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Animal nutrition

Historical evolution of productive indicators in dairy cows in grazing systems

Evaluación historica de indicadores productivos en vacas lecheras en sistemas a pastoreo

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Abstract

We used retrospective data corresponding to the lactations of 300 primiparous and multiparous Holstein cows, collected between 1992-2012 in farm located in Casilda, province of Santa Fe-Argentina. The animals were divided into two groups: pure cows (VP, n = 120) and cows with breeding registers (VRC, n = 180). The dispersion diagrams resulting from jointly representing the values of the milk index (Y) and the total milk production (X), corresponding to each individual, were prepared first. Dispersion diagrams were made linking the same indicators, but restricting the association to pure cows and with breeding registers, within each category (low, medium and high) of production. For pure cows: low production cows: r = 0.883; P <0.0001; cows of intermediate production: r = 0.577; P <0.0001 and high production cows: r = 0.391; P = 0.0139.For the cows breeding record: low production cows: r = 0.739; P <0.0001; cows of intermediate production: r = 0.691; P <0.0001 and high production cows: r = 0.568; P <0.0001. The slopes were positive and significant. A decrease in the value of the slope (P <0.0001) was observed together with an increase in the residual variance with the increase in milk production. It is concluded that in addition to the total liters of milk, the contribution of other variables such as longevity, efficiency in breeding and reproductive efficiency should be incorporated.
Keywords: Holstein cows, productive efficiency, evaluation criteria, grazing system

Resumen

Se utilizaron datos retrospectivos correspondientes a las lactancias de 300 vacas primíparas y multíparas de raza Holstein, recolectados entre los años 1992-2012 en un lechería-cabaña ubicado de la localidad de Casilda, provincia de Santa Fe-Argentina. Los animales se dividieron en dos grupos: vacas puras (VP, n=120) y vacas con registro de cría (VRC, n=180). Se procedió a confeccionar, en primer término, los diagramas de dispersión resultantes de representar en forma conjunta los valores del índice de leche (Y) y la producción total de leche (X), correspondientes a cada individuo. Se realizaron diagramas de dispersión vinculando los mismos indicadores, pero restringiendo la asociación a las vacas puras y con registro de cría, dentro de cada categoría (baja, media y alta) de producción. Para las vacas puras: vacas de baja producción: r = 0,883; P <0,0001; vacas de producción intermedia: r = 0,577; P <0,0001 y vacas de alta producción: r = 0,391; P = 0,0139.Para las vacas registro de cría: vacas de baja producción: r = 0,739; P <0,0001; vacas de producción intermedia: r = 0,691; P <0,0001 y vacas de alta producción: r = 0,568; P<0,0001. Las pendientes fueron positivas y significativas. Se observó una disminución del valor de la pendiente (P <0,0001) junto con un aumento de la variancia residual con el aumento de la producción de leche. Se concluye que además de los litros totales de leche, debería incorporarse la contribución de otras variables tales como longevidad, eficiencia en la recría y comportamiento reproductivo.

Palabras claves: vacas Holstein, eficiencia productiva, criterios de evaluación, sistema a pastoreo

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1 Introduction

The application of the system approach represents a totalizing and macroscopic vision in the face of the reductionist approaches that are common in agricultural production that focus their attention on a few isolated variables; the system approach implies the recognition of the interactions between their elements. The systemic vision makes it possible to understand the mechanisms associated with the productivity and the efficiency of the whole, as well as the dynamics of its properties over the time. Following the Cartesian mandate to divide reality to make it comprehensible and facilitate its interpretation, traditional disciplines have evolved by dividing the global process of agricultural production into smaller units. The adoption of this analytical strategy by the researchers, although has contributed to a more detailed knowledge of the parties, has also delayed the understanding of the integral processes involved in the whole which not only encompasses them, but also exceeds them (Bertalanffy, 1976; Viglizzo, 1989). An example of this is the search for the maximization value of a productive variable at the expense of the remaining variables, which has altered the equilibrium and deteriorated the overall efficiency of the productive systems (Rabasa, 1980).

