Genetics and Reproduction

Review

Reproductive Efficiency of Artificial Insemination in Cattle Systems Current Trends and Prospects

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ABSTRACT

Background: New technologies are bringing new alternatives to improve the reproductive efficiency of artificial insemination in cattle systems, though their success will depend on accurate organization and evaluation of the whole process. **Aim:** To summarize the main concepts, trends, and prospects, regarding the reproductive efficiency of artificial insemination in cattle systems.

Development: Several different criteria are used to define reproductive efficiency. Hence, due to differences existing in production systems and their goals, which are more evident between annual and seasonal calving systems, the above issue and the complexity of practical evaluations were examined. A new concept of reproductive efficiency applicable to any system was defined.

Conclusions: A definition of reproductive efficiency based on parent fertility, cost-effectiveness, human intervention, and environmental effects, was made. Zootechnical alternatives like seasonality associated to fixed-time artificial insemination (TAI), and reproduction control through the overall bio-reproductive efficiency index (OBREI), were evaluated.

Key words: reproductive performance, cattle, reproduction control, seasonal reproduction (*Source*: *AIMS*)

INTRODUCTION

Presently, advances in technology are produced at a faster pace than 75 years ago, when AI was developed (Lamb *et al.*, 2016); however, their full potential has not been put into practice yet,

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since success depends on the action of multiple factors. For instance, embryo transfer, which is applied worldwide, is now a comprehensive part of modern cattle raising concepts. However, although it permits better use of the genetic potential of females than AI, it only employs 1-2% of the elite reproductive population (Niemann and Seamark, 2018).

These new technologies create a wide spectrum of alternatives to improve the reproductive efficiency of artificial insemination in cattle systems, though they would only be successful when organization and evaluation are performed accurately throughout the process. Accordingly, these technologies seek for alternatives that contribute to evaluation of herd performance. Stevenson and Britt (2017) note that traditional measures of reproductive efficiency, like days open, service per conception, and calving intervals, are less valued, since they lack temporary sensitivity to current herd fertility trends.

The sustainable intensification of pasture-based production systems can link the ever-growing world food demands to the needs of environmentally efficient ruminant production (Horan and Roche, 2019).

Consequently, the aim of this review is to summarize the main concepts, trends, and prospects, regarding the reproductive efficiency of artificial insemination in cattle systems.

DEVELOPMENT

Reproductive efficiency

Several different criteria define reproductive efficiency, which on many occasions is confused with reproductive performance. This situation is given, partly, by the fact that the two cases use reproductive indicators, to which objectives such as calving intervals, are assigned.

According to González-Stagnaro (2005), reproductive efficiency is the optimum state of expression and development of physiological activities of reproduction, at the onset of genesic life and cyclicity seen in the optimization of productions, and favorable economic parameters. Moreover, Macmillan *et al.* (2020) indicate that this term is used to describe the set of parameters associated to the reproductive process in cattle, which is hard to determine, because it is the result of a series of interactions.

The low reproductive efficiency is associated to the individual health of the cow and herd (Chebel and Ribeiro, 2016), and according to Speckhart *et al.* (2018), the loss of gestation is the main contributing factor that causes a growing number of non-gestating cows, piling up maintenance costs, lower total weight at weaning, and higher sacrifice rates.

Accordingly, reproductive efficiency can be defined as ***obtaining a calf per cow within a permissible period to maximize cost-effectiveness as an expression of parent fertility, human intervention, and environmental actions.***

In addition to the previous criteria, its practical evaluation is complex due to existing differences among production systems and their goals, which are more apparent between the annual and seasonal calving systems. Additionally, reproductive indicators and goals, which are hard to accomplish in double purpose cattle in the tropics, are used.

According to Diskin (2011), the application of a set of specific goals to every production system is impossible. Although he notes that calving interval (365 days *vs* <420 days), infertility rejection (< 5 % *versus* < 10 %), and calving concentration (80% calving in 60 days in seasonal systems), are useful as initial measures for reproductive performance in herds under seasonal and annual calving systems.

Year-round calving systems

This is the most commonly applied system worldwide to evaluate reproductive efficiency. The prevailing indicator is calving intervals, which mainly depends on the sensitivity of estrus detection, according to Bekara and Bareille (2019).

