



Sustainable dairy farming and the nexus between technical, economic and environmental efficiency: a bibliometric analysis

Pecuária de leite sustentável e o nexo entre eficiência técnica, econômica e ambiental: uma análise bibliométrica

Simone Geitenes COLOMBO^{1,2*}, Ademir Kleber Morbeck de OLIVEIRA², Mirian Batista de Oliveira BORTOLUZZI¹, José Francisco dos REIS NETO², Gilberto Gonçalves FACCO², Rosemary MATIAS², Ana Letícia Barbosa dos SANTOS¹

¹ Federal University of Mato Grosso do Sul (UFMS), Nova Andradina, MS, Brazil.

² University Anhanguera (UNIDERP), Campo Grande, MS, Brazil.

* Contact email: simone.g@ufms.br

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ABSTRACT: The rise in the economic situation of countries allied to the increase in life expectancy of the population resulted in augmenting the demand for food. To meet this demand, an economic model emerges based on the vertiginous exploitation of natural resources oriented only to productivity and profit. However, this type of model is unsustainable in the long term and causes significant environmental impacts. Production systems must not only be economically viable for producers, but also adhere to environmentally sustainable standards. Therefore, this article focuses on the application of a bibliometric review to trace a profile of scientific production in relation to sustainable dairy farming examining efficiency in three dimensions: technical, economic and environmental. The analysis of the works revealed that several strategies can contribute to the development of environmentally sustainable dairy farming. However, for these alternatives to have a practical effect in relation to their objectives, they must be incorporated into the activities carried out by producers.

Keywords: desenvolvimento; ambiente e sustentabilidade; produção rural sustentável.

RESUMO: Melhorias na situação econômica dos países, aliadas ao aumento da expectativa de vida da população, resultaram no aumento da demanda por alimentos. Para atender essa demanda, surge um modelo econômico baseado na exploração vertiginosa dos recursos naturais, orientado apenas à produtividade e ao lucro. Porém, esse tipo de modelo é insustentável a longo prazo e causa impactos ambientais expressivos. Nesse

sentido, são necessários sistemas de produção que atendam demandas ambientalmente sustentáveis, além de serem economicamente viáveis aos produtores. Portanto, este artigo se concentra na aplicação de uma revisão bibliométrica com o objetivo de traçar um perfil de produção científica em relação à pecuária de leite sustentável sob a ótica de três dimensões de eficiência: técnica, econômica e ambiental. A análise dos trabalhos permitiu verificar que já existem diversas estratégias que podem contribuir com o desenvolvimento da pecuária de leite ambientalmente sustentável, porém, para que essas alternativas tenham efeito prático em relação aos seus objetivos, é necessário que sejam incorporadas de fato nas atividades realizadas pelos produtores.

Palavras-chave: desenvolvimento; ambiente e sustentabilidade; produção rural sustentável.

1. Introduction

The expanding population and extended life expectancy have created greater worldwide demand for food production. The necessity for this has led to the excessive exploitation of natural resources to cultivate plants and animal protein for nourishment.

The improvement in the economic situation of the countries has fuelled the growth in global animal production. Should these patterns persist, the increase in population and life expectancy will contribute to further increase the demand for milk and meat.

Presently, there is a great concern about the environmental impacts generated by the increase in food production, including those caused by livestock farming on land, water use, and on the emission of greenhouse gases, which have a strong influence on climate change (Salter, 2017; Mu *et al.*, 2017, Mekonnen *et al.*, 2019). The agriculture and livestock industries must balance food production with reducing their environmental impacts (Gislon *et al.*, 2020).

Even though there has been significant emphasis on improving crop productivity to relieve pressure on land use, there has also been less attention to the implications generated by the intensification of dairy cattle production (Bosire *et al.*, 2016).

Selective breeding through genetic improvement, the development of more efficient feeding strategies, changes in management practices, and improvements in animal health and welfare are considered notable improvements to the efficiency of animal production (Salter, 2017). However, these practices are not yet accessible to all producers.

Smallholder farms, for example, are characterized by complex systems, as the benefits for raising livestock go beyond the revenues obtained from the sale of products and animals. They include analyzing milk consumption, diversifying activities and promoting other social values (Udo *et al.*, 2016). It is usually more difficult for producers to access innovative practices to improve production efficiency due to their limitations of resource.