For a long time the impact and some geneticists who alleged that their effects, if they existed, should be negligible (Boettcher, 2001), minimized consequences of this type of interaction. The experimental existence evidence of this genotype-environment interaction is not always coincidental and is expected to occur when there are big differences between the genotypes and/or between the environments; therefore, the effects are present especially in productive systems with low or medium environmental control (Geay y Robelin, 1979; Molinuevo *et al*., 1982; Oldham, Simm y Marsden, 1996).

Every open system receives inputs and then processes and generates outputs. In the case of production systems, the concept of efficiency refers to the most appropriate way of using resources, with existing technology and products. Because of this positioning is considered that a production process is efficient if the maximum output is obtained with the lowest possible inputs (Coelli *et al*., 2005). In dairy production, the term "maximize the outputsçan present different connotations: to maximize the individual production by lactation or to maximize the production considering the totality of cow's life which implies to include in the analysis the reproductive success.

The consultants of dairy establishments require updated and constant information that allows them to monitor the activity and to plan actions that contribute to process the inputs in such a way that they influence positively on the outputs of the system. This information, referred as indicators, should adequately reflect what happens on the premises and serve as a reference to know where each establishment is located at any given time. The indicators aim to show in a simple and didactic way the achievements derived from the fulfillment of the objectives associated to the different actions that proposed in a farm, so that these can be easily understood and evaluated. In this sense, they are information elements that summarize the characteristics of a system and "indicate" what happens in it (Piccardi, 2014; Carstensen, 2013).

According to the International Institute for Sustainable Development (IISD), an indicator allows to quantify and simplify complex phenomena by improving the understanding of reality. Among the most common indicators in dairy farms are the attributes of milk production that can be derived from lactation curves. The parameters that characterize these curves and, therefore, are used as elements to be evaluated are: the lactation duration in days, the days in lactation to the peak of lactation and the liters of milk to the peak of lactation (Keown *et al*., 1986; Ludwick y Petersen, 1943). The liters of milk adjusted to 305 days of lactation, also represent a productive indicator of frequent use that refers to the liters of milk accumulated in lactation, with that average theoretical duration (Piccardi, 2014). Even though the liters of milk produced by a cow can be considered the most important indicator in the framework of intensive systems, they do not alone represent the most appropriate reference to make operational a complex variable such as productive efficiency, when it is intended to take advantage of grazing systems. In these cases, it should be supplemented, or even replaced, by other indicators that are constituted as alternatives of a more comprehensive measure to assess the production behavior in those systems in which the pasture represents the basic component of the diet. To have indicators of this nature would help to avoid the overvaluation of one of the characters involved in the valuation of a good dairy cow over other transcendent, and would allow to identify the biotypes

that are more adapted to the different environments at the evaluation site. The aim of this study was to evaluate the biological efficiency of two populations of dairy cows, in a grazing system, with two productive indicators recorded over 21 years.

2 Materials and methods

Retrospective data were used corresponding to 300 primiparous and multiparous cows of Holstein breed, American-Canadian biotype with records of all their productive life, since their incorporation to the system until their sale or death, collected between the 1992 and 2012 in the Argentinian farm belonging to the Agrotechnical School Gral. José de San Martín, dependent of Universidad Nacional de Rosario. The farm is located in Casilda, Caseros department, Santa Fe province, Argentina (33° 02′ 39′ South latitude, 61° 10′ 05′ West longitude).

The establishment has official milk control of the Rural Society of Totoras, official entity N° 13 and presents the following characteristics: (1) exclusive use of Holstein cows; (2) feeding is basically by grazing (alfalfa meadows) with supplementation (maize grain, corn silo and rolls), and supplied in different proportions according to the seasonal availability of alfalfa meadows; (3) a periodic gynecological control; (4) official dairy control is performed; (5) It is free of brucellosis, tuberculosis, campylobacteriosis and trichomoniasis; with Leptospirosis control, bovine infectious rhinotracheitis and bovine viral diarrhea; (7) reported data are reliable and (8) American and Canadian semen is used for artificial insemination. These characteristics guarantee minimum management guidelines in health, food and technical assistance that place it above the general average of the aforementioned department, in these respects.