In tropical conditions, post-calving anestrus is common in cattle, along with other factors that influence pasture feeding (Soto *et al.*, 2017), lactation (Orihuela and Galina, 2019) and the environment (García-Díaz *et al.*, 2019). In Cuba, according to Álvarez (2015), a distorted herd structure leads to reproductive and productive deterioration, which is manifested in low production efficiency, and little growth of the mass, according to the Ministry of Agriculture (MINAG, 2017). For several years, natality has not surpassed 54% in the country.

In Siboney de Cuba and Mambi de Cuba females, García-Díaz *et al.* (2019) reported a marked deterioration of calving intervals at first service, as well as calving-gestation, and calving-calving, as the main reproductive indicators evaluated with the lowest values in the cows with parturitions in the July-August-September quarter. This was attributed to the fact that the last third of gestation takes place during the months with the highest pasture availability, improving nutrition of the gestating animal, and ensuing greater body condition (BC).

In lactating dairy cows, the interval between calving and the first ovulation is generally four-five weeks (Santos, Bisinotto, and Ribeiro, 2016), though it is longer in lactating cows feeding their progeny (Crowe, Diskin, and Williams, 2014). Several studies done in tropical conditions have concluded that restricted suckling favors follicle growth, and a restart of ovarian activity (Orihuela and Galina, 2019; Lassala, Hernández-Cerón, Pedernera, González-Padilla, and Gutierrez, 2020).

In year-round calving systems, a voluntary waiting period (VWP) is implemented as the time interval following parturition, during which the female is not served. VWP is determined when the cow is eligible for insemination (Stangaferro *et al.,* 2018), known in Cuba as period of *recentina* (recently calved cows), which lasts up to 60 days after parturition.

The importance of insemination rates is also emphasized through comparisons between herds under year-round and seasonal calving systems. The primary reproduction measures, generally lower in year-round calved herds, were caused mostly by lower insemination rates (Morton, 2010).

To reduce the cost of reproductive management, Kim and Jeong (2019) noted that nutritional, environmental, and managing strategies to maintain BC ≥3.0, prevent heat-related stress during insemination, and reduce the incidence or provide effective treatment to peri- and postpartum disorders, might be necessary to improve the conception rate at first service in high-yielding herds under intensive systems, as a way to cut down the costs of reproductive management.

Seasonal production systems

The utilization of seasonality in cattle production is widely spread in the world, in Australia (Morton, 2010), New Zealand (Blackwell, Burke, and Verkerk, 2010), and Ireland (Kelly, Shalloo, Wallace, and Dillon, 2020). To achieve the above, the calving season is planned in such a way that the maximum yielding peaks of dry matter (DM) requirements coincide with the maximum DM production peaks in the grassland, thus guaranteeing almost all the food for consumption, and high cost-effectiveness. Advances in pasture enhancement also offer potential ways to improve animal yields, by associating animal requirements with the nutritional contents of forage (Wilkinson, Lee, Rivero, and Chamberlain, 2018).

In seasonal systems, insemination takes place in limited periods every year, starting at the beginning of the reproduction program, with all calvings taking place in a restricted period of time (Morton, 2010). In these herds, reproductive yields generally are evaluated as the proportion of cows fertilized in specific intervals after the beginning or end of the reproduction program. Consequently, the calving pattern is critical to achieve farm cost-effectiveness (Shalloo, Cromie, and McHugh, 2014).

Every area adapts their systems to their climatic specifications. For instance, Liu *et al.* (2018), noted that in the tropical climate of Taiwan, the lactating cows must be fertilized in the winter and spring (December to May), since the beginning of the seasonal reproduction program, whereas heifers must be fertilized in the summer.

In Cuba, the seasonal performance patterns of births that came up spontaneously have changed throughout time (Mendoza *et al.,* 2019), but they have not been commonly used as a practice in commercial cattle raising, though Loyola *et al.* (2015) demonstrated the potential offered by concentrating calving in the most favorable season of the year, to keep up with natural grass availability, which resulted from the positive effect of bioeconomic indicators of herds.

Possibilities of seasonal production

As an alternative to estrus detection, fixed-timed artificial insemination (TAI) ensures serving cows a little after the voluntary waiting period, regardless of the ovarian cyclicity state. This procedure is widely known due to its advantages in relation to comparisons using the traditional method (Salgado-Otero, Vergara-Avilés, and Vergara-Garay, 2015), since the final result shows a potential increase in the service rates (100%), and therefore, in pregnancy rates and cost-effectiveness (Baruselli, SáFilho, Ambrósio, and Ferreira, 2016).

