energy requirements met, respectively. References: 1. Rumpf & Van Vleck, 2004; 2. Roberts et al., 2015; 3. Wiltbank et al., 1962; 4. Bellows & Short, 1978; 5. Goehring et al., 1989; 6. Corah et al., 1975; 7. Gregory et al., 1990; 8. Houghton et al., 1990; 9. Perry et al., 1991; 10. Wiley et al., 1991; 11. AFRC, 1993; 12. NRC, 2000; 13. NRC, 2016; 14. Pang et al., 1999.

The interaction between the dynamics of the herd structure and the supply of energy to the animals was used for the development of the herd structure and forage production submodels, as described by Sessim et al. (2020).

2.2 Herd structure submodel

The simulation was operationalized from the beginning of the breeding season, which lasted 90 days (November 1st to January 29th). In this model, bulls were purchased at two years of age, used for six breeding seasons, and subsequently sold, at an annual culling rate of 20%. Cows from two years of age are mated by natural breeding at a ratio of one bull to 25 females, while heifers undergo artificial insemination (A.I.) at 14 months of age. Gestational losses of 4% were considered for all systems (Dunne et al., 2000) after pregnancy diagnosis on March 1st. The calving season occurred from August 16th to November 18th and was divided into four 21-day periods (Pang et al., 1999).

The maximum age for cull cows, calving, weaning and mortality rates, varied according to the proportion of cows in each age group. Cows that failed to calve were culled at the end of the calving season, while cows that did not wean their calf or that reached the arbitrary LT for each system were culled at weaning on April 1st (Figure 1). However, after the climatic disturbance characterized by the level of energy restriction (Year 1), the retention of cows that did not wean a calf was only admitted in cases where the system does not produce sufficient replacement heifers for the maintenance of the herd (1,000 cows). In this circumstance, the retention priority was for the youngest cows. The number of cows that calved and weaned a calf in relation to the number of cows subjected to mating in the previous season represented the rates of calving and weaning, respectively (Barcellos et al., 1996).

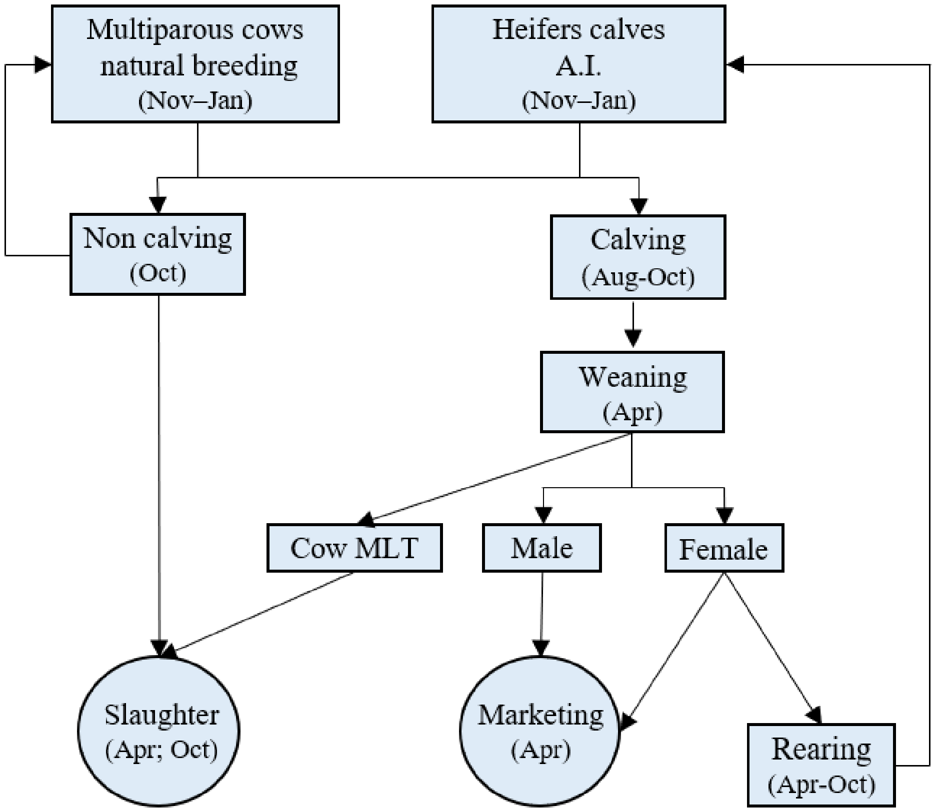

Figure 1. Cow-calf system flowchart (A.I.: Artificial Insemination; MLT: Maximum Lifetime).

Replacement heifer retention was decided at weaning and the criterion was maintenance of the heaviest females, considering only those produced in the system to maintain the herd with 1,000 cows. There were no purchases of animals from outside the system. When the number of heifers produced did not reach the minimum necessary for replacement, before ER, the system was not simulated, as it would not remain stable. For this reason, LT4 was the youngest simulated system. Despite the retention of cows in this system that failed to conceive, this practice is not advised, not only because it limits genetic improvement of the herd but also increases costs by maintaining a non-productive cow for a year. In this study, it was considered necessary to maintain herd size.

