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Selection indices for Nellore production systems in the Brazilian Cerrado

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ABSTRACT

The aim of this study was to develop selection indices for Nellore cattle raised in two complete cycle production systems in the Brazilian Cerrado, with Tropical climate, where bulls are mated with heifers and mature cows. The resulting offspring are retained as replacements or sold at 2 years. In System 1 (S1), the animals were raised and finished on pasture, while in System 2 (S2), the animals were raised on pasture and males were finished in the feedlot. The economic values were determined by stochastic simulation of the production system using partial derivatives of the profit function, changing one trait at a time, by 1 unit, while keeping the other traits constant. Relative economic values were calculated for cow weight at 5 years, weaning weight, maternal weaning weight, postweaning average daily gain, fat thickness, ribeye area, and stayability. The economic values were, respectively, US$0.67, US$0.41, US$-0.15, US$0.09, US$-0.17, US$187.6 and US$2.7 for S1, and US$0.47, US$0.45, US$-0.004, US$0.28, US$-0.59, US$157.5 and US$0.73 for S2. Consequently, increased profitability can be obtained by improving the cows' ability to stay in the herd, cow weight, ribeye area, weaning weight, and postweaning gain. The accuracy of the indices was 0.85 (S1) and 0.86 (S2). The application of these indices will aid Nellore breeders to select superior animals, facilitating the genetic progress and profit of the herd.

1. Introduction

One-third of Brazilian beef is produced exclusively in extensive pasture-based systems, with the herds being composed of Zebu breeds, particularly Nellore, adapted to the tropical conditions of the Cerrado biome (Faria et al., 2015). However, even with supplementation, these systems prolong the time that the animals remain on the farm to reach slaughter weight, when compared to animals produced in feedlot systems, mainly because of the well-defined climatic seasons of these regions in which cattle gain weight during summer, the rainy season, and lose weight during winter, the dry season. One interesting management strategy to render this production cycle more efficient is the use of feedlots systems, which is already a reality and has been growing substantially in recent years in Brazil. However, even today animals are kept in feedlots or supplemented mainly during the dry season, when pasture availability is low, in order to maintain a constant beef supply (Millen et al., 2009; Gomes et al., 2015).

With respect to genetic improvement, one strategy for increasing herd efficiency is the selection of animals based on selection indices, which is considered the most effective approach to simultaneously improve different traits in a production system (Hazel, 1943). Economic selection indexes combine the estimated breeding value (EBV) and the economic value of economically important traits in a single measure that represents the total breeding value for overall profit of each selection candidate. Although economic selection indexes are already used in several countries such as South Africa, Australia, Argentina, United States, Namibia, New Zealand and the United Kingdom (eBEEF.ORG, 2014; BREEDPLAN, 2019) for different species of economic interest, including beef cattle, dairy cattle and sheep, this methodology is still rarely employed in Brazil because of the difficulty in obtaining data on income and expenses management of the farms, in addition to differences between the production systems adopted in Brazil and the productive and reproductive parameters used, which makes it difficult to apply a single economic selection index for national beef cattle.

Indices have been developed in recent years for Angus, Braford, Hereford, Nellore and crossbred beef cattle (Campos et al., 2014; Carvalho and Bittencourt, 2015; Peripolli et al., 2016; Costa et al., 2017; Fernandes et al., 2018; Simões et al., 2019). Analysis of these studies shows differences in the production systems, in the traits used as

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breeding objectives and selection criteria, and in the importance of each trait in the selection indices due to the specific objectives of each breed and system. In practice, the indices used in Brazilian breeding programs are empirical, i.e., they are not calculated using economic values, and focus on growth and carcass traits because of their link with the end product (Santana Jr. et al., 2012). However, it is necessary to include important traits, especially those related to reproduction, that directly affect performance parameters and profit but are not yet commonly measured and selected for.

In recent years, cow-related traits have received increased visibility because of the length of time these animals remain in the herd. Traits such as heifer pregnancy, cow weight, cumulative productivity, and stayability have been evaluated together with other traits already used in breeding programs (Schmidt et al., 2018; Kluska et al., 2018; Bonamy et al., 2019). These studies have demonstrated genetic variability and important genetic correlations between reproductive traits with production and carcass traits, such as body weight at different ages, ribeye area and fat thickness, that would permit to obtain genetic gains through multitrait selection, in addition to the identification of superior animals in terms of traits related to the end product and to dams that will remain in the herd.

