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A Methodology to Evaluate Bio-reproductive Efficiency in Cattle Herds

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ABSTRACT

Background: Several indicators have been used to evaluate reproductive efficiency of cattle herds with serious limitations. **Aim**: To create a global index that integrates all the aspects of herd bio-reproduction arranged in such a way that facilitates application in any scenario. **Methods:** A global index of reproductive efficiency was created based on two partial indexes or basic components in cattle: growing females and births, all interpreted through deviation of values in relation to the farm (fulfilled aim), using three levels of accreditation of desired reproductive efficiency. A simulation was performed to illustrate the utilization of the methodology suggested in a 117-cow herd, of which 54 animals were nulliparous, with a mid-accreditation level (age at first calving and calving intervals of 32 and 16 months, respectively), and monthly periodicity. **Results:** The values achieved in partial cow births (0.82), partial index of growing females (1.19), and global index of bio-reproductive efficiency (1.01) indicated that the herd kept its levels of accreditation. This evaluation may also be transversally added at any time unit used, or be longitudinally seriated, representing a system of continuous improvement of herd bioreproductive efficiency, until reaching biologically permissible limits. **Conclusions:** A methodology is suggested to build a customized global index to evaluate herd bio-reproductive efficiency and farmer performance.

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

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INTRODUCTION

In every system used to organize reproduction, the actions of process control will only be effective if they come with systematic evaluation of its efficiency. Indicators like open days, servicing, and calving intervals, have had severe limitations for several years (Plaizier and King, 1996; Weigel, 2004), since they refer to past events, and therefore, are not effective to perform dynamic measurements of the real efficiency of reproductive management.

Besides, integrated or combined indexes have been criticized (González, 2001). Today, several alternatives are still being used, such as, Stevenson and Britt (2017), who said that as part of a total performance in Holstein, they included a fertility index combining various reproductive traits of young and adult cows.

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

Accordingly, what is the suitable way that could be used to perform a dynamic evaluation of the reproductive behavior of herds? To accomplish it, it is important to use a global index that comprising all its sides, with a structure or metrics that overcomes the said inconveniences, which, in turn, facilitates calculations and interpretations, and can be applied to any kind of production. It would cover low input cattle raising or elite herds based on excellence, using skilled human resources and state of the art technology. Consequently, the aim of this research was to propose a new methodology to evaluate bio-reproductive efficiency in cattle herds.

MATERIALS AND METHODS

The methodology proposed is focused on *births*, the main output variable in the arrangement system and reproduction control (Bertot *et al.,* 2011), thus keeping humans from handling the females at certain moments of their reproductive lives. This methodology has three stages: division of the useful reproductive life of cows, organization of herd accreditation categories, and definition of indexes, which are explained below:

I. Division of the useful reproductive life of cows.

It was divided at an unequivocal point of reproductive continuity (Fig. 1); therefore, the most convenient time is age at first calving (AFC).