Female calves that were not used to recompose the system and all male calves were sold after weaning. The Total Production (TP) of the scenarios was obtained by sum of the kg sold in each category, and the productivity by the relation between TP and the area used for production (kg/ha). For all systems, the same weight of the animals was considered, in each age group, both at the time of sale, and for the animals that remained in the herd.

2.3 Forage production submodel

This submodel was used to calculate the stocking rate capacity of each breeding system. The production area in hectares (ha) was estimated prior to the energy restriction, so that the systems could fully meet the energy requirements of animals in a herd of 1,000 cows. Thus, LT4, LT6 and LT11 had their area fixed at 1,210, 1,363 and 1,472 ha, respectively. Energy restriction was considered as the reduction of forage availability without alteration in the production area, based on the premise that the size of the farm is fixed.

The construction of the submodel was based on data from natural pastures typical of the Southern region of Brazil (Carvalho et al., 2017) and scientific articles looking at cultivated oat/ryegrass pastures (*Avena strigosa/Lolium multiflorum*) (Restle et al., 1999; Roso et al., 1999; Piazzetta et al., 2009) to estimate forage mass, daily accumulation rate, grazing rate and metabolizable energy of forage in the interval of two standard deviations from the mean. The use of native pasture throughout the year was considered, while oat pasture (April to August) with ryegrass (May to October) only from April to October. Manual verifications of the input parameters and the results obtained in the submodels were carried out throughout their construction to avoid distortions or typing errors. In addition, careful validation based on relevant scientific references was performed to ensure the model's representativeness.

The model was run for a period of seven years, from the climatic adversities in Year 1 to the total reestablishment of productivity in all systems in Year 7. Thus, the results confirmed the permanence of resilience after having been this had been reached.

3. Results

Changes in the herd structure are demonstrated in all systems (Figure 2), with a rupture in the harmonic distribution of the age groups in Year 2. LT4 and LT6L had a higher participation of calves in their herd structures, but in the year immediately following the restriction there was a predominance of one year old heifers. In LT11L there is a similar movement, but adult cows are predominant in appropriate situations and after the restriction they lose their participation to the heifers and take four years to recover normality. Furthermore, there was a reorganization of the systems over the years, with higher speed in LT6 and LT11.