During this period, all the cows were in the same milking facilities. The animals were divided into two groups: pure cows (VP, n= 120) and cows with breeding register (VRC, n = 180). The difference between the two is because the first ones are always inseminated with semen of bulls, whereas this practice is not maintained constantly in the case of the second ones. To achieve the condition of pure cow, seven generations are required with proven parents, which imply that the members of the group of cows with breeding record are at different times of that path to achieve it. During the period covered by this evaluation, cows consumed forages under direct grazing (green pastures of winter and summer season) or conserved (whole-plant silo of maize and sorghum, prairie hay) and concentrates (grains of maize and sorghum). In the same period, the climatic environment was very variable, both in precipitations and in the combination of temperature and relative humidity.

The following variables were recorded:

Milk Production (PL) in liters: liters of milk produced per cow, adjusted to 305 days of lactation.

Date of birth (FN) in days.

Age at first delivery (EPP) in days.

Total milk production (LT) in liters $[LT = \sum pli]$, where pli are the liters produced in the i-th lactation.

Milk index (milk production per day of life) iL: LT/e, where e is the age in days at the end of the last lactation(Marini y Oyarzabal, 2002*a*,*b*).

Both pure cows and those with breeding register were classified, in thirds according to the value of their total milk production (LT), thus defining three categories for each group: CB – low production cows, CM – average production cows and CA – High production cows.

For both groups of cows, it was proceeded to make, firstly, the dispersion diagrams resulting from jointly representing the index milk values (y) and the total milk production (X), corresponding to each individual. In the second instance, dispersion diagrams were carried out linking the same indicators, but restricting the association to the pure cows and with breeding register, within each production category (low, medium and high).

2.1 Statistical analysis

The association degree between both indicators – total milk production and milk index– for pure cows and with breeding record of each third low, medium and high production- is quantified from the calculation of the Pearson's product-moment correlation coefficient.

The data -milk index versus milk production- for each productive category, purebred cows and cows with breeding register, were adjusted by simple linear regression, after finding the linear behavior by a test of streaks or cycles (Sheskin, 2011). The estimators of the regression line parameters were

compared by a covariance analysis. The ratios between production thirds for each type of cow (pure and with breeding record) were limited to the respective slopes, while those corresponding to the type of cow for each production level (low, medium and high) also included the heights (sorted to the origin).

3 Results

3.1 Comparison of the cow behavior belonging to the categories of low, medium and high production, in each of the two groups: purebred cows and cows with breeding record.

Figure 1 summarizes the ratio between the milk index and total milk production for the three productive categories in pure cows (VP). It is observed that higher accumulated milk production corresponds to a higher value of the milk index. Even though this is an expected association since the production value is part of the calculation of IL, when considering all the data, the association is not linear but shows a tendency to stabilize, which is translated into a decrease in the correlation coefficient value when moving from less productive to the most productive cows, according to the following detail: First third (low production cows): R = 0.883; P<0.0001; Second third (intermediate production cows): R= 0.577; P<0.0001 and 3 third (high production cows): R= 0.391; P= 0.0139.