Efficiency in dairy farming needs to be aligned with environmentally sustainable demands, as well as being economically viable for producers. This research focuses on the application of a bibliometric review to outline a profile of scientific production in relation to sustainable dairy farming based on three dimensions of efficiency: technical, economic and environmental.

2. Methodology

Since it is difficult to conduct a systematic literature review, this study adopted specific criteria

for the systematic search of the literature. It has followed methodological parameters of bibliometric analysis similar to those adopted by Bortoluzzi *et al.* (2021) and Santos *et al.* (2019). The project consisted of two primary phases: a bibliometric analysis and the reading of the articles.

The research was driven by the following inquiry: what is the current scenario regarding studies related to sustainable dairy farming? This question led to the definition of the keywords and search criteria shown in Figure 1.

The selection of articles was then refined by year of publication, so that articles from the last five years (2016-2020) were searched in order to understand the most recent researches related to

sustainable dairy farming. Figure 2 shows the systematic review process adopted.

The first stage consisted of bibliometric analysis to measure important characteristics related to publications: the number of publications over the years, the countries with the largest number of publications, and the journals with most publications on the subject.

The initial search using the aforementioned keywords and time frame returned a total of 353 articles. From this initial selection, a bibliometric analysis was carried out to measure the contribution of scientific knowledge to the area related to sustainable milk production.

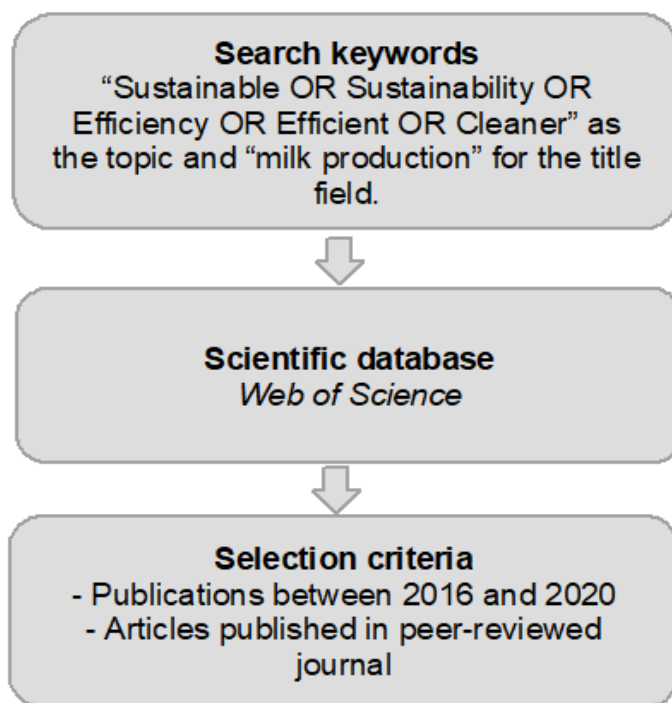


FIGURE 1 – Research criteria.