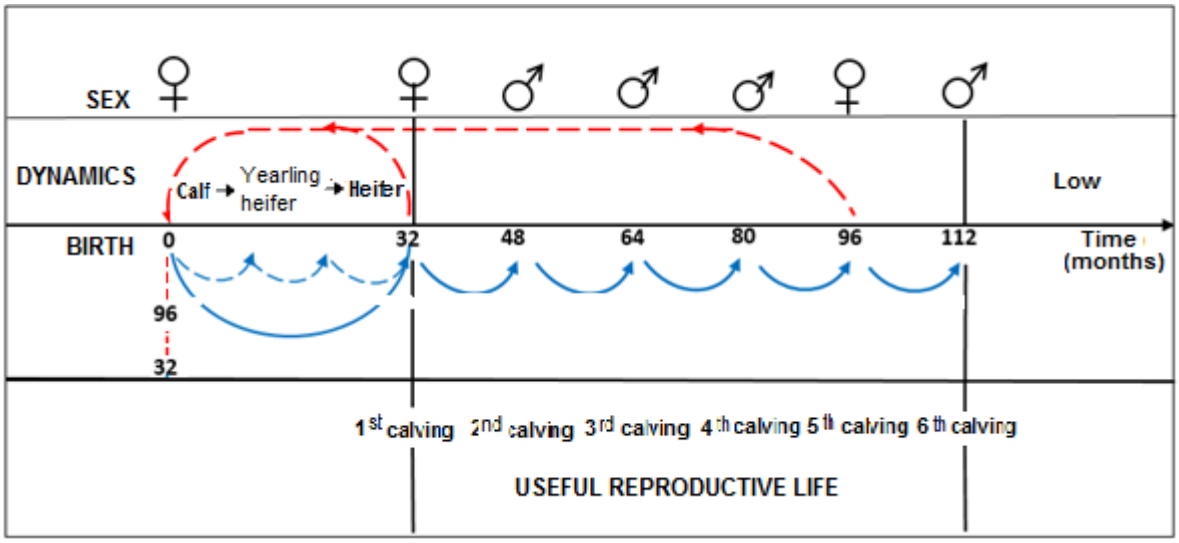

Fig. 1. Dynamics of the reproductive life of a cow with six calvings in a herd with an average reproductive efficiency (first calving at 32 months, and average calving intervals of 16 months).

In such a way, partition is not made at a uncertain point, in relation to the active incorporation of the cows to reproduction or their first fertile estrus, whose continuity (prospective or retrospective) is uncertain due to its relation to the genetic influence of sexual maturity (Corvisón and Vázquez, 2005). Moreover, the nutritional management and growth rate, both in dairy (Akins, 2016), and beef heifers (Larson, White and Laflin, 2016; D'Occhio, Baruselli, and Campanile, 2018) have a determining role in heifer development, and age at first calving, as a result of human efforts.

II. Creation of accreditation levels or categories for herds

Three accreditation levels or categories (Table 1) were established, according to the goals set in each of them, in terms of age of first calving (AFC), calving interval (CCI), replacement rate (RR), and the means of all births produced (calving average) in the herd, so that the desired reproductive efficiency is achieved. The goals of every level or category are included in the calculation of index as transient constants (TC), and represent a system of continuous improvement of reproductive efficiency of the herd, until the biologically permissible boundaries are reached.

Table 1. Accreditation levels or categories suggested for the herds

Indicator	Accreditation levels or categories		
	Low	Medium	High
AFC (months)	36	32	28
CCI (months)	20	16	13
RT (%)	20	16	12
Calving average	3.5	4.0	4.5

***The number values represent transient constants (TC)**

III. Definition of the global index, its components, and relative contribution

Global index of bio-reproductive efficiency (GiBRE)

A GiBRE is built when using any time unit for evaluation, calculated according to the average of the two partial indexes or basic components, as follows:

Partial index of developing females (PiDF). It evaluates females since they are born to their first calving.

Partial index of cow births (PiCB). It evaluates all the useful reproductive life of adult females, until their reproductive decline. Whenever calvings or births are mentioned as events that take place at the same time, they should be understood as the condition that calvings lead to simple and viable births.

Which is expressed as follows:

$$GiBRE = \left(\frac{PiDF + PiCB}{2}\right) = (0.5 * PiDF) + (0.5 * PiCB)$$

0.5 = Impact or relative contribution of each component on the partial index.

Partial index of developing females (PiDF)

Working on developing females is more demanding; it is the fundamental element determining that in the future the herd can be seen as a productive company, be reduced, stabilized or developed.

$$PiDF = \frac{BOH}{EBN}$$

Being,
PiDF = Developing females (AFC is the underlying classical indicator).
BOH = Births observed in heifers at the Time Unit for Evaluation (TUE).
EBN = Births expected from the total initial nulliparous animals at TUE.
Then, it is important to define or clear up some terminology:

The *time unit for evaluation* (TUE) refers to the desired number of systematic or periodic self-evaluations: Commonly, they are performed on a monthly basis, periodicity equal to 12, but could be bi-monthly, quarterly,with a periodicity equal to 6 and 4, respectively.

