EFFECT OF REDUCED AGE AT FIRST CALVING AND AN INCREASED WEANING RATE ON CO_2 EQUIVALENT EMISSIONS IN A COW-CALF SYSTEM

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ABSTRACT

The objective of this study was to evaluate the impact of using technology to reduce the age at first calving (AFC; from 48 to 24 months) and increase the weaning rate (WR; from 60% to 80%) in beef herds. The need for pasture area (hectares) and the CO_2 equivalent emissions (CO_2eq.) of animals present in the production system were analyzed. Data from a livestock breeding system were used to produce 400 male calves per year: System 1) using reproductive biotechnology (fixed-time artificial insemination [FTAI] and System 2) without the use of reproductive biotechnology (only natural mating). System 1, which used reproductive biotechnology (FTAI; composed of 1,540 AU of animals in 1,540 hectares), presented a lower AFC (24 months), a higher WR (80%), and lower CO_2eq. emissions per year (2,311.3 tons). System 2, which did not employ reproductive technology (composed of 2,475 AU [450 kg of animals] on 2,475 hectares), had the highest AFC (48 months) and lowest WR (60%) and emitted 3,714.5 tons of CO_2eq. per year. The reduction in CO_2eq. emissions per year was 1,403.3 tons in the system that used reproductive biotechnology, corresponding to gains of US$ 135,920.42 (US$ 96.86 per ton of CO_2eq.). It is estimated that the adoption of the FTAI increases the reproductive efficiency of a cow-calf operation system, which can produce the same number of male calves (400) on 935 fewer hectares of pasture (-37.3%) and with a reduction of 1,403.3 tons of CO_2eq. produced per year.

EFEITO DA REDUÇÃO DA IDADE AO PRIMEIRO PARTO E DO AUMENTO DA TAXA DE DESMAMA NAS EMISSÕES EQUIVALENTES DE CO_2 NO SISTEMA PECUÁRIO DE CRIA

RESUMO

O objetivo desse estudo foi avaliar o impacto da utilização de tecnologia para redução da idade ao primeiro parto (IPP; de 48 para 24 meses) e aumento da taxa de desmama (TD; de 60 para 80%) em rebanhos de corte. Analisou-se, também, a necessidade de áreas de pastagem (ha) e as emissões equivalentes de CO_2 (CO_2eq.) dos animais presentes no sistema de produção. Foram utilizados dados de um sistema pecuário de cria para a produção de 400 bezerros machos por ano: Sistema 1) com uso de biotecnologia da reprodução [inseminação artificial em tempo fixo (IATF)] e Sistema 2) sem uso de biotecnologia reprodutiva (somente monta natural). O sistema com emprego de biotecnologia da reprodução (IATF; composto por 1.540 UA de animais em 1.540 ha) apresentou menor IPP (24 meses) e maior TD (80%) e emitiu menos CO_2eq. por ano (2.311,3 ton.). O sistema de produção sem adoção de tecnologia reprodutiva (composto por 2.475 UA de animais em 2.475 ha) possui maior IPP (48 meses) e menor TD (60%) e emitiu 3.714,5 toneladas de CO_2eq. por ano. A redução na emissão de CO_2eq. por ano foi de 1.403,3 toneladas em favor do sistema que emprega biotecnologia, correspondendo a ganhos de US$ 135.920,42 (US$ 96,86 ton. de CO_2eq.). Estima-se que a adoção da IATF aumenta a eficiência reprodutiva de uma fazenda de cria, que pode produzir a mesma quantidade de bezerros machos (400) com redução de 935 hectares de pastagens (-37,3%) e de 1.403,3 toneladas de CO_2eq. emitidas por ano.

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INTRODUCTION

Global agri-food exports have grown in the last decade and have strengthened the agricultural sector, bringing opportunities to increase the economic performance of emerging economies. According to the *State of Food and Security and Nutrition in the World Report* (2020), the need for food production encompasses not only the growing demands of the population but also the production of safe food for the consumer, with less impact on the environment and in an economically viable and accessible way. Thus, the transformation of food systems has become necessary to meet the current and future scenario. Brazil stands out in the global food industry, especially for *commodities* such as beef. Therefore, countries must pay attention to the productivity of the support base of livestock activity, which is the breeding system (Rovira, 1996).