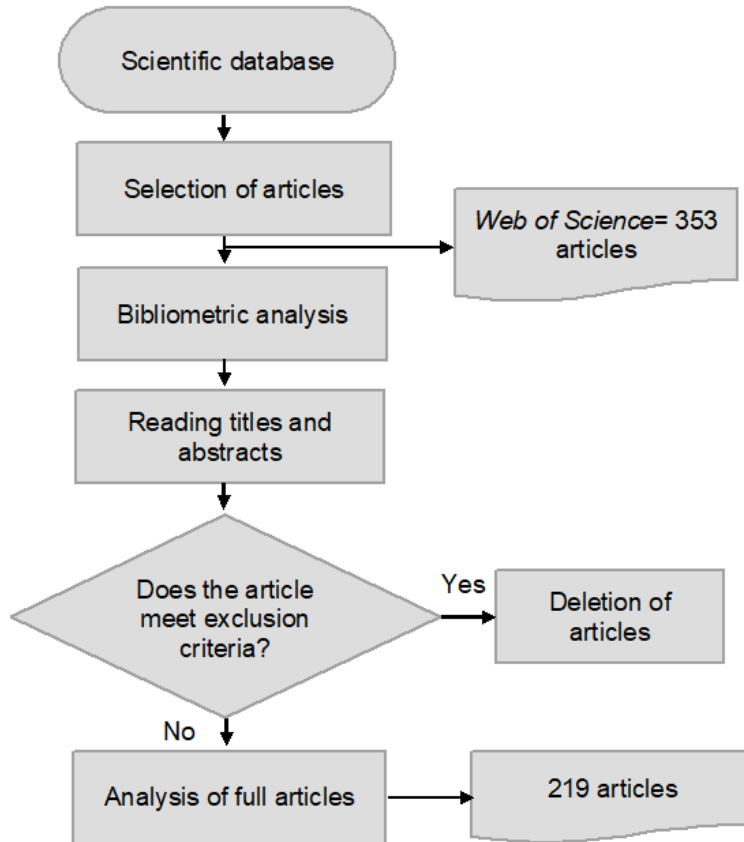


FIGURE 2 – Flowchart of the systematic review process.

Following the bibliometric analysis, a preliminary examination of the article titles and abstracts was carried out to identify which ones were aligned to the scope of this study. To facilitate comparison of the articles, the results obtained were analyzed by title and abstract, applying the following criteria:

a) The study should be connected to dairy farming systems in its primary phase. In other words, articles referring to the processes of industrialization and chemical analysis of milk were discarded.

b) Articles dealing with issues concerned with the production of animals other than cows were also discarded.

After conducting a thorough analysis, 134 articles were eliminated according to the exclusion criteria, resulting in a total of 219 articles for the next stage.

The second step consisted of the comparative analysis of the articles to identify the primary te-

chniques adopted in sustainable livestock and the most frequently addressed topics. For the analysis of the articles, they were separated into three key dimensions: technical, economic, and environmental.

Technical efficiency regards strategies adopted to improve the performance of milk production, such as animal feed, good management practices, animal health and welfare, and genetic improvement. Economic efficiency refers to studies on the economic performance of the dairy production activity, such as the analysis of production costs and factors that affect the profitability of producing properties. Finally, environmental efficiency deals with issues that relate dairy farming to environmental aspects, addressing topics such as life cycle

analysis, sustainability indicators, and environmental footprints.

3. Results and discussions

3.1. Literature review

The first results obtained refer to the annual growth rate of articles published related to the subject. There was a 50.94% growth in publications from 2016 to 2020.

Figure 3 shows the increase of publications between 2016 and 2020.

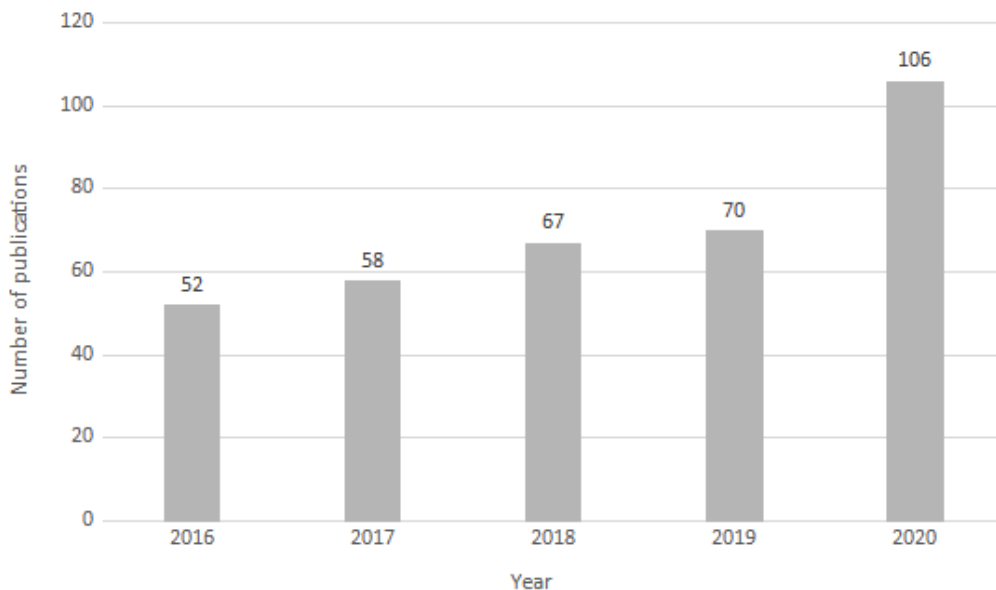


FIGURE 3 – Increase in publications between 2016 and 2020.