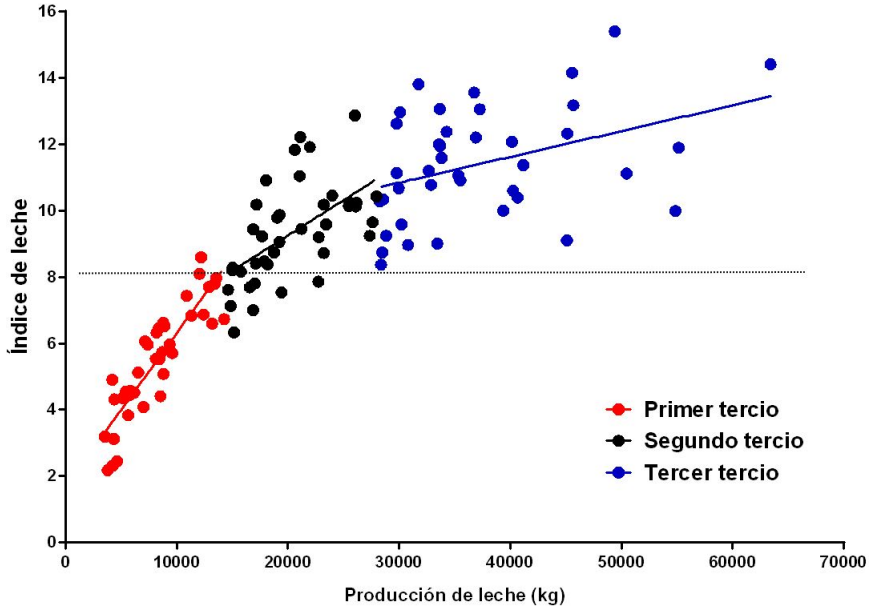

Figura 1. Ratio between the milk index and the accumulated milk production of purebred American-Canadian Holstein cows discriminated by thirds according to their production

Table 1 presents the results derived from the linear adjustment of each of the three sections mentioned. For none of them the hypothesis linearity was rejected (the test of cycles or streaks was not significant, P>0.05). All the slopes were positive and significantly different from zero (P<0.05). A decrease in the slope value was observed (difference between statistically significant slopes: F = 17.13; P<0.0001) with an increase in the residual variance (Sy. x)

Tabla 1. Regression slope value, linearity test and residual variation of the ratio between milk index and total milk production in purebred American-Canadian Holstein cows discriminated in thirds by their accumulated milk production

	First third	Second third	Third third
b ±Sb	0,000462 ±0,000040	0,000213 ±0,000049	0,000078 ±0,000030
Ho) β = 0	F = 131 P <0,0001	F = 18,9 P <0,0001	F = 6,68 P = 0,0139
Sy.x	0,785	1,233	1,589

b±Sb: slope of the line and standard error of the estimation
Sy.x : residual variance

Figure 2 summarizes the ratio between the milk index and total milk production for the three productive categories in cows with breeding register (VRC). As expected, in this case is reiterated that higher milk production corresponds to a higher value of the milk index. Again, if the data is considered as a whole, the association is not linear, but tends to stabilize by the values of the respective correlation coefficients: first third (low production cows): R= 0.739; P<0.0001; Second third (intermediate production cows): R= 0.691; P<0.0001 and Third third (high production cows): R= 0.568; P<0.0001.

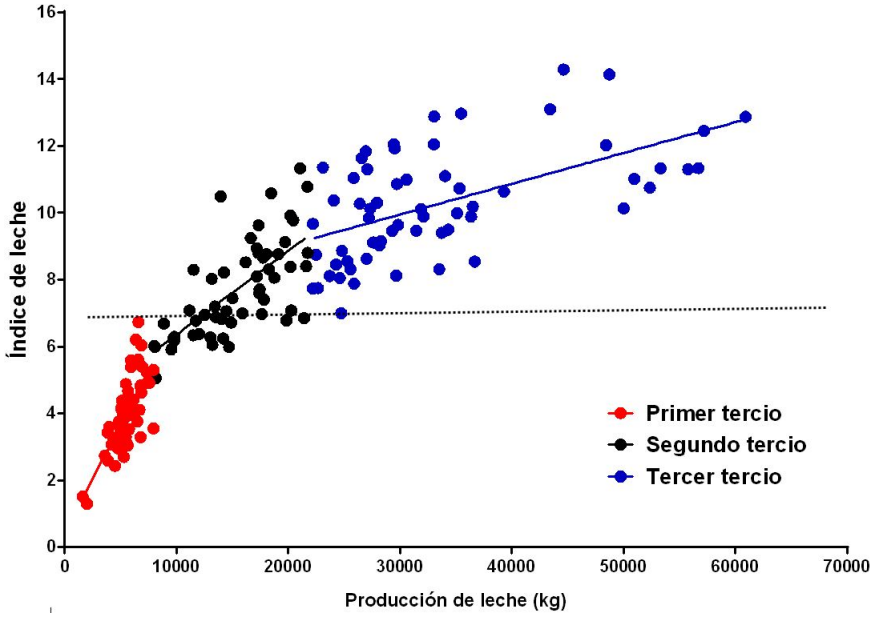

Figura 2. Ratio of the milk index and the accumulated milk production of American-Canadian biotype Holstein cows with breeding record discriminated by thirds according to their production

As in the case of pure cows, each of the three sections was adjusted with a linear function (Table 2). For none of these sections the linearity hypothesis was rejected (the test of cycles or streaks was non-significant). All the slopes were positive and meaningful. Also in this category of animals was observed a decrease in the slope value (the difference between slopes was statistically significant: F = 18.82; P<0.0001) with an increase in residual variance (Sy.x).