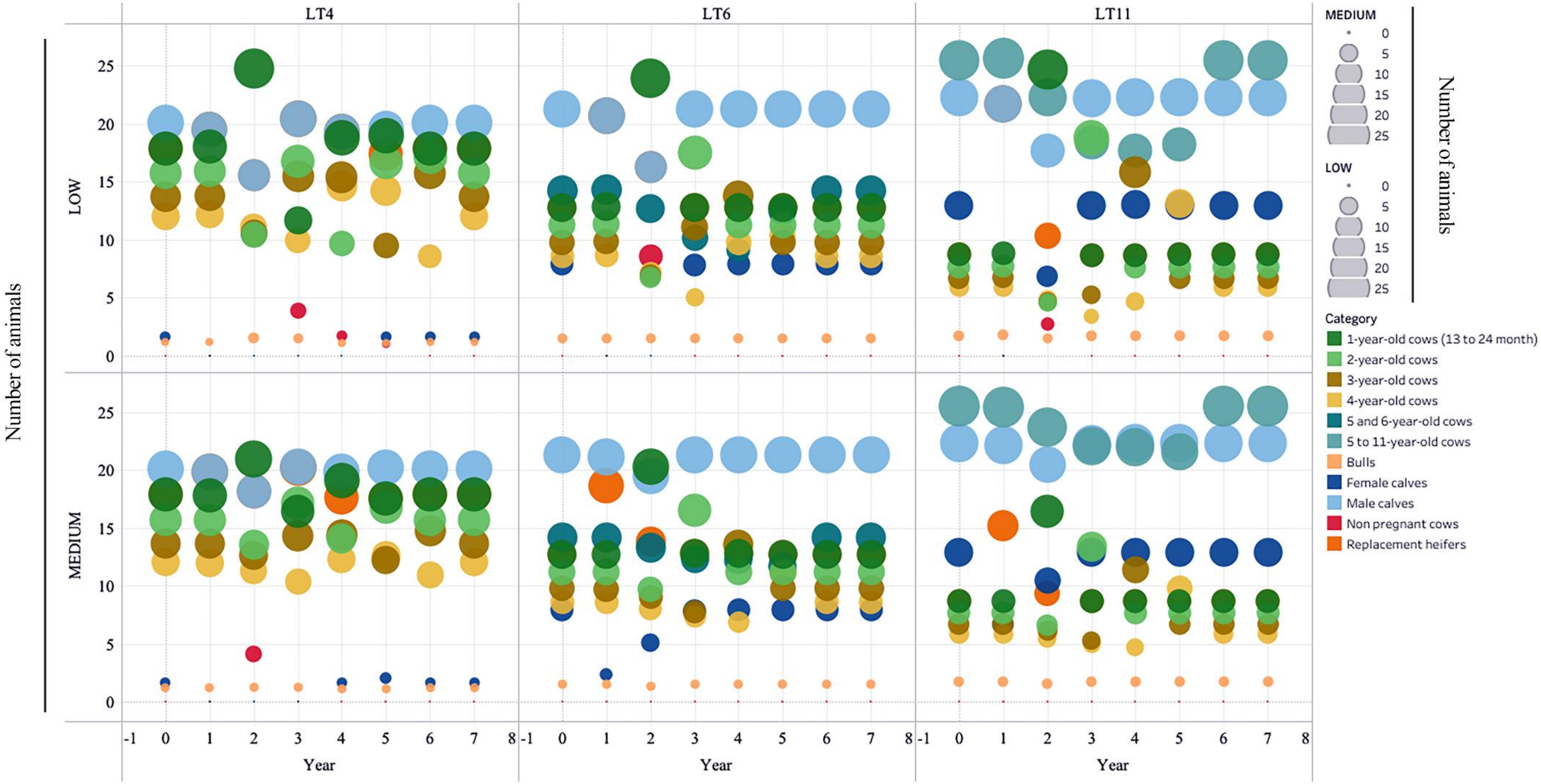

Figure 2. Herd structure of three cow-calf systems (1,000 cows) with different lifetime of cows (LT) and different levels of energy availability over seven years. Bubble size represents the number of animals in herd. LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

The reduction in the age of cull cow and low energy require a greater retention of non-pregnant cows so that the herd remains at the same size and does not hinder the production of calves in the coming years. The highest retention of non-pregnant cows after energy restriction was observed in LT4L (27%), followed by LT6L (14%), LT4M (8%) and LT11L (4%). In addition, LT4L needed to retain non-pregnant cows for four years, while the rest needed only the year after the restriction.

The decline in the weaning rate in Year 2 was greater in low energy systems compared to their normal levels (prior to energy restriction), with the largest reduction recorded in LT4L (41%), followed by LT6L (36%) and LT11L (33%) (Table 2). The decreases observed in three systems of medium energy were smaller and similar (about 16%). When comparing the variation in the productivity rate between systems of the same cow LT, an average reduction of 57% is observed in low energy systems.

Table 2. Weaning rate (%) of cow-calf systems with different lifetime cow (LT) and energy availability.

Systems	Energy availability	Year 1	Year 2	Year 3 to Year 7
	Low	81.6	49.8	85.0
LT4	Medium	84.3	70.9	85.0
	High	85.0	85.0	85.0
	Low	82.3	54.3	85.5
LT6	Medium	84.9	72.1	85.5
	High	85.5	85.5	85.5
	Low	82.7	57.6	85.8
LT11	Medium	85.4	72.9	85.8
	High	85.8	85.8	85.8

LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

The composition of kilograms sold demonstrated that LT4 were the systems that had the highest proportion of cows (65%) prior to energy restriction. Both LT6 obtained the same representation of kg of cow and calf sold (49%). In contrast, the kg sold in LT11 was predominantly of calf origin (64%) (Figure 3).

After the energy restriction, there was variation in kg sold for more than two years only in LT4L (Year 1 to Year 5). The kg of cow sold decreased by 7% in Year 3, while in other years there was an average increase of 3.5%. All other systems varied only in Year 1 and 2. During this period, LT4M obtained an average increase of only 3% in the kg of cow sold, while LT6L and LT6M of increased by 18% and 14%, respectively. LT11L was the system with the greatest variation in kg sold, with an increase of 31% in cow kg, while in LT11M it was 18%.