Source: survey data

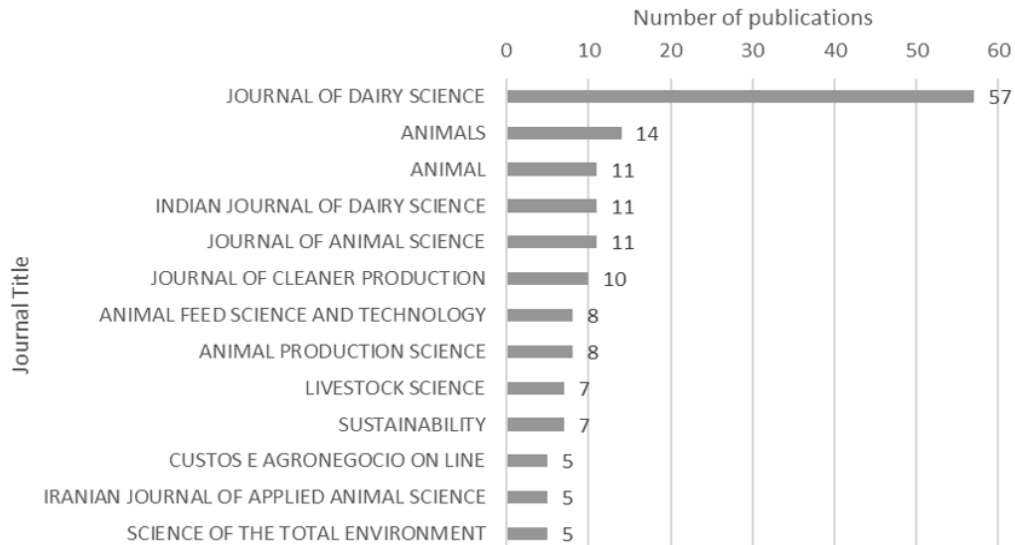


FIGURE 4 – Main journals with published articles and their respective number of publications between 2016 and 2020.

Source: survey data

This result indicates the researchers' concern regarding efficiency and sustainability in milk production chains.

Following confirmation of a rise in publications in recent years, an analysis was carried out as to the main journals used for publication. Figure 4 shows these journals, as well as the number of articles published for the period analysed.

The *Journal of Dairy Science* is the one with the highest number of publications: 57 articles. This journal is well ahead of the second-placed journal, *Animals*. *Animal*, *Indian Journal of Dairy Science* and *Journal of Animal Science* are in third position, with 11 articles each. Other journals published less than 5 articles.

In order to verify the extent to which these researchers partnered with researchers from other

nations, the frequency of collaborations by country in the analyzed sample was listed (Figure 5).

The *ranking* of countries with the most publication collaborations with other countries is led by the USA with a total of 149 collaborations. Closely behind is Brazil with 143 collaborations and, in third place, are China and India with 90 collaborations each. Figure 6 shows the map with the collaboration network between authors from different nations. The more evident the red line, the greater the frequency of collaboration between countries.

The USA was one of the countries with the most research partnerships, having collaborations with countries such as Brazil, China and Canada. In addition to the USA, China has also conducted collaborations with Canadian researches.