Considering the variable number of females in reproduction, TUE should be adjusted based on Table 2. When the herd is very little, in certain TUE, no births are observed in heifers or cows, or both, which might result in 0 after estimating the partial values. Regardless of a possible compensation throughout time, this situation might discourage farmers temporarily.

Table 2. Recommendations of desired periodicity, depending on the existing females in reproduction within the herd

N (Females in reproduction)	TUE	Periodicity
> 119	Monthly	12
90-119	Bi-monthly	6
60-89	Quarterly	4
30-59	Every four months	3
< 30	Every six months	2

This adaptive property of the index ensures coping with seasonality, whether it is natural (Mendoza *et al.*, 2019) or man-made, through synchronization of estrus or more advanced fixed-time artificial insemination techniques (IATF) (Oosthuizen *et al.*, 2018).

Thus, for example, if the first calving of heifers is expected to take place at 30 months of age, and self-evaluations are intended with a periodicity of 4, meaning quarterly, a simple rule of three produces a value of 3/30 = 0.1 expected quarterly calvings per nulliparous animals (females from the first day of birth until the day before calving). Finally, the EBN value is obtained by multiplying (0.1) by the number of existing nulliparous cows in the herd at the beginning of the quarter or the end of the previous quarter.

Partial index of cow births (PiCB).

$$PiCB = \frac{AB}{EB}$$

Being,

PiCB = births in cows (CCI as underlying classical indicator).
EB = Births expected from the total initial cows at TUE.
AB = Actual births observed in cows at TUE.

Once the CCI goal has been set in months to achieve the desired number of births per cow, it is easy to calculate the corresponding value within the TUE used, which is then multiplied by the total existing cows; the result will be the EB value.

For example, in a herd of 80 cows, to produce one calf per cow every 20 months, and run a bi-monthly self-evaluation or control, the equivalent number of expected calves every two months would be,

$$EB = \frac{2}{20} = 0.1 \text{ per cow}$$

EB= 0.1 $* 80 = 8$ total births in the TUE.

Variants of these two partial basic reproductive indexes might be obtained from the replacement rate and the average of calvings or births from cows in the herd, acting as underlying classical indicators, which is now outside the desired scope of this study.

Optional partial indicators

It is possible to expand GiBRE with the inclusion of other components related to breeder management, and the purpose of the herd, which includes the stages below:

Partial index of female mass growth (PiMG)

The role of this temporary partial index is to evaluate increases in the size of herds, control their stability, and especially, manage undesired decreasing trends. It is calculated as follows:

$$PiMG = \frac{FE}{IE}$$

Being,

FE = Final existence of females in the herd, at the TUE.
IE = Initial existence of females in the herd, at the TUE.

This component is expressed according to classical controls of initial and final existence in herd movement; just like the previous, it maintains the same metrics, but without TC. It is transient because after stabilizing the desired size of the herd in a sustainable manner, it can be varied not to compromise the global index unnecessarily.

This index can also be calculated with the addition of males, a variant that was not included in this paper.

Partial index of male development (PiMD)

This is an optional and complementary index whose aim is to evaluate male development in beef, dairy, or double-purpose cattle. Generally, in dairy cattle, male raising and development is valued as a by-product of milk production, but in terms of building a global bio-reproductive index (as the one suggested), raising is another action in comprehensive herd management, and eventually, a result from the reproductive activity of their mothers. It is calculated as follows:

$$PiMD = \frac{DSLM}{DSME}$$

Being,

DSML = The number dropouts due to sale of males that met the requisites in the TUE.

DSME = (The total number of expected dropouts due to the same reason) = Total births of males in the TUE, with a time delay equal to the time set to meet the output requisites, or definitive dropout from the herd.

Observation: The determine DSME, special attention must be paid to the relation between TUE and the time set to meet the output requisites.

Impact or relative contribution of each partial index to the global index.