The utilization of postpartum TAI in primiparous dairy and beef cows, reduces the calving-conception interval, and consequently, the calving interval, with a critical effect on the economic performance of the farm (Baruselli, Ferreira, Sa Filho, and Bó, 2018). It also offers advantages to breeding cattle, by concentrating about half of conceptions in the first days of the season, and stimulating cyclicity and estrus reappearance in the cows that were not fertilized before.

The most frequently used alternative to treat prolonged post-calving anestrus, and to synchronize estrus in tropical production conditions, is the application of hormonal therapies (Baruselli, SáFilho, Ambrósio, and Ferreira, 2016; García, Hernández Barreto, and Pazinato, 2017), but their common disadvantage is the application of multiple manipulations to animals, and necessary visual detection of estrus. In pasture systems, AI is generally implemented after spontaneous estrus (through aided observation or detection of estrus), but entire herd or directed synchronization (timed +/ AI) can be introduced in reproductive management to help maximize estrus occurrence rates (Butler *et al.*, 2019).

Although the efficacy of entire herd synchronization programs has been demonstrated in grazing conditions, they have not been fully adopted. This is explained, in part, by the lack of labor and food resources produced, resulting from the concentration of parturitions (Roche *et al.*, 2017). Other important elements are preparation for transportation and processing of harvested milk, and the zootechnical and veterinary care needed by the large numbers of resulting calves, which is routinely done in countries that adhere to these practices. Several different technologies, like TAI, and other actions that contribute to higher reproductive efficiency, can be used to move the calving pattern closer to the most convenient moment (Morton, 2010; Blackwell, Burke, and Verkerk, 2010; Kelly, Shalloo, Wallace, and Dillon, 2020).

The implementation of a seasonal dairy production system, adapted to the Cuban conditions, according to Soto *et al*. (2017), can offer a significant response to the country’s needs to increase the productive performance sustainably. In selected Cuban companies, Hernández Marrero *et al.* (2016), demonstrated that TAI is a viable alternative. Moreover, since the final gestation rate is not influenced by seasonal variations (Horrach *et al.*, 2012), it can be applied in any season of the year. Butler *et al.* (2019) claimed that the efficiency of milk production in pasture-based systems is strongly influenced by the calving pattern, which requires an excellent reproductive performance in a short reproduction season.

Besides the sustainability of systems in terms of productive plans, their environmental impact must be considered, along with climatic change, and animal welfare. Good cattle raising practices are fundamental to achieve highly efficient artificial insemination. However, on Cuban cattle farms, the relevance of this issue is minimized or disregarded. In this sense, Ritter, Beaver, and von Keyserlingk (2019) highlighted the multidimensional relationship of welfare, production, and reproduction traits.

To fulfill the above-mentioned definition of reproductive efficiency, it is important to establish goals based on key elements, which enable systematic evaluation, help conduct proactive actions to stabilize positive results, and in general terms, ensure the sustainability of the system. Consequently, indicators and goals that include births, and take into account all the cows in the herd, should be used.

Indicators used to evaluate reproductive efficiency

Several reproductive indexes have been integrated or combined to evaluate reproductive efficiency, including Herd (Britt), Fertility (FI, Kruiff), Fertility state (Esslemond FS), and Fertex. In a detailed review of this problem, González-Stagnaro (2005) concluded that it is hard to evaluate fertility, and analyze the causes of low reproductive efficiency, objectively, using only one indicator, possibly because the figures resulting from the parameters used are needed prior to estimation.

Although measures like calving interval, birth index, calving-conception interval, and days open, are poor indicators of the current efficacy of reproductive management, perhaps they should not be used in modern dairy herds. Particularly, they are inaccurate due to normal variations, bias, dynamics, lagging effects (Cook, 2010), and low heredity (Espinoza Villavicencio *et al*., 2015).

Given the complexity of the evaluation of bio-reproductive efficiency, no indicator, however complex, could achieve it thoroughly, alone. Moreover, an index made of various indicators will necessarily bring overlapping and partial repetition of certain contents, or be broken down into more than one indicator.

Key performance indicators (KPI)

KPIs are a number of steps focused on organizational performance, which are most critical for the present and future success of the organization (Parmenter, 2015).

Calving interval is the KPI used in year-round calving systems, whereas the insemination rate is the one used in seasonal systems to monitor the progress rate of insemination, especially during the first three weeks (Roche *et al.,* 2017).