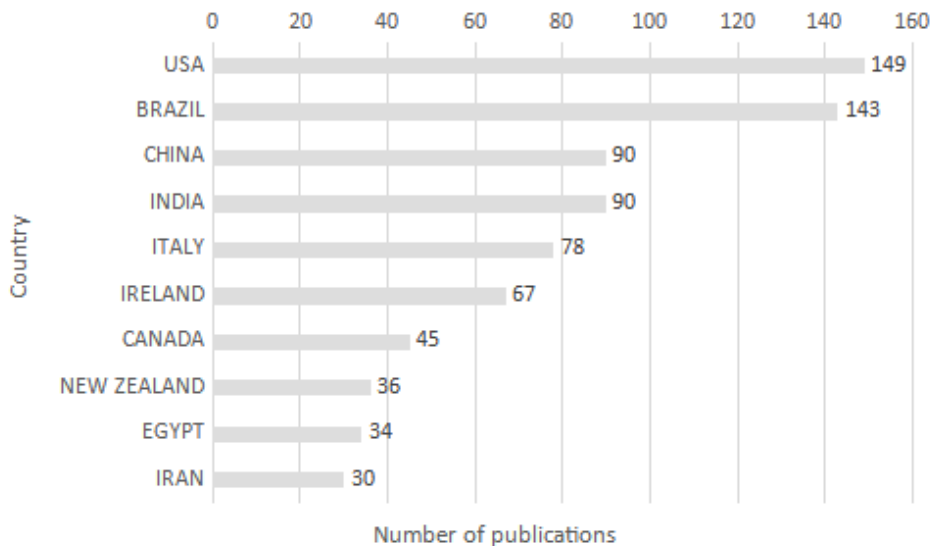


FIGURE 5 – Frequency of collaboration of publications with other countries.

Source: survey data

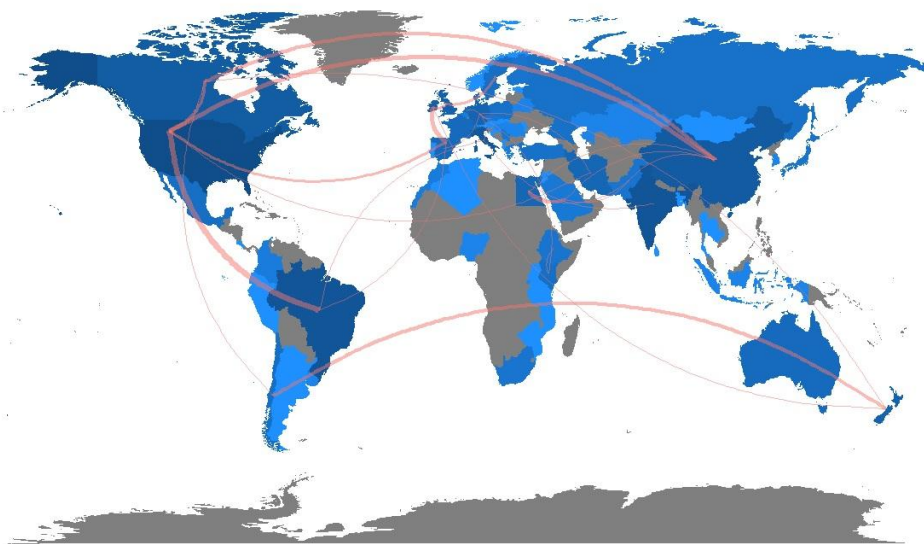


FIGURE 6 – Collaboration network between researchers from different countries.

Thin lines represent an interaction of up to 3 collaborations between countries, medium lines between 4 to 5 collaborations and thick lines between 6 and 7 collaborations.

Source: survey data

3.2. Analysis of the articles

After the bibliometric analysis was performed, the next step consisted of analysing articles based on the reading of the remaining works after excluding those that were not part of the scope of this research, according to the criteria defined above. The reading

provided a summary of the primary topics addressed by the authors in the area.

The works were separated into three dimensions according to the subjects addressed: technical efficiency, economic efficiency, and environmental efficiency. Table 1 presents the synthesis of the main issues according to the dimensions.

TABLE 1 – Summary of the main issues addressed in the articles.

Dimension	Theme	Number of items	Description
Technical efficiency	Animal feed	111	Analyses of feed efficiency and milk production using various feeding strategies.
	Breeding	10	Address issues related to the genetic potential of animals for milk production and feed efficiency, genetic selection to reduce greenhouse gases
	Animal health and welfare	19	Diseases that impair the animal's performance for sustainable milk production; Consequences of heat stress on milk production Technologies for physiological monitoring of animals and milk production.
	Good management practices	5	Relationship between milk production, milking quality and frequency. Evaluation of producers' practices with hygienic milk production.
	Grazing	8	Challenges and opportunities for grazing in milk production systems; Policies to encourage the use of grazing instead of using concentrated feeds. Factors for sustainability in pasture-based milk production systems. Efficiency in the use of pastures.
Economic efficiency	Factors of production	6	Analyse and discuss determining factors for the technical efficiency of milk production such as socioeconomic factors, levels of modernization, subsidies to dairy farming, herd size, infrastructure, permanence in the activity, etc.
	Production costs and competitiveness	23	Barriers and strategies for milk production Factors influencing the economic efficiency of milk production; Determining factors for the competitiveness of the sector; Production cost analysis.