The impact or relative contribution of each partial index is expressed by the coefficient of each component to the value of the global index. For instance, it is 0.5 in this case, because it is made of two partial indexes (and relative because its sum equals the unit). If the global index were expanded to include three or four partial indexes, then it would be easily understood that, due to the same reasons, the value of that coefficient would be 0.33 and 0.25, respectively, provided that the relative contribution is kept.

To demonstrate the usefulness of the method, a simulation was made in a herd made of 117 cows and 54 nulliparous animals (calves, yearling heifers, and heifers), which produced 6 and 2 calvings, respectively. The GiBRE was calculated using a mean level of accreditation or category (AFC and CCI or 32 and 16 months, respectively), to calculate the two basic partial indexes, with a monthly periodicity.

RESULTS AND DISCUSSION

The simulation results (Table 3) suggest that the herd has not meet the requisites to change the category, since the cow births are still insufficient. Therefore, actions should be focused on heifers, and efforts should be made to reach stable reproductive cycles in cows, such as, the implementation of nutritional and health programs that reduce the risk of metabolic alterations, as well as changes produced in body condition (Barletta *et al.,* 2017).

Table 3. Simulation results of a herd in one TUE

Existence of females		Births		Components		GiBRE
Nulliparous	Cows	Heifers	Cows	PiDF	PiCB	
54	117	2	6	1.19	0.82	1.01

This result is also possible by adding data from several small herds, or data accumulated with more than one TUE. Having reached values near the unit, as a stable average of GiBRE during a prolonged period of time (a year), the current level (mid) must be changed to higher level TCs.

In case a more rigorous selection is desired for genetic breeding of cows with the intention of speeding the transit to excellence levels of bio-reproductive efficiency, but there are difficulties with the male sale contracts, it is advisable to keep the same time unit of self-evaluations, begin to use TC corresponding to the medium level, and choose a full GiBRE, as in the way below:

GiBRE = 0.25 (PiMD + PiDF + PiCB + PiMG)

Being,

GiBRE = Global index of bio-reproductive efficiency

PiMD = Partial index of male development

PiDF = Partial index of developing females

PiCB = Partial index of cow births

PiMG = Partial index of basic mass growth

At a breeder's request, an external evaluation made by a team of specialists, will audit the control charts and records evidencing every self-evaluation, and they will issue a certificate of accreditation, depending on the corresponding level.

Although the global index has a practically zootechnical connotation, it does not deal with management, feeding, health, and genetic selection, but, on the contrary, all the above is assumed indirectly as part of much broader concepts, such as the production system and good livestock raising practices, which will depend more on human activity to accomplish successful development of a herd.

Moreover, the proposals made may be customized, though the strictest way to adjust them would be by using the first quartile, the median, and the third quartile, or the mean ± typical deviation, based on previous experience, thus proving the flexibility of the method.

The application of this method requires previous analysis to set up realistic goals that encourage farmers to improve their results considering local factors and social aspects affecting the insemination staff, as well as all the livestock raising personnel, in general. These aspects were mentioned by Russi, Costa-e-Silva, Zúccari, Recalde and Cardoso, (2010), in Brazil, and by Horrach *et al.* (2017), in Cuba.

Maximum reproductive efficiency

When the herds reach the category of high reproductive efficiency, three choices are recommended to measure further improvement:

1. To leave everything the same way up to the highest efficiency category (the simplest choice), and evaluate further improvements depending on the extent of the global index. How big is it in relation to the unit?
2. To add another category using TC near the permissible biological threshold by species (for instance, CCI = 12, AFC = 24, and calving average = 5). In that case, the RT is not included, because there is no point in monitoring it at those levels of efficiency. In that sense, Chebel and Ribeiro (2016) noted that herds under efficient reproductive management, which are not being expanded, do not need to purchase replacement heifers to keep a constant number of lactating cows in the herd.
3. To use more demanding components or indicators that tend to eliminate the difference between the real sale of males and heifer births and the expected births of their mothers in the TUE, which can be done by integrating the cow birth component (PiCB) to female development (PiDF) or male development (PiMD) in the same index, since all the cases do not need the partial index (PiMG). At these efficiency levels, monitoring should not be a concern.