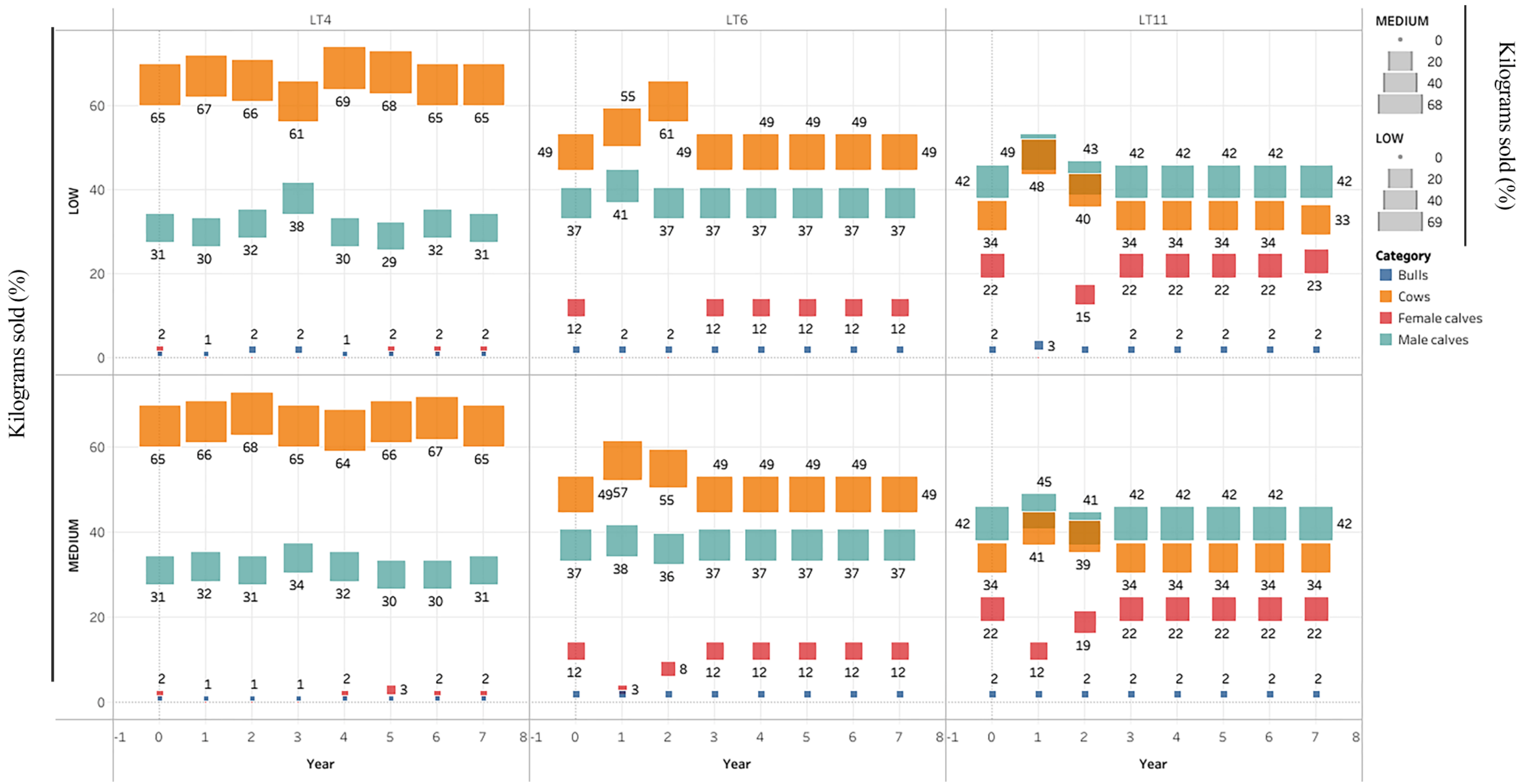

Figure 3. Stratification of kg sold for each category of beef cattle in three cow-calf systems with different cow lifetimes (LT) and energy availability (Low and Medium). Year 0 expresses the constant distribution of kg sold prior to the restriction. Box size represents the kilograms sold (%). LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

The return of productivity to pre restriction levels meant that systems that remain with their cows until adulthood are more resilient than those that cull young cows, independent of the level of energy availability to which they are submitted (Table 3). LT6 and LT11 needed only two years to reach return to normal with a restriction or disturbance characterized by low or medium energy, while for LT4 a further year was needed.

Table 3. Productivity (kg/ha) of cow-calf systems with different lifetime cow (LT) and levels of energy availability.

System	Energy availability	Year							
		0	1	2	3	4	5	6	7
LT4	Low	207	191	118	172	221*	228	205	207
	Medium	207	196	178	192	211*	216	215	207
LT6	Low	163	130	105	159*	160	162	163	163
	Medium	163	156	143	161*	161	162	163	163
LT11	Low	137	108	91	134*	134	136	137	137
	Medium	137	126	120	136*	136	137	137	137

*Moment when system returned to pre-restriction levels. LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

The highest LT also demonstrated better productivity control, since they obtained and remained with values close to those produced in high energy situations from Year 3 on (Figure 4). In contrast, LT4 required at least five years to return and remain at the system's normal productivity, which also demonstrates the greatest difficulty in achieving stability.

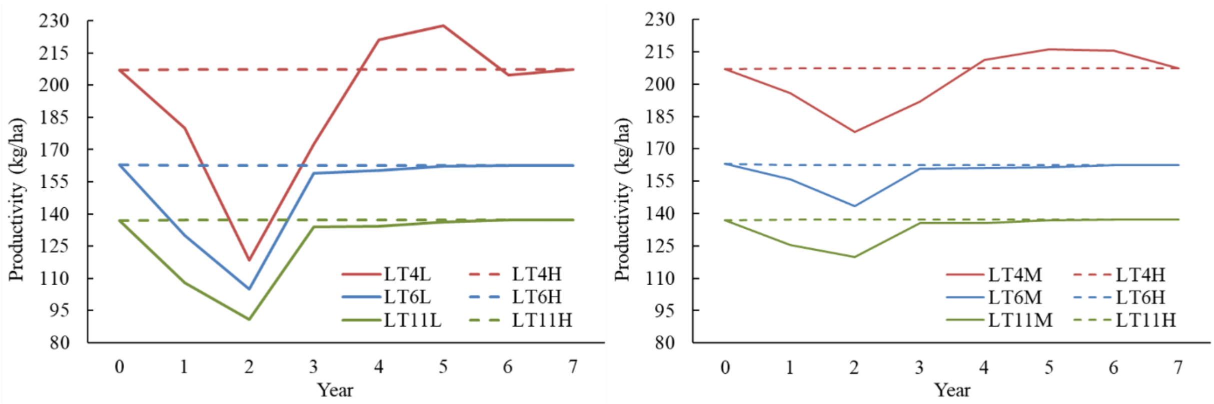

Figure 4. Productivity of three calves systems with different lifetime cow (LT) at low (L), medium (M) and high (H) energy availability levels. LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

Moreover, to the shorter time to return to pre-restriction levels, systems with cull cows of intermediate and high age suffered a lower decrease in productivity than systems that remained for less time with their cows, independent of the level of energy available (Figure 5). In the low energy scenario, LT4 obtained a productivity reduction of 19 and 26%, respectively, greater than LT6 and LT11, while with medium energy the decrease was 17% higher than the other two systems. In the year that LT6 and LT11 reached pre-restriction levels (Year 3), LT4L and LT4M achieved productivity of 17 and 8%, respectively, below their normal level.