Environmental efficiency

Environmental footprints and sustainability

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Studies carried out to evaluate environmental footprints (soil, water, carbon, methane, among others) and studies involving the analysis of the life cycle of milk production. Evaluation of the sustainability of milk production systems considering socioeconomic and environmental factors

Source: the authors

3.3. Technical efficiency

Table 1 shows that approximately 73% of the studies address issues related to the technical efficiency of milk production. The main themes deal with experiments that adopt different animal feeding strategies to evaluate feed efficiency and milk production.

Some of these strategies involve the use of by-products from other processes, such as sugarcane bagasse (Molavian *et al.*, 2020), Japanese pumpkin residues (Valdez-Arjona *et al.*, 2020), pine bark flour (Kairenius, Mantysaari & Rinne, 2020) and crop by-products such as corn stover (Sun *et al.*, 2020), wheat and soybean meal (Bonanno *et al.*, 2019; Fessenden *et al.*, 2020). Innovative studies have explored the use of inoculants (biological agents) in grass and maize silages to reduce the use of concentrates and increase sustainable milk production. Results have demonstrated favourable efficiency (Uzun *et al.*, 2018; Eisner *et al.*, 2020).

Additional topics associated with the technical efficiency of milk production are related to animal health and welfare and genetic improvement. The welfare of lactating dairy cows has significant impacts on milk production and animal health. Animals that face environmental factors such as heat stress, for example, due to exposure to high temperatures, experience detrimental effects on nu-

trient absorption (Kaufman *et al.*, 2020). Ranjitkar *et al.* (2020) point out that climate change will have significant consequences for the dairy sector. Temperature increases, besides causing environmental impacts, affect the performance of dairy cows.

Within the context of technical efficiency and environmental impacts, Breider *et al.* (2019) analyzed genetic selection as a factor in reducing methane emissions and decreasing greenhouse gases. The authors identified that methane production is moderately linked to animal heritability, indicating that genetic selection to reduce greenhouse gas emissions is possible.

Grazing has also been discussed regarding the sustainability of dairy farming. Grazing is a feeding strategy in which dairy cows feed freely on pastures, unlike the confinement system in which they are kept in establishments where they are fed and milked.

Concerning the balance of ecosystems, pastures contribute to the preservation of biodiversity, carbon storage, erosion control, and regulation of the water and nutrient cycle (Delaby *et al.*, 2020). They also contribute to the increase of pollinating agents and predators of herbivorous insects, thus reducing the use of pesticides and, consequently, the production costs (Lora *et al.*, 2020; Paiva *et al.*, 2020).

From an animal welfare perspective, the practice of planting hedges and wooded areas integrated with pasture, for example, provides shelter and shade to protect animals from heat stress and reduce disease transmission between herds (Delaby *et al.*, 2020; Paiva *et al.*, 2020).

The adoption of a silvopastoral system, which integrates pasture and forests in the same area, also contributes to biological pest control, carbon sequestration, better water infiltration, better pollination services, and erosion reduction (Vásquez *et al.*, 2020; Delaby *et al.*, 2020; Paiva *et al.*, 2020).

While there are many economic, environmental, animal welfare, and social benefits to grazing, there are also challenges to keeping pasture in the diet of dairy cows. This feeding strategy requires a series of skills to manage the production system, including animal and pasture management and feed management during times of low pastures abundance (Hennessy *et al.* 2020).

To improve the use of grazing in dairy farming, it is necessary to augment the knowledge of those involved in the process about the interaction between pasture and ecosystem services (Van Den Pol-Van Dasselaar *et al.*, 2020). One of the solutions presented is to reward producers for grazing as a service to society, the so-called payment for environmental services (Faccioni *et al.* 2019; Van Den Pol-Van Dasselaar *et al.*, 2020; Delaby *et al.*, 2020; Stampa *et al.*, 2020). This measure could contribute to ensuring support for producers to adopt grazing. To effectively carry out this obligation, it is necessary to strengthen extension and information systems for producers through training with animal and plant experts (Van Den Pol-Van Dasselaar *et al.*, 2020).