In the first choice, the scale to be used must come from the unit with a cut off, to assign very high, elite, or maximum efficiency categories.

In the second choice, efficiency is measured by the extent of the index, also with a cut off, but otherwise (how the value nears the unit), since in the goals of the second choice or the requisites of the third, it is practically impossible to reach the value of the unit.

In the third choice, it is important to include the concept of *herd reproducibility* (HR), defined as the capacity the herd has to use all its reproductive potential, and its adaptability to the environment to fit generational replacement. It is measured by the relationship between births or calvings of adult cows, and the births or total calvings of their female progeny (heifers in their first calving). Applied to males, it would be the relationship among male births or calvings from adult cows, and those males that will be sold.

The above leads to the creation of an integrated index to achieve maximum efficiency, which could be *Simple* (SIRR) if applied separately to either sex (m and f), or *Compound* (CIRR), if both sexes are averaged, as follows:

$$SIRR(h) = \frac{BOH}{0.5\ EB*}$$

$$SIRR(m) = \frac{DSML}{0.5\ EB*}$$

$$CIRR = \frac{BOH}{EB*} = \frac{DSML}{EB*}$$

* Expected births in the high category (CCI = 13) in the TUE, with a delay equal to the time set to meet the sales contract requirements for males, and the AFC in females.

Seemingly, this integrated index variant would be enough to accomplish the aim of this paper, using three cut offs to establish four intervals in a 0-1 scale, and assign each interval category the categories low to very high, or elite.

However, this procedure does not help detect where the problem is to deal with it following a systematic and continuous approach. On the other hand, the frequencies of value 0 or near 0, would discourage farmers, especially in small and midsized herds, or herds with mid fertility. Also, the TUE would have to be arranged for lower periodicity to perform self-evaluations without timely improvement measures. Therefore, the application of such integrated index in herds with low or mid reproductive efficiency makes no sense. Then, it would be necessary to gradually transit through the lower categories, in order to achieve maximum efficiency.

Summary of the general features of the global index

The main feature of this index is that all its methodology in centered on *births*. It performs a dynamic evaluation of the amount and quality of the results, and the speed it can be reached at, moving prospectively and retrospectively throughout the whole life cycle of animals (Fig. 2). The calculations are made in the same time unit chosen, and normal continuity (temporary series) of the time variable.

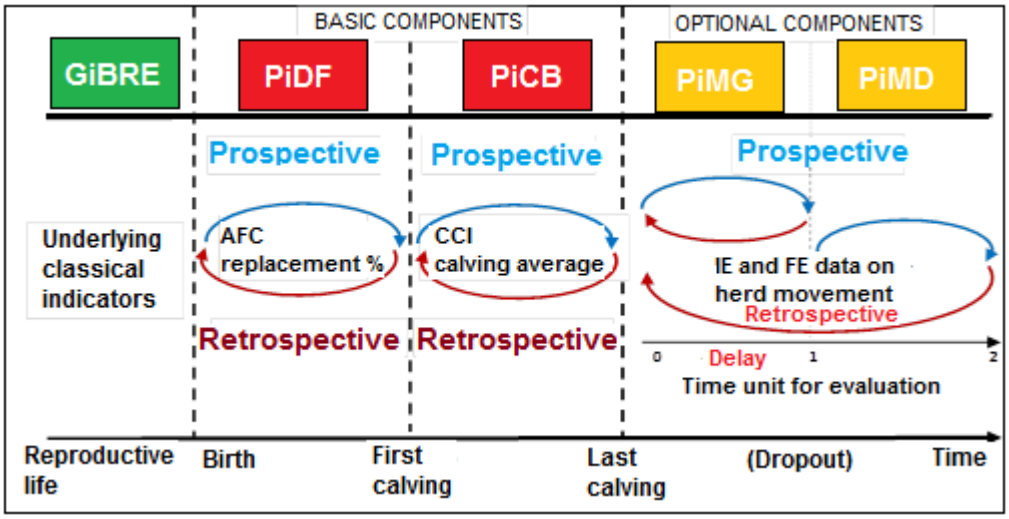

Fig. 2. Graphic representation of the basic components of the global index of reproductive efficiency (GiBRE), and its relationship with the classical reproductive indicators, and the useful reproductive life of females. The prospective and retrospective character of PiDF and PiCB are outstanding, showing the possibility of including other components (optional), like PiMG and PiMD.