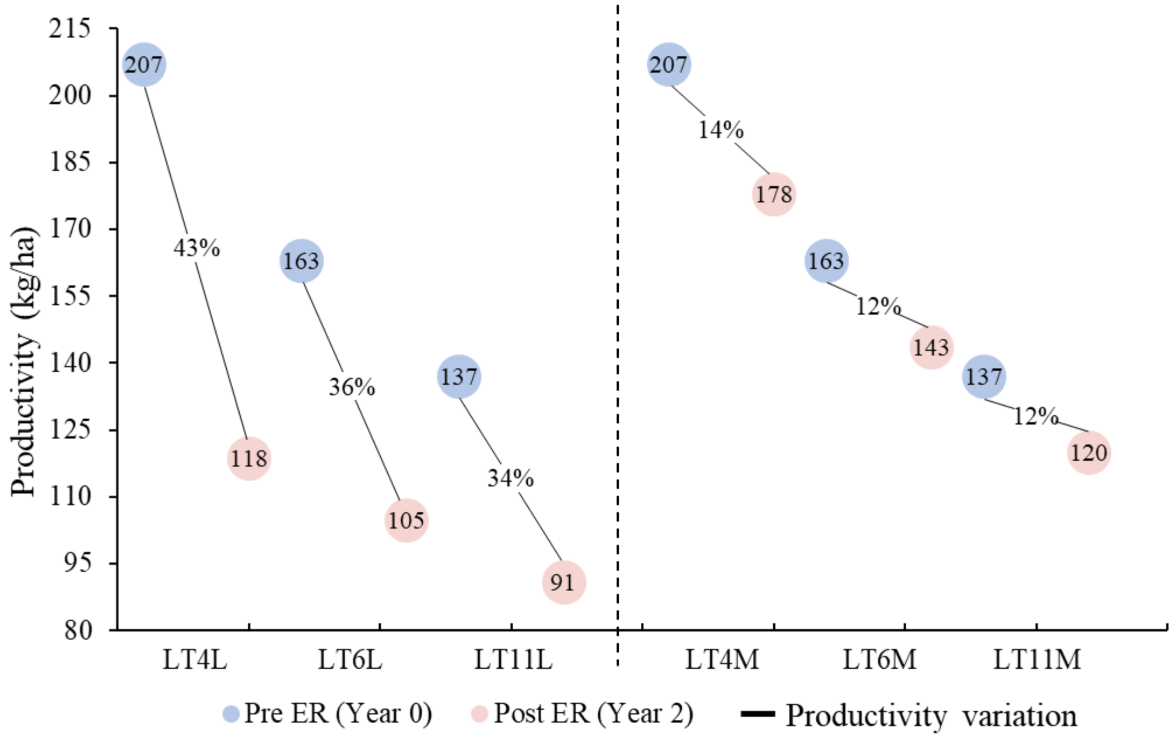

Figure 5. Productivity of three cow-calf systems with different cow lifetime (LT) in the years of pre energy restriction (Pre ER) and post energy restriction (Post ER). The energy restriction (ER) was based on the availability of energy considered to supply the requirements of the animals in the herd, in which: in ER the energy availability of 50% (Low) and 75% (Medium) was considered and in the Pre ER and Post ER it was considered 100% of energy availability (High). LT4: cow lifetime of four years; LT6: cow lifetime of six years; LT11: cow lifetime of eleven years.

Despite needing the same time to return to normal after low energy availability, LT6 saw a reduction in productivity 6% higher over LT11. However, when subjected to the availability of average energy, these systems showed a similar decrease.

4. Discussion

The model developed here properly portrayed part of a real system and was validated by verification and performance evaluations (Dent and Blackie, 1979). Logic and validated experimental data (Lamb et al., 1992; Pang et al., 1999; Roberts et al., 2015; Seidel and Whittier, 2015) were used for the construction of the herd structure submodel. The proportions that were maintained between the age groups in each system demonstrate the consistency of the results when the availability of energy was high. Similar studies have shown equivalent herd structure results when comparing the participation of each age group of cows at calving (Lamb et al., 1992; Roberts et al., 2015). In addition, verifications and tests were carried out on the herd structure to ensure that the results were in line with reality.

The decline in the calving rate forced some systems to retain non-pregnant cows in the year after the nutritional disorder, since there were not enough heifers for replacement. Retention was used as a strategy to minimize the effects caused on the herd's structure (Gunderson, 2000) and to reduce the time to return to stability. This strategy was used on a larger scale in herds that culled younger cows, as the proportion of young cows with a greater reduction in calving rate under conditions of restricted energy intake is higher in herds that cull younger cows (Bellows and Short, 1978; Richards et al., 1986).