Finally, some studies address the technical efficiency of milk production, with emphasis pla-

ced on the identification of determining factors for this aspect. Most of the variations in the efficiency of dairy farms are caused by the inefficient use of inputs (Yilmaz *et al.* 2020). The association of producers in milk cooperatives is also an important factor in improving technical efficiency since producers now have technical assistance and access to information regarding more efficient practices and tools (Mahida *et al.*, 2018).

3.4. Economic efficiency

Economic efficiency refers to the use of production resources in the most fruitful way possible to maximize the revenues earned by producers. The investigation of factors that affect the profit obtained, both positively and negatively, is relevant to direct measures towards improving the efficiency of the properties.

Several variables can have a significant effect on the economic efficiency of dairy farms. Maina *et al.* (2020) identified that the average age of members and family size, labor hiring, as well as concentration costs. and the size of the area of the properties have negative effects on economic efficiency.

The higher the age and the number of family members, the lower the efficiency. Older producers tend to be more resistant to the use of innovative techniques, while larger families tend to increase expenses, thus decreasing the profit obtained. Likewise, the hiring of labour and the concentration of costs also increase the expenses incurred on the property, ultimately impeding its economic efficiency. Additionally, the magnitude of the property's area may also hinder efficiency, since small properties tend to use their areas more intensively in an attempt to ease the restriction of land.

Cooperatives can make an important contribution to the profitability of smallholders. These, in general, face greater obstacles to dealing with the seasonality of production, as they produce lower volumes, have little working capital a greater difficulties in accessing credit (Silva *et al.*, 2017). Through the formation of cooperatives, producers work together to achieve economies of scale and negotiate better prices for inputs and the final product. They may also have assistance in veterinary technical assistance, feed supplies, and even financial support services (Wynn *et al.*, 2019).

The creation of milk producers' associations can be considered a social business model. It allows for the implementation of several processes to improve farms' production, such as better payment for milk quality and price increases, which results in greater economic gains for each producer (Okano, 2017).

3.5. Environmental efficiency

The sustainability of production systems is key to meeting future consumer demands. The increase in population and people's life expectancy increases the exploitation of natural resources for the production of food and other consumer goods. Therefore, the best use of natural resources such as water and soil, for example, and the use of environmentally sustainable production systems has become indispensable.

A thorough analysis was undertaken on issues related to environmental footprints in milk production systems, that is, studies that account for the pressure that activities related to dairy farming cause on natural resources. Studies dealing with sustainability indicators in dairy production were

also evaluated, as they measure how certain socio-economic and environmental factors influence on the sustainability of the system.

In recent years, there has been a special focus on the intensity of the environmental impacts caused by beef production, but this attention is still minimal when it comes to milk production (Mazzetto *et al.*, 2020).

In many countries, the trend is towards environmentally friendly processes and products. Life Cycle Analysis (LCA) is a tool that has been developed to assess the environmental consequences of a product or process considering its impacts throughout its complete life cycle (Vigon *et al.*, 2020).

Mazzetto *et al.* (2020) recommend the application of a combined Life Cycle Analysis in milk and meat production systems, as farms that work with dairy farming often need to replace dairy heifers. Therefore, animals no longer used for milk production are destined for beef cattle. The authors understand that research needs to consider beef typologies and beef production systems at the regional level, since they minimize greenhouse gas emissions and use land more efficiently, in order to intensify environmental efficiency on a national and international scale.

Jayasundara *et al.* (2019) compared the economic performance of dairy farms in Ontario, Canada, to carbon footprints (total estimated greenhouse gas emissions). The authors concluded that there is a synergy between the two sustainability indicators. As a result, by improving production efficiency, economic performance is improved and greenhouse gas emissions are reduced. In the study, low-emission farms produced higher amounts of milk per cow, using a smaller amount of feed throughout the herd, compared to high-emission farms. This result can

be attributed to the use of homemade animal feed by low-emission farms, in contrast to high-emission farms, which used purchased feed.