The cow-calf system is one of the main cost centers in beef cattle, with direct impacts of weaning and rearing of heifers, beef cows, and bulls on the economic efficiency of activity (Oaigen, 2008). Moreover, the cow-calf system occupies approximately 70% of the productive area of a property, leaving 30% of the area for breeding and fattening. In this context, the use of reproductive biotechnologies to increase the production and profitability of properties has gained prominence in recent years. The artificial insemination (AI) technique accelerates genetic gain by using semen from breeding bulls, resulting in more productive calves, which generate greater economic returns on livestock (Baruselli *et al.*, 2017).

In addition, insemination, when combined with ovulation synchronization protocols (fixed-time artificial insemination [FTAI]), allows the age at first calving (AFC) to be anticipated, conception concentrated at the beginning of the breeding season, and production efficiency increased by timing the midway point of calving at the optimal time of the year (Valle, 1998; Bó *et al.*, 2007). Calves born at the beginning of calving season can express an additional gain of 20 kg in weaning weight when compared to calves born at the end of breeding season (Baruselli *et al.*, 2018; Baruselli, 2019). Therefore, technological advancement in livestock seeks to achieve more sustainable production from an economic and environmental point of view.

In 2020, 41.5 million head of cattle were slaughtered in Brazil, representing 14.3% of world beef production. Between 1990 and 2020, beef productivity in Brazil increased by 159%. In 1990, meat production was only 4.6 million tons (1.6@/ha/year), while in 2020 it reached 10.3 million tons (4.2@/ha/year). In addition, data from the *Brazilian Association of Meat Exporting Industries* (ABIEC; 2021) indicate that the use of pasture areas in Brazil is decreasing, and productivity per unit area is increasing. Since 2005, there has been a considerable decrease in land use (millions of hectares) and an increase in productivity per hectare per year (ABIEC, 2021).

Despite technological advances and growth in the productivity of Brazilian beef cattle, the sector is still plagued by environmental problems, such as greenhouse gas emissions (Steffen *et al.*, 2015; Malafaia *et al.*, 2021). Direct emissions from animal production from enteric fermentation and manure losses contribute 11% of total anthropogenic greenhouse gas (GHG) emissions (Gerber *et al.*, 2013). However, there is no precise way to determine the CO_2 balance on beef farms.

Life Cycle Assessment (LCA) is an assessment of the total environmental impact of a product throughout its production and/or consumption and allows for a broad comparison of production systems. Traditional LCAs do not consider the potential for carbon sequestration and increased soil productivity, which has a possible climate benefit. Still, there are aspects that go beyond carbon emissions, such as the impact of the use of technology on production (nutrition and increased reproductive efficiency), water use and land occupation. Thus, assessments that contemplate the complete carbon cycle are necessary for all models of production systems.

Several studies point to strategies for mitigating methane and nitrous oxide emissions from animal production. Some of this research has tested the effects of land use change, waste management, nutritional strategies, intensification of the production system, promotion of animal welfare and health, increased reproductive efficiency, and genetic improvement (Eckard *et al.*, 2010; Gill *et al.*, 2010; Beauchemin *et al.*, 2011; Buddle

et al., 2011; Zervas, Tsiplakou, 2012; Bellarby et al., 2013, Gerber et al., 2013, Hristov et al., 2013). Thus, there are possibilities for progress and readjustment of the production system to meet current sustainability concepts through the diagnosis of the most unbalanced points of each production system (Steffen et al., 2015; Malafaia et al., 2021).

Increasing the reproductive efficiency of production animals has great potential to reduce GHG emissions by 4% (Beauchemin et al., 2011). Low fertility places a greater demand on the number of animals in the herd to meet production objectives and requires a higher replacement rate to maintain the herd, and these two factors directly increase the intensity of GHG emissions (Llonch et al., 2016). Decreasing the age at first calving has also been described as a GHG mitigation strategy, which can lead to decreases in GHG emissions on the order of 8% to 10% in dairy cow production systems (Nguyen et al., 2013). On this premise, the objective of this study was to evaluate the impact of the use of technologies (FTAI associated with genetic and productive improvement) on reproductive efficiency (reduction in the age at first calving and increase in the weaning rate) on GHG emissions in a cow-calf breeding system.

MATERIAL AND METHODS

Were used data from a breeding farm that uses reproduction technology under Brazilian management conditions, located in the municipality of Lavínia, state of São Paulo. The data from this farm were used to conduct modeling of a commercial herd with 1,000 breeding cows that produce 800 calves per year (male calves are sold at weaning, and female calves are used to replace the herd matrices).