The proportion of one (13 – 24 months old) and two (25 – 36 months) year-old females (71%), and the absence of adult cows in LT4L, led to a higher retention of non-pregnant cows among the systems, due to the low calving rates associated with the high necessity for system replacement. Despite a slightly lower participation of one and two-year-old females in LT6L (48%), the retention of non-pregnant cows was practically half that of LT4L. This is because the system has adult cows that produce a higher number of heifers due to a higher calving rate. This is also the reason why LT4M retained non-pregnant cows. Even though it received more energy than low energy systems, the high percentage of one and two-year-old females caused a significant decrease in heifer production, which prevented a minimum production to maintain the number of calves constant.

In addition to having the highest retention of non-pregnant cows, LT4L needed to retain them for four years to reverse the instability caused in the herd's structure and reach the pre-restriction state, as only 50% of the cows mated in the previous year weaned their calf. Although retention of non-pregnant cows was a strategy to reorganize the herd, it was clear that it prevented the increase in the sale of calves and cull cows, which increased the time for the system to return to productive stability and achieve resilience.

Failure to impregnate within the mating season is the main reason that leads to cull cows under appropriate nutritional circumstances (USDA, 2010). In addition to causing a productive reduction in the system (Nasca et al., 2015; Roberts et al., 2015) it prevents genetic improvement of the herd with the production of replacement offspring and subfertility may be transmitted to their daughters. However, the nutritional quantity and quality are preponderant to minimize the elimination of cows from the herd due to reproductive failures (Rogers et al., 2004; Stockton et al., 2014). Therefore, in situations where the availability of low energy results in a reduction in the pregnancy rate (Wiltbank et al., 1964; Corah et al., 1975) it is acceptable that cows are not culled, as the main reason for not having producing a calf is inadequate nutritional level of the animals and not reproductive problems inherent to the cow.

The variation in the weaning rate of the systems in Year 1 was only due to the increase in calf mortality, as the energy levels used do not cause significant losses at the end of pregnancy (McFarlane et al., 2018). In contrast, the retraction in the weaning rate of LT4L in Year 2 was due to the greater difficulty that one and two-year-old females have to be pregnant with an energy supply that supplies only half of their requirements (Wiltbank et al., 1964; Dunn et al., 1969; Wiley et al., 1991). This is because the culling of younger cows induces the system to a higher replacement with heifers and, therefore, to a higher proportion of cows that calved for the first and second time compared to systems that culled older cows (Roberts et al., 2015; Seidel and Whittier, 2015). This explanation also clarifies the higher reduction in the weaning rate in LT6L compared to LT11L.

The lower number of calves weaned also has a direct effect on the kg of cow and calf sold, in addition to reducing the productivity of the calf system (Lampert et al., 2020). The decrease in calf production can increase the number of cows to be culled (Turner et al., 2013). In this study, the greater reduction in the sale of calves, associated with the smaller decline in the sale of cull cows, explains the higher increase in the share of kg of cows sold in the systems that cull older cows. The disorganization of these systems, after a prejudicial climatic event, was contained with the retention of heifers and little or no retention of cows that failed to wean a calf.

It is natural that systems submitted to a lower energy availability increase the proportion of kg of cow sold, since the production of calves is lower (Dunne et al., 1999; Ciccioli et al., 2003). However, when the system does not reach the production of heifers necessary for replacement and retains non-pregnant cows instead of selling them, the increase in this proportion can be mitigated. LT4L was the only system that obtained a lower increase in the share of kg of cow sold compared to its analogous medium energy system (LT4L) in the first two years of the simulation. This is explained by the higher reduction in the sale of cull cows, among all systems until to Year 5, necessary for the reorganization of the herd. In addition, the approximation of the percentages of the kg of cow and calf sold in LT4L in Year 3 was due to the reestablishment of the sale of male calves. However, the sale of cull cows was still reduced to maintain a constant number of breeding cows.

Although systems that cull younger cows suffer higher losses in calf production under intense depression of energy availability, they cull older cows and show higher alterations in their sales product (kg live weight). This is because of their higher dependence on the commercialization of calves, which makes them more susceptible to variations in the structure of their sales under crises of energy and productivity. In addition to determining the best LT for the cow-calf herd, it is essential that the manager considers the market in which the system is inserted, since the increase or reduction in kg of cow or calf sold reflects on the economic result (Turner et al., 2013; Ash et al., 2015).

Systems that cull young cows are indicated for countries like Brazil, because, despite being a by-product of the calf produced, females make up to 48% of the total of cattle slaughtered in Brazil (IBGE, 2018; NESPro, 2018) and remunerate about 70% of the price paid for the calf (ESALQ, 2019; NESPro, 2019). These market characteristics allow greater security for the production of these systems in the face of unfavorable weather and market periods. However, for countries like the USA, where cows make up just over 35% of the animals slaughtered and their sale pays an average of only 36% of the calf price (USDA, 2019), systems that cull older cows are more advisable. Even with the higher change in production in periods of dietary restrictions, the sale of kg of calf remains higher than that of cows in these systems.

The shorter time to resilience presented by LT6 and LT11 occurred due to the greater capacity that these systems have in increasing the retention of replacement heifers to anticipate recovery caused by bad weather conditions. This mitigates the disorganization of the herd and, therefore, allows faster return to the pre-restriction state and are therefore more resilient. This strategy, of anticipating problems with the retention of more animals than is necessary for the moment, but which will be necessary in the future to avoid the impacts caused by adversities, is common among rural managers (Gunderson, 2000).