Tabla 2. Regression slope value, linearity test and residual variation of the ratio between the milk index and the total milk production in American-Canadian biotype Holstein cows with breeding record discriminated in thirds by accumulated milk production.

	First third	Second third	Third third
b ±Sb	0,000641 ±0,000077	0,000250 ±0,000036	0,000092 ±0,000017
Ho) β = 0	F = 70,0 P <0,0001	F = 49,2 P <0,0001	F = 28,2 P = 0,0001
Sy.x	0,737	1,058	1,378

b±Sb: slope of the line and standard error or the estimation
Sy.x : residual variance

3.2 Behavior comparison of the three production categories -low, medium and high- between pure cows and cows with breeding record

Figure 3 shows the behavior comparison of the milk index according to the total milk production between VP and VRC belonging to the first third (low production). The difference between the slopes was statistically significant (F= 4.162; P = 0.044) with higher value for cows with breeding register (VRC: b = 0.00064; VP: b = 0.00046).

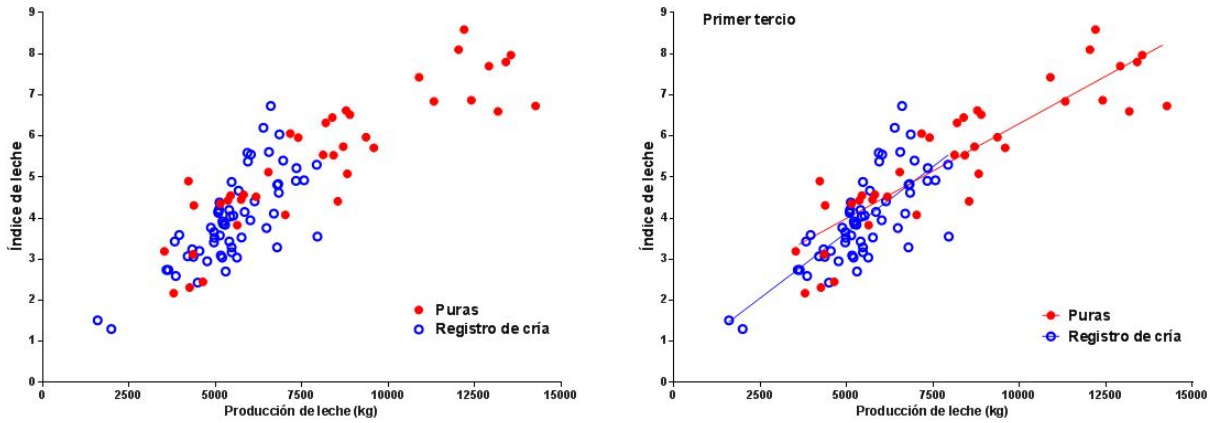

Figura 3. Comparison between purebred cows and cows with low production register (on the left: experimental values; on the right: linear adjustments)

Table 3 shows that in the group of cows with breeding register there is a higher percentage of animals that only remain in the one-lactation system.

Tabla 3. Absolute and relative values of pure cows and register of low-production breeding discriminated according to the number of calvings during their productive life

	Pure		Breeding record	
N° of calving	**N° of cows**	**%**	**N° of cows**	**%**
1	21	54	37	62,7
2	11	28	11	18,6
3	5	12,8	8	13,6
4	1	2,6	2	3,4
5	1	2,6	1	1,7
Total	39	100	59	100

Figure 4 shows the behavior comparison of the milk index according to the total milk production between VP and VRC belonging to the second third (intermediate production). The difference between slopes was not statistically significant (F= 1.191; P= 0.278) which allowed to calculate a common slope (0.00025) and to compare the heights of the regression lines. Although the line corresponding to the pure cows shows a tendency to be placed in the Cartesian plane above the one corresponding to the non-pure cows, the difference was not statistically significant (F = 2.493; P = 0.118) with a common height equal to 3.94.