The animals were kept in a grazing system, and the number of animals housed in the production system was converted to livestock units (LU), with 1 LU corresponding to 450 kg of live weight (LW). The evaluated system included the following animal categories: calves and heifers (from birth to weaning), heifers from 12 to 24 months of age, heifers from 24 to 36 months of age, heifers from 36 to 48 months of age, cows, and bulls. The corresponding LU for each category was 0.3, 0.7,

0.8, 0.9, 1.0, and 1.5, respectively.

Simulation is a mathematical test carried out with the help of models to estimate the behavior of a system under different conditions (Fialho, 1999; Silva, 2002). The methodology used to develop the simulations projects the model of an original system intending to compare alternatives or scenarios (Pegden, 1995). The advantage of using mathematical models is the possibility of selecting bioeconomically viable production systems (Braga, 1997; Souza et al., 2001).

Thus, two breeding systems were simulated to produce 400 male calves sold per year: 1) using reproductive biotechnology (FTAI; n = 1,000 cows with 24 months of AFC and 80% of WR) and 2) without the use of reproductive biotechnologies (natural mating; n = 1,335 cows with 48 months of AFC and 60% of WR). The modeling of production systems comparing the different zootechnical indices of the breeding farms was implemented using simulated scenarios (Beretta et al., 2001; Beretta et al., 2002), as proposed by Figueiredo et al. (2017).

Data on methane (CH_4) and nitrous oxide (N_2O) emissions were obtained by analyzing beef cattle production systems on pasture, described in Figueiredo et al. (2017), and converted to livestock units (LU). Emissions produced by animals and manure were considered. Emissions of methane (52 kg of CH_4 LU per year), and nitrous oxide (0.52 kg of N_2O LU per year; Figueiredo et al., 2017) were calculated for animals in the breeding system. The manure produced was considered to be kept untreated in the grazing system where the animals were allocated during the study period. Methane emissions from 1 LU manure were 1 kg of CH_4 LU per year (Figueiredo et al., 2017).

Estimated emissions of CH_4 and N_2O were converted to grams of CO_2 equivalent/year from the global warming potential (GWP; in kg CO_2 equivalent). The GWP is an index related to the radioactive force at present associated with cumulative effects caused by a unit mass of a given gas emitted. This factor is applied to compare the impact of gases on the maintenance of heat in the atmosphere versus a standard gas (CO_2). The GWP is based on a time window of 100 years and is equal to 25 for CH_4, 298 for N_2O, and 1 for CO_2 (Forster et al., 2007).

To compare the systems evaluated in this study, the CO_2 equivalent emissions per year were converted from euros to dollars using the *EU Emissions Trading System* carbon quote (values as of January 24, 2022; European Commission, 2022). The following parameters were converted into dollars: 1) emissions from the production system per year; 2) emissions in animal units per month; 3) emissions per production cycle (considering the difference in heifer maintenance in the breeding system).

RESULTS AND DISCUSSION

In beef cattle, the breeding system is the basis for obtaining a productive and sustainable herd. In this context, the implementation of reproductive technologies is key to optimizing meat production. Data from the present study indicate that in System 1, which established as a basis the presence of 1,000 cows (with an 80% weaning rate and an age at first calving of 24 months) to produce 400 male calves per year, showed higher production efficiency with lower CO_2eq emission per year. In System 2, without reproductive technologies (only natural mating), 1,355 cows (with a 60% weaning rate and 48 months of age at first calving) were needed to produce the same number of calves in an annual cycle. In addition to the higher number of breeding matrices (cows), model 2 allows replacement heifers 2, 3, and 4 years of age in the breeding system. However, in the system that uses biotechnology (synchronization techniques to program reproduction), only replacement heifers up to 2 years of age were used.

The production system using reproductive technology (System 1) presented lower CO_2 equivalent emissions per year and per production cycle, when compared to the production system that did not use reproductive technology (System 2). Under System 1, annual emissions were 37.8% lower (2,311.26 tons of CO_2eq. year[-1]), and emissions per production cycle were 85.4% lower (22.51 tons of CO_2eq. year[-1]), when compared to System 2. The data are presented in Table 1.

These positive results for emissions of CO_2eq. per year were a consequence of the reduction in the permanency of heifers in the system and, consequently, the decrease in the number of animals in this category. In the system with low reproductive efficiency, 1,200 heifers can produce 400 male calves per year, while in the system with high reproductive efficiency, only 400 heifers are needed to provide the same number of calves per year. These data suggest a higher contribution of the production model that uses reproductive biotechnologies to the increase in productivity and sustainability of beef cattle ranching.