The longer time for the LT4M to return to the pre-restriction state confirms that the capacity to retain heifers is preponderant to reduce its effect. Even though the weaning rate was similar to the other medium energy systems, there were not enough heifers to prevent the herd structure from breaking down and it was necessary to retain non-pregnant cows. As a result, the reduction (~ 10%) of its best-selling product (kg of cow) persisted until Year 3, which prevented it from returning to stability earlier. The greater resilience of cow-calf systems is dependent on the flexibility of the herd replacement categories and the rural manager's predisposition to adapt the herd for the period necessary to resolve crises or anticipate a lasting problem (Mosnier et al., 2009).

The lower retention of non-pregnant cows and for fewer years for LT4M compared to LT4L did not guarantee its return to pre-restriction state in a lower time frame. However, the system demonstrated better control over productivity by obtaining a lower reduction and lower peaks after reaching resilience. In years 4 and 5, the higher productivity compared to the system standard in years of high energy observed in LT4L is due to the higher sale of cows at maximum age. This is because, during this period, non-pregnant two-year-old females held in Years 2 and 3 reached the predetermined age limit for the system to cull them. The productivity peaks of LT4 after resilience, demonstrate the greater vulnerability that a herd structure in a young system, composed of few age groups, presents in the face of unfavorable climatic situations. This suggests that the lower diversification of individuals in a system makes it less resilient (Peterson et al., 1998), but can be easily corrected by retaining cows until a later age.

The reduction in productivity in all systems reflected the abrupt decline in the pregnancy rate of cows due to energy restriction. The biggest decline obtained among low energy systems by LT4 was a consequence of the disorganization of the herd, which led the system to a longer time to resilience. During this period, sales were 43% below standard, due to the greater reduction in the sale of cows and mainly due to the lower weaning rate. In a similar simulation model, a calf system subjected to different calf pregnancy and mortality rates for two to five years, required two to three years to achieve system resilience and four years in the scenario of greater reduction pregnancy rate (Viet et al., 2013). Although the disorder remains present for longer than in this study, resilience behaved similarly.

In cow-calf systems, the time to return to pre-restriction levels is dependent on the structure of the herd prior to stress (Nozières et al., 2011) and, in this simulation, it was clear that systems that already have adult cows in the herd are more resilient after a unfavorable weather conditions or other causes of short-term feed restriction. In addition, the short-term disorder has the same time necessary for resilience in medium-term disorder (Viet et al., 2013), provided they are foreseen, and the losses mitigated. Moreover, the greater intensity of the stress generated does not increase the time to resilience, because similar LT systems present the same time to return to stability, regardless of the level of the changes caused. However, those who do not have adult cows in their composition (LT4) present greater disorganization of the herd in the face of different intensities of climatic stress.

The assessment of resilience in sequential years right after climatic stress can cause misinterpretations. This is because herds that have the highest magnitude in the decrease in productivity are those that depend more on the sale of culled cows. However, they need to retain them so as not to suffer major disorganization in the herd structure, which leads to a slower return to productive stability. Therefore, it is recommended that the assessment of resilience be considered at longer intervals, but with frequent monitoring of changes in the system.

The climate to which the herd is subjected should also be considered to determine the ideal age to cull cows. The scarcity of feed related to the unfavorable weather conditions, even for relatively short periods, causes more prolonged damage to the systems where the cow is culled at a younger age. One measure that can be adopted to overcome this problem is the production and storage of preserved forage in good years to offer to animals and mitigate the effects of reduced energy availability. In addition, the purchase of preserved forage, or even supplements, can also be a solution in this case, despite the considerable increase in costs that this strategy represents. Thus, for these decisions it is necessary to consider the economic feasibility of implementing these technologies in future research.

Finally, this model allows the simulation of the dynamics of the herd structure of cow-calf systems in the face of biological disturbances initiated by any nature. In addition, parameters with different characteristics can be insert in order to analyze the duration of their impact on the production of the system. Another possibility is to connect it to other models, such as an economic model as already developed in other research (Stockton et al., 2014; Nasca et al., 2015; Thomas et al., 2015), but with the intention of evaluate the bioeconomic resilience of the cow-calf system.

5. Implications

Adjusting the lifetime cow in the herd is essential to mitigate problems in cow-calf systems generated by unfavorable weather or market periods that cause changes in the structure of the herd. The age at culling of the cow is decisive for greater resilience, while the intensity of the disturbance tends not to incur losses. Systems with intermediate and high lifetime for cows suffer lower productivity decreases after an energy restriction and there is a necessity for less productive cycles to achieve resilience due to the lower deconfiguration of the herd. In contrast, the shorter lifetime cow is slower to obtain resilience, but allows for lower changes in the system's sales structure, which are aggravated by the increased intensity of energy restriction.

Thus, regions that are more susceptible to variations in feed availability and difficulties in purchasing feed in times of scarcity, should be prioritized for cow-calf systems that already have adult cows in their structure. In contrast, systems based on younger cows should consider regions for their production where there is higher certainty of the provision of adequate feed for animals or higher ease of purchase in times of feed scarcity. In addition, satisfactory remuneration for the cull cow is decisive for the survival of this type of system.