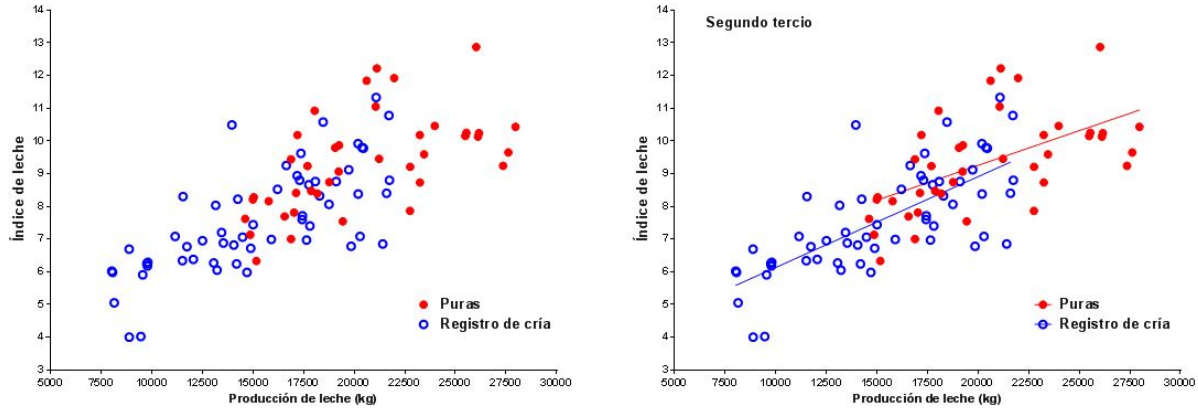

Figura 4. Comparison between purebred cows and cows with breeding record of medium production (to the left: experimental values; to the right: linear adjustments).

Table 4 shows that both groups -pure cows and cows with breeding register- have a similar distribution percentage of animals with different numbers of lactations.

Tabla 4. Absolute and relative values of pure cows and breeding record of the average production category discriminated according to the number of calving during their productive life

	Pure		Breeding register	
N° of calving	**N° of cows**	**%**	**N° of cows**	**%**
1	2	5,0	9	15,0
2	14	35,0	12	20,0
3	9	22,5	20	33,3
4	8	20,0	5	8,3
5	1	2,5	10	16,7
6	4	10,0	3	5,0
7	1	2,5	0	0,0
8	1	2,5	1	1,7
Total	40	100	60	100

In Figure 5, as observed when comparing cows of the second third, the difference between slopes was not statistically significant (F= 1.185; P= 0.668) which allowed to calculate a common slope (0.000088) and compare the heights. Unlike the cows of the second third, the line corresponding to the pure cows of the third third is located in the Cartesian aspect above the one corresponding to the non-pure cows with a statistically significant difference between the two (F= 7.023; P= 0.009).

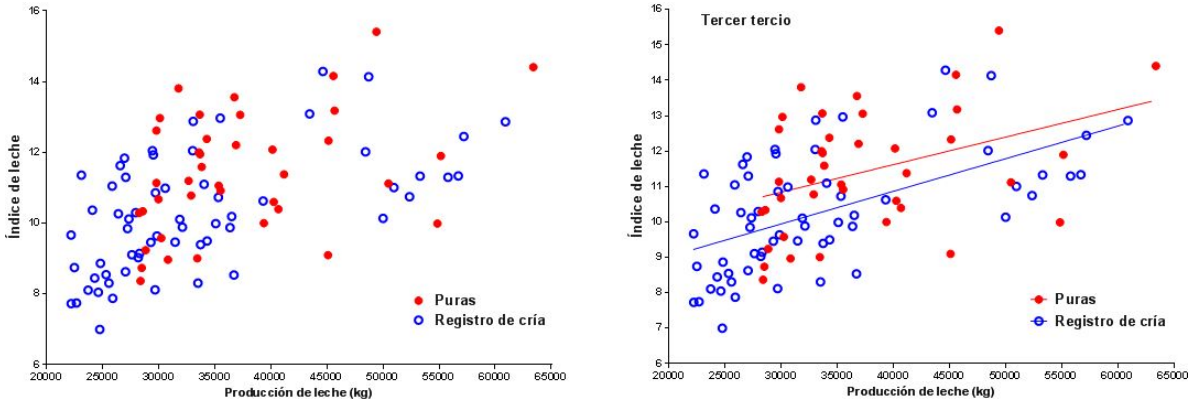

Figura 5. Comparison between purebred cows and cows with register of high production (to the left: experimental values; to the right: linear adjustments)