KPIs assist organizations and companies to set up their goals, and measure progress; they must be quantifiable, and reflect the goals established by the organization. When they are not quantifiable, they cannot be measurable or usable. Together with KPI objectives, there should be goals; the definition of same-level objectives and goals is not supposed to change from year to year. The goals and objectives should only be changed after the goal is fulfilled (Reh, 2020).

The behavior of fertility is a referent of the environmental quality of the animal, general husbandry, and nutrition. To have a positive effect on fertility, the farm's management team should access updated information actively. A selection of proper KPIs for the system used, and the data available are critical for this task. As understanding of post-calving physiology becomes broader, new KPIs should be developed, that allow farmers and veterinarians to monitor animals during this critical period (Smith, Oultram, and Dobson, 2014).

The service period is the element determining the duration of the calving interval (Plaizier and King, 1996), and its extension depends on the re-initialization of normal ovarian cyclical activity after calving, which is conditioned by the capacity of the cow to recover from a negative energy balance, with a large loss of BC, especially after parturition (Carvalho *et al.,* 2014). It includes endocrinological changes, immune system function (Velázquez *et al.,* 2019), and the metabolic and health states (Macmillan *et al.,* 2020), aimed to enable uterine evolution, and increase the likelihood of future gestation occurrence.

The relationship of energy ingestion, energy production, and the form of energy in the diet (fiber *versus* carbohydrates without fiber), leads to enormous effects on the cow's metabolic state, and in some cases, on reproductive performance of dairy and beef cattle (Wiltbank *et al.,* 2015). Studies done to recently-calved cows are vital to maintain the periodicity of reproductive cycles, and prevent their inclusion in the empty category, as a result of prolonged post-calving anestrus.

According to Hermans *et al*. (2018) a KPI may be a simple average or the result of complex calculation, which is inherent, and can be calculated within a specific dimension. Time is one of the most important dimensions, since it permits aggregation and data summary within specific time frames (months, quarter, year), and the group in which it is calculated, that may be formed according to certain parameters (location, group of animals or people).

On tropical dairy farms Moran and Chamberlain (2017) numbered a total of 174 KPIs, and highlighted the importance of giving them a high priority, depending on their relevance for the current farm development stage, if herd size remains stable, the farmer's capacity to interpret data for future decision-making, and the easiness and accuracy to collect rough data needed to determine every KPI. The issue of which KPIs are most useful, is a challenge, and will often depend of the particularities of farms. They can be defined by discussing yields and the current objectives of the herd (Hewitt, Green and Hudson, 2018).

Based on the previous analysis, there is no doubt that births should be the main KPI to evaluate in cattle production systems, since it measures everything, and its declaration is mandatory. Recently, Vázquez, Bertot, and Horrach (2020) suggested the methodology of overall bio-reproductive efficiency index (OBREI), which tackles this KPI, and moves prospective and retrospectively along the entire life cycle of animals, which cannot be achieved using the traditional indexes.

This methodology is a novel alternative that does not guarantee improvements *per se*, but permits proper control and evaluation of performance, make fair accreditation decisions, and offer a number of orientations or measures to ensure a continuous improvement plan. Among other advantages, it reduces the excessive amount of indicators, which are sometimes hard to interpret, and offers simple, easy to interpret results, based on births, the main output in the organization and control of the reproduction system (Bertot *et al.*, 2011), which prevents humans from manipulating moments of the reproductive life of female animals.

In many cases, improved reproduction results in the capacity of changing managing decisions on the reproductive program, due to greater availability of replacement females. For instance, it reduces the need to inseminate all cows; permits the use of semen from beef breeds in a portion of the herd to produce crossbred calves; increases the role of genetic selection, since it can produce replacements of the best cows in the herd; and ensures more flexible and economical slaughtering decisions (Thatcher and Santos, 2020).

CONCLUSIONS

Reproductive efficiency can be defined as obtaining a calf per cow within the biologically permissible period to maximize cost-effectiveness as an expression of parent fertility, human intervention, and environmental actions.

Out of the arsenal of available zootechnical alternatives, it is important to assess the ones occurring today in terms of land and cattle owning in Cuba, which under a harsh economic environment, and in face of climate change, can contribute to improve the reproductive efficiency of cattle systems under artificial insemination.

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AUTHOR CONTRIBUTION

Research design and idea: MNHJ, JABV, RVMO, MGD, data analysis and interpretation: RVMO, JABV, MNHJ redaction of the manuscript: MNHJ, MGD, JABV, RVMO.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.