To reduce the time for the system to return to its pre-restriction state, as well as the intensity of the impacts caused by disturbances in the system, the rural manager should determine the age at which the cow is culled based on previous knowledge such as: 1. Behavior of the climate to which the system will be submitted; 2. Feed production and conservation in favorable periods; 3. Possible food suppliers; and 4. Buyers' market capable of absorbing farm product.

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CAPÍTULO IV

Considerações finais

Compreender e ajustar o tempo de permanência da vaca no rebanho é fundamental para a eficiência e a resiliência de sistemas de cria. Isso porque a presença de mais vacas jovens pode melhorar a produtividade e a receita do sistema, mas também possui alta complexidade operacional e custo de produção.

Ainda assim, o menor tempo de permanência da vaca permite o acréscimo da eficiência biológica e econômica, quando a área de produção for o recurso mais importante do sistema e for considerado para gerar o resultado econômico. Entretanto, apresentam alta vulnerabilidade frente às intempéries climáticas, ou a qualquer tipo de restrição alimentar, e maior tempo para atingir a resiliência do que sistemas que mantêm vacas em idades mais avançadas. Por outro lado, sistemas de maior tempo de permanência da vaca possuem melhor eficiência econômica quando a vaca de cria é o principal recurso, mesmo que a eficiência biológica seja inferior. Além disso, apresentam resiliência em um menor tempo apesar de sofrerem maior alteração da estrutura de venda sob intempéries climáticas.

Dessa forma, os sistemas com vacas mais jovens são indicados para regiões que permitam a intensificação da produção, paguem mais pela vaca de descarte e sejam menos suscetíveis às variações climáticas. Enquanto locais onde há dificuldade de intensificação e comercialização da vaca de descarte de forma lucrativa, além de, clima de alta instabilidade, devem ser explorados preferencialmente por sistemas de vacas mais velhas.

Uma possível limitação desse estudo é que o modelo assume valores determinísticos para alguns custos variáveis como sal mineral e sanidade animal, além de uma distribuição pré determinada para mortalidade dos animais do sistema, quando, talvez, esses *inputs* fossem melhor representados por seus padrões estocásticos. No entanto, esses pontos técnicos não minimizam a relevâncias desses resultados.

O estudo da resiliência abordou apenas os aspectos físicos do sistema de cria; portanto, é possível realizar simulações econômicas sob esse tema. Além disso, deve-se avaliar a viabilidade de criar mecanismos de intervenção para mitigar os efeitos ou riscos gerados por escassez de alimentos.

O modelo proposto não teve o objetivo de avaliar os aspectos relacionados ao progresso genético do rebanho de cria que está envolvido com o aumento ou redução do intervalo entre gerações. Em sistemas reais os gestores mudam as estratégias dos sistemas ao reter, muitas vezes, animais indesejáveis ou prolongar a permanência da vaca, porque seguir uma política de descarte poderia reduzir o rebanho e a produção futura. Comprar novilhas de reposição em um país onde as taxas de natalidade são relativamente insuficientes para um elevado descarte seletivo, pode também incorporar no sistema animais de baixo potencial genético oriundo de rebanhos que não tem excedente de fêmeas, mas que as comercializam como oportunidades de mercado.

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Apêndice

Apêndice 1. Endereço eletrônico do Guia para Autores da revista Agricultural Systems.

Os manuscritos do presente estudo serão submetidos na revista Agricultural Systems conforme o Guia para Autores (https://www.elsevier.com/wps/find/journaldescription.cws_home/405851?generatepdf=true). A Agricultural Systems possui atualmente Fator de Impacto 4.131 e Qualis A1.

Vita

Amir Gil Sessim, filho de Paulo Roberto Dias Sessim e Magali Gil Sessim, nascido em 29 de junho de 1987, em Porto Alegre – RS. Cursou o ensino fundamental na E.E.E.M. Albano Alves Pereira em Palmares do Sul – RS e no Colégio Marista São Pedro em Porto Alegre - RS, e o ensino médio no Colégio Marista São Pedro em Porto Alegre - RS. Em 2008, ingressou no curso de Medicina Veterinária, na Universidade Federal de Pelotas – UFPel – RS. Durante os anos do curso desenvolveu atividades de pesquisa e extensão junto aos grupos LADOPAR, NUPEEC e LIPOA sob as orientações dos professores Tania Regina Bettin dos Santos, Márcio Nunes Corrêa e Helenice Gonzales de Lima, respectivamente. Formou-se em Medicina Veterinária em dezembro de 2012 e iniciou trabalhos com sistemas de ciclo completo de bovinos de corte em Dom Pedrito – RS. Em abril de 2014 ingressou no Mestrado em Produção Animal, pelo Programa de Pós-Graduação em Zootecnia – UFRGS, sob orientação do professor Júlio Otávio Jardim Barcellos e desenvolveu o trabalho de "Análise econômica de sistemas de produção de bovinos de corte na região do pampa do rio grande do sul". Em abril de 2016 iniciou o Doutorado na Universidade Federal do Rio Grande do Sul sob orientação do professor Júlio Otávio Jardim Barcellos. Foi submetido a banca de defesa de Doutorado em março de 2020.