Table 5 shows that if are considered cows with up to five calving their proportion is higher than in pure cows [VP= 81.6% (32/38); VRC= 67.8% (40/59)] whereas, if the proportion of cows with more than five calving is considered, the ratio is reversed [VP = 18.4% (7/38); VRC = 32.2% (19/59)].

Tabla 5. Absolute and relative values of pure cows and breeding record of the high production category discriminated by number of calving during their productive life

	Pure		Breeding register	
N° of calving	**N° of cows**	**%**	**N° of cows**	**%**
1	0	0	1	1,7
2	5	13,2	10	17
3	5	13,2	7	11,8
4	11	28,9	10	16,9
5	10	26,3	12	20,3
6	3	7,9	6	10,2
7	2	5,3	5	8,5
8	1	2,6	2	3,4
9	1	2,6	5	8,5
10	0	0	1	1,7
Total	38	100	59	100

4 Discussion

The discrimination of cows based on the total milk production throughout life (LT) allowed having three categories within each group (VP and VRC). The limits of the low, medium and high production categories were not set a priori, but were determined within the system, trying to assess the potentialities and limitations of them. In Figures 1 and 2, regardless the category VP or VRC, the lower IL values of the low production category (cows of the first third) could be directly attributed to this low milk production, which determines a lower value of the milk index; also partly associated with a lower length of its productive life -as shown in table 3- indicating in the first case a higher relationship between IL and the production or a higher impact of other IL components on the studied relationship, even with low production levels.

Milk production and the efficiency in the breeding would only intervene in the conformation of IL. Therefore, the slope is higher because there would be more cows with low production and IL; whereas there is more reproduction in the case of pure cows. The cows that belong to the group of medium production category are those of LT intermediate of milk, however, there are cows that have more IL in this group compared to some cows belonging to the third third of production. This last result agrees with the observed by Marini y Oyarzabal (2002*a*,*b*) in the fact that within the average production group there are farms with higher or similar values of IL, demonstrating more efficiency these cows of intermediate production when compared with those of the other two categories (table 4).

The cows of the high production category are those that have the highest total production and in general the highest milk rate. This group would represent the type of cow expected if the productive cow level of the low production category increased, considering the latter the type of cow with habitual productive levels in the farms of the region, without affecting its reproductive performance (5000 to 15000 total liters during the life cycle). The cows of the high production category would be the cows of higher production during their whole life; although they present the same milk average index than the cows belonging to the intermediate production category, they achieve it by increasing the production at the expense of a deterioration in the reproductive values, VP: 498 ± 78; VRC: 452 ± 41 calving interval in days (Marini *et al*., 2017).

As the production of accumulated milk increases, in addition to reducing the association value, an increase in the variance of the data was found. For accumulated production of more than 30 000 kg, corresponding to high production cows, values of IL= 14 were found in cows with yields of 30 000 and in those with 65 000 kg of milk. The same happens if an IL value= 9 is taken as a reference. This indicates that as the value of accumulated production increases, other components that are part of the milk index are important and contribute to its variance

(Figures 1 and 2).

As with purebred cows in cows with breeding register, there was also a decrease in the association between accumulated milk production and milk index, since the first one increased, although the associations corresponding to the cows of intermediate and high production tended to be higher in the case of cows with breeding register. In addition to reducing the association value, an increase in the data variability was found; an increase in this case was lower, perhaps linked to a lower impact of the reproductive aspects on the IL values in this type of animal. Camargo (2011) said that the high-yielding dairy cow, through selective, continuous, unbalanced and careless pressure has been adapted mechanically to the needs of the market and has arrived to the limit of its vital potential. It becomes increasingly difficult to condition a non-limiting environment, being almost impossible to achieve during the initial phase of breastfeeding (Lucy, 2001, 2003; Mackey *et al*., 2007). This deepens in grazing systems, where the environment is limiting in most of the year.