Although the second characteristic is theoretically complex and difficult, its application is very simple in practice, both for calculation and interpretation of each partial or global index.

It is the addition of two basic partial indexes that can rise to four, to include a temporary partial index related to herd size and growth (PiMG), and another optional index related to male rearing and development (PiMD).

It can be matched to the level of desired requirement (low, mid, and high), through goals of classic indicators frequently used in any of the systems of reproduction organization.

It can be calculated with transversally added data, using any aggregation type (herds, companies, municipalities, etc.), and lengthwise accumulated data for any TUE.

It is *integrated* because it is made of partial indexes that indirectly include all the herd reproductive management labor.

It is *flexible* because it recommends options of components that can be included, modified, and even eliminated from the global index, in order to adapt to any scenario.

It can be customized to a desired time unit for record, control, and self-evaluation (monthly, bimonthly, etc.), and to any herd size (small, mid, and large), or any production system.

It is *simple* because its calculation is done using the four basic arithmetic operations, and can be built by controlling a reduced number of variables and classic indicators (CCI and AFC), which are related to the goals set, but do not need control or calculation.

It can be easily interpreted, based on the deviation of the value of each component or global index, with respect to the unit representing goal accomplishment; values lower than 1 indicate accomplishment, greater values indicate over-accomplishment. It has the capacity to detect, within the dynamic of the useful life cycle of animals, where the main difficulties are.

Throughout the development of this paper, unnecessary use of rigorous scientific names has been avoided; symbols like sum, subscripts like i^{th}, and others, and concepts like dimensionality, additivity, weighing (w_i), multi-collinearity, weighed sum, asymptote, etc., were excluded. The intention was to facilitate understanding of farmers who use traditional methods of information recording in field books, or individual animal IDs or controls, in relatively small herds.

In addition to the previous, it can also be used by businesspeople and skilled personnel who employ IT to control generally bigger herds, with automatic record collection and information processing.

CONCLUSIONS

This methodology is a contribution to the solution of an old scientific problem. It helps build a global index to evaluate herd reproductive efficiency, and can be customized. This methodology is easy to use, dynamic, easily interpreted, it ensures the detection of the main difficulties of such a complex biological process, and, above all, it is flexible in terms of the conditions required for application.

This methodology can be applied to any herd at the desired time, which is very convenient, compared to other indicators like CCI, with an annual calculation base, transversal results, and the exclusion of proactive reproductive work, thus enabling the adoption of measures to improve the dimension affected.

RECOMMENDATIONS

To broaden the scope of the recommended methodology, by making little changes, the global index can be adjusted to include relations with productive or economic indicators through incentives or penalties, based on the relative contribution coefficients, and for application to other livestock species, uniparous and multiparous, always using the same structure and metrics.

To conduct a new research project so all the contents of this methodology, including the first recommendation, are integrated into specific software for general evaluation of reproductive efficiency and computer-assisted herd management.

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AUTHOR CONTRIBUTION

Roberto Vázquez Montes de Oca conceived and designed the research following the limitations and criticism to the traditionally used indexes for evaluation of reproductive efficiency of bovine herds. Analysis, data interpretation, and redaction of the manuscript.

José Alberto Bertot Valdés, analysis, data interpretation, and redaction of the manuscript.

Maydier Norman Horrach Junco: analysis, data interpretation, and redaction of the manuscript.

CONFLICT OF INTERESTS

The authors declare the absence of conflict of interests.