Following this approach, Zucali *et al.* (2018) used LCA to assess the environmental performance of homegrown forage crops in northern Italy to analyse the different impacts of cropping systems on milk production. They concluded that the cultivation of leguminous forages such as alfalfa and soybean can reduce the use of chemical nitrogen fertilization due to its ability to fix atmospheric nitrogen. Wilkinson and Garnsworthy (2017) also assessed the carbon footprint from analyses of different types of diets. Dairy cows fed grass-based diets and grass silage had lower methane emission rates than corn silage-based diets.

To increase the sustainability of milk production systems, it is necessary to improve the efficiency of land use on the farm through the use of forages that improve feed efficiency as well as increase the carbon stock in the soil. In order to properly address this matter, it is essential that we conduct investigations that consider the development of forage systems involving the dynamics of soil carbon stock (Gislon *et al.*, 2020).

For Salter (2017), it is imperative that alternative management techniques are adopted, including the adoption of new types of more sustainable animal feed to minimize pressures on the environment. The author presented a literature review on options to improve the sustainability of livestock production. Among the most promising options that need further research are reducing dependence on crops such as soybeans, wheat and corn in animal feed and reducing meat consumption in developed countries. As an alternative to the crops currently used in animal feed – which require the exploitation

of large areas to be cultivated –, the use of insects raised on substrates (animal waste and domestic waste) as a protein source in feed, is an innovation that needs further studies.

As previously mentioned, several authors state that a pasture-based production system brings several advantages to the sustainability of dairy farming. However, Bosire *et al.* (2016) address that environmental conservation can be improved by intensifying dairy farming, citing the uses of confined animal spaces to minimize the need for extensive pasture. The authors point out that adequate cultivation practices are needed for feed production that minimize environmental degradation.

It is noted that there is a trade-off between environmental preservation and efficiency of milk production systems. On the one hand, by adopting intensive dairy farming, there would be a reduction in the need for extensive pasture areas, allowing these areas to be used for environmental preservation, infrastructure development etc. This type of system also allows for an increase in production volume and, consequently, producers' profits. However, the intensive system requires greater feed consumption and forage production for food. This would also imply the use of large areas for cultivars necessary for the production of feed, such as corn, soybeans and wheat, for example, jeopardizing the creation of environmental preservation areas.

When it comes to small producers, the discussion becomes even more complex. It has been reported that poor feeding is the main problem in milk production in small farms. A large volume of research on feed efficiency has been carried out. However, small producers hardly have enough resources to invest in better feed for their animals, in genetic improvement and animal health, which

are determining factors to improve the efficiency of the activity.

For Udo *et al.* (2016), global studies on the debate on livestock intensification and climate change mitigation have underestimated household-level constraints on changes in production systems, since smallholders seek innovations that match their resources and objectives. Thus, for smallholders to make a contribution to the reduction of climate change, it is necessary to develop mitigation options that have a positive effect on the livelihoods of these producers and that correspond to the resources available to them.

Based on the studies analyzed, it is observed that animal feed is a critical point when it comes to production efficiency and environmental impacts for dairy farming. The choices of producers regarding the types of feed used may have a great influence on the environment.

Therefore, considering the complexity of the issue, the need for more in-depth discussions is highlighted in the elaboration and execution of agricultural public policies for small milk producers. These policies must facilitate access to credit for smallholders, promote environmental preservation, and provide technical assistance on the efficient use of production resources, such as proper land use, feed efficiency, property management to control costs, and production revenues.

4. Concluding remarks

This work demonstrated that several researchers have developed the technical, economic and environmental efficiency of dairy farming. Many of the strategies presented report promising results by adopting different types of animal feed that use crop

by-products, biological agents instead of chemical inputs to increase forage production and even the possibility of using insects as a protein source in the feed.

Grazing is also a beneficial alternative from an environmental point of view because it contributes to animal welfare, increased biodiversity, erosion control, increased pollinating agents and regulation of the water and nutrient cycle.

In order for these alternatives to have a practical effect as to their objectives, it is necessary that they are actually incorporated into the activities carried out by producers. However, for this to be achieved, there are still many challenges that need further investigation and discussion. For example, the creation and implementation of favourable agricultural public policies especially to small landowners, and the incentive for the creation of associations and cooperatives of milk producers that provide technical assistance, property management courses and environmentally correct practices.

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