With the current evaluation criteria that prioritize the productive aspects, the cows that belong to the high production category in the first term, and then the cows of the half production category would be the best to present the best daily milk production and the best lactation average. But, when these are evaluated according to their milk rates, the cows belonging to the high production category are no longer good compared to those of the half production category. Cows with lower productive values have better reproductive rates presenting the same milk index. A milk rate for pure cows of 8.5 liters/day can be obtained with cows of 12 000 (CB), 22 000 (CM) and 29 000 liters (CA) (Figure 1, indicating the horizontal line), and a milk index for cows breeding record of 6.5 liters/day can be obtained with cows of 9 000 (CB), 15 000 (CM) and 21 000 liters (CA) (Figure 2, indicating the horizontal line) and its value reveals the reproductive and longevity concomitant deterioration with the best productive performance (Figure 1 and 2, Table **??**, **??**and **??**), beyond the differences between the two groups of cows (VP and VRC).

The difference is given by the number of calving, which is an indicator of the longevity of each group. Independently that both have equal median 1 and also the same range (1-5), the distribution percentage of the number of calving is not the same for each group. The reason for which pure cows have more IL, is because even though they belong to the same third, they have higher production which positively impacts on the average value of IL. The accumulated VP production (arithmetic mean $\pm$ standard error) of the high production category is 37.471 $\pm$ 1.372 kg, significantly higher than the value (33.516 $\pm$ 1.313 kg) corresponding to the non-pure cows of the high production category.

This information confirms previous results that indicate that a higher individual production at the end of the productive cow life (LT) does not always guarantee a better productive efficiency (Marini y Oyarzabal, 2002*a*,*b*; Marini *et al*., 2017). In productive systems based on direct grazing there would be a limit on the expected production of a cow over which its reproduction is affected and therefore its permanence in the rodeo. In order to produce milk, the cow must reproduce itself, which is a clear antagonism that must be taken into account when deciding the improvement criteria to apply in this type of systems. According to Mancuso (2017) a good cow for grazing systems could be considered the one that produces the largest quantities of solids, from the lower amounts of financial and physical inputs, with the ability to walk, graze, with aptitude to be milked with a minimum of work and greater reproductive efficiency (Nauta *et al*., 2006; Kolver *et al*., 2002; Roderick, 2008). This type of animal would allow the genuine growth of the dairy rodeo, with more incorporation of heifers to the rodeo (increase of the rodeo) that discards involuntarily, essential aspect for the sustainability of this type of establishments (Madalena, 2002, 2011; Laborde, 2004; Molinuevo, 2005).

To have information on the implications of directional selection by production of interest helps to define selection criteria that do not affect other characters such as reproductive, and contribute to the discussion on how to determine which are the most adapted and profitable biotypes in grazing systems that lead to more sustainability of these systems. In 1 and 2 is presented a clear dispersion of the potential expressed by the cows, no matter the group (VP and VRC), in the 21 years of analysis, when a search for greater production cannot be achieved for all, and proving that the most producing cows do not end up being the most efficient in the system.

In Argentina, since in 1992 began the massive importation of semen with American and Canadian origin, investing the values of export and im-

port (Etcheverry, 2012; Musi, 2008; Casanova *et al*., 2011), the search for greater individual production was massively imposed as a general criterion for all dairy establishments. The cow that belongs to the medium production category seems to be the one that best maintains a balance between what is produced and the environment in which is lived, and this allows having stability throughout its productive life and greater predictability in its behavior. Although it is not the cow that most produces by lactation, in many cases it becomes the most efficient cow: it produces more liters per day at the end of its productive life (IL), with better reproductive indicators. Average production cows for grazing production systems in temperate regions would be the most adapted, as they would not express a significant imbalance between their genetic potential for milk production and the levels of food that may guarantee the system.

5 Conclusions

Even though total cow production expressed as liters of milk can be an efficiency indicator in intensive systems with high environmental control that prioritize individual performance, in grazing systems should be considered the contribution of other variables included in the milk index -longevity, efficiency in breeding and reproductive behavior- in the search for an aggregate indicator aimed at achieving more productive efficiency.

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