There are an estimated 170 million hectares of pasture in Brazil, and of these, 120 million hectares (70%) are occupied by cow-calf operation systems (ABIEC, 2021). This fact reinforces the importance of cattle breeding for the productivity and genetic efficiency of the beef production chain. Applying a production system that increases reproductive efficiency could achieve lower greenhouse gas (GHG) emissions. With the reduction of the number of cows on the farm producing the same number of calves, there is less need for pasture areas to assemble the same amount of meat. It is noteworthy that it is necessary to use biotechnologies associated with nutritional, sanitary, and animal welfare

Table 1. Comparison between CO_2 equivalent emissions [in tons (ton.)] of different beef cattle rearing systems that did or did not use reproductive biotechnologies to produce 400 male calves per year

	System[1] 1		System[1] 2	
	ton. CO_2eq.	US$	ton. CO_2eq.	US$
CO_2eq. emissions (UA/month)	0.13	12.11	0.13	12.11
Total CO_2eq. emissions per year	2,311.26	223,868.91	3,714.53	359,789.33
CO_2eq. emissions on productive cycle[*]	22.51	2,180.11	154.34	14,949.59

[1]System: 1) with the adoption of reproductive biotechnology (FTAI) and 2) without the adoption of reproductive biotechnology (natural mating).

[*]Production cycle: In System 1, a production cycle was considered in which the category of heifers remained in the program for 2 years with a weaning rate of 80%. In System 2, a productive cycle was considered in which the category of heifers remained in the program for 4 years with a weaning rate of 60%.

management to improve zootechnical indexes (Baruselli *et al*., 2021).

Few scientific studies have attempted to estimate the consequence of including reproductive techniques on GHG emissions. These studies focused on multiple variables, such as changes in the nutritional management of animals, genetic selection, animal breeds, and changes in zootechnical indices, among others (Beauchemin *et al*., 2011; Cullen *et al*., 2016). There are still differences in the units of measurement and analytical methods used. Some authors use the amount of GHG emitted per kilogram of marketable product (Beauchemin *et al*., 2011; Cullen *et al*., 2016), per kilogram of average daily weight gain in the category to be evaluated (Becoña *et al*., 2014), per breeding animal (Quinton *et al*., 2017; Figueiredo *et al*., 2017), or per hectare (Figueiredo *et al*., 2017). In addition, there are differences in the boundaries of the models built, in terms of both time scale variations and the type of production systems adopted.

In the United States, researchers evaluated a beef cattle production system using elaborate models and estimated that 80% of GHG emissions came from the breeding system, with methane emissions representing 63% of total greenhouse gases (Beauchemin *et al*., 2011). By applying techniques that promote an increase in the longevity of breeding cows and a higher weaning rate per cycle, the researchers reported an 8% reduction in GHG emissions compared to the model with no changes in these reproductive efficiency indicators (Beauchemin *et al*., 2011). The same results were obtained in Australia, where researchers analyzed the impact of reducing the age at first service and the use of strategies to increase fertility in breeding herds. The adoption of these techniques on farms resulted in a 25% reduction in GHG emissions and promoted an increase in the economic return on a full cycle of beef production (Cullen *et al*., 2016).

CONCLUSIONS

- The system that used reproductive technology employing FTAI (composed of 1,540 UI of animals in 1,540 ha) had the lowest AFC (24 months) and highest WR (80%) and emitted less CO_2eq. per year (2,311.3 ton.). The production system that did not adopt

reproductive biotechnology (composed of 2,475 UI of animals on 2,475 ha) had the highest AFC (48 months) and lowest WR (60%) and emitted 3,714.5 tons of CO_2eq. per year. The reduction in CO_2eq. per year was 1,403.3 tons in favor of the system that used biotechnology (System 1), corresponding to gains of US$ 135,920.42 in carbon credits (US$ 96.86 per ton of CO_2eq.). It was estimated that the adoption of reproductive technology would increase reproductive efficiency, producing 400 male calves for the meat production chain with fewer matrices and with a reduction of 935 hectares of pastures (-37.3%) and 1,403.3 tons of CO_2eq. issued per year.

AUTHORSHIP CONTRIBUTION STATEMENT

ABREU, L.A.: Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing; **REZENDE, V.T.:** Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing; **GAMEIRO, A.H.:** Conceptualization, Project administration, Supervision, Validation, Writing – review & editing; **BARUSELLI, P.S.:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

DECLARATION OF INTERESTS

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