Indices that represent the reality of Brazilian production systems, focusing on the genetic progress in productive and reproductive traits and on the economic return of herds, are necessary to increase the profitability of producers and to facilitate genetic progress of the breed. Therefore, the aim of this study was to develop economic selection indexes for Nellore cattle raised in two complete cycle systems, a pasture-based system and a feedlot finishing system, in the Brazilian Cerrado.

2. Material and methods

2.1. Definition of the breeding objective

The breeding objective traits were determined using the method of Ponzoni and Newman (1989), described in four steps: (i) specification of the production system; (ii) estimation of expenses and income; (iii) determination of traits that affect expenses and income, and (iv) calculation of the economic value of each trait.

The breeding objective established for the development of selection indices for Nellore animals raised in a complete cycle for the Cerrado was to increase the profitability of two operations: System 1 (S1) in which calves born to heifers and mature cows were fed on pasture after weaning and received protein and mineral supplements until slaughter age (32 months); System 2 (S2) in which calves born to heifers and mature cows were fed on pasture after weaning and received protein and mineral supplements, with females remaining on pasture and males being feedlot fed for 120 days until slaughter age (24 months). Thus, the following traits were evaluated: mature cow weight (CW), weaning weight (WW), maternal weaning weight (MWW), postweaning average daily gain (ADG), subcutaneous fat thickness (FAT), ribeye area (REA), and stayability (STAY). The CW was considered at 5 years of age of cow. WW was used as it allows the sale of calves at this age. The MWW was calculated based on additional milk production to increase the 1 kg of WW, where 34 kg of milk per calf from birth to weaning was used. The period considered for ADG was between weaning and slaughter. FAT and REA were considered because affect the animals' carcass premiums. The REA was considered the improvement of a deviation from the median of the expected progeny differences (EPD) for the trait, the median being equal to zero. The median was used because it is an absolute measure of dispersion, adequately representing the trait evaluated. The STAY is the ability of the cow to remain in the herd, measured in this case by the cow's ability to have three calves until 5 years of age.

2.2. Choice of selection criteria

The selection criteria for the indices were obtained from the 15 traits evaluated by the Geneplus beef cattle breeding program of Embrapa Gado de Corte to obtain expected progeny differences (EPD) of animals. In the present study, the following 7 traits were considered: WW in kg, postweaning ADG in kg, yearling weight (YW) in kg, scrotal circumference at yearling (SC) in cm, REA in cm^2, FAT in dm, age at first calving (AFC) in days and CW at weaning in kg, due to favorable genetic correlations with the breeding objectives.

2.3. Estimation of economic values

The identification of the sources of income and expenses in a herd enables the development of a profit equation, which is obtained as the difference between income and expenses of a given system (Ponzoni and Newman, 1989). Thus, economic values are derived from partial differentiation of a profit function (Ponzoni and Newman, 1989). The sources of income and expenses for the two complete cycle production systems of Nellore cattle raised in the Cerrado were identified and profit was simulated for the production of 10,000 cows (3 to 10 years of age) and their products using the SAS 9.4 program (SAS Institute, Inc., Cary, NC).

It was assumed that the calves were born from mature cows and heifers, were weaned at 240 days old, and, after this period males and females remained on pasture until the age and slaughter weight (32 months) in S1. In S2, after weaning, females remained on pasture and males were confined until reaching slaughter weight. Replacement heifers were obtained from the herd itself and surplus females were sold. The income was obtained entirely by selling the animals for slaughter.

The calculations were done based on the market prices in Brazil (in Reais, R$) in 2017 and converted to US dollars (US$) using the average exchange rate of the same year (US$ 1.00 = R$ 3.28).

The production systems considered for the selection indices were modeled based on more than 150 Nellore cattle farms in the Brazilian Cerrado region, where data on management, performance parameters, administration, revenues and expenses were obtained by benchmarking (2016/2017) performed by the Brazilian company Terra Desenvolvimento Agropecuário. Average values of each information were obtained. For this purpose, a pasture rental rate of US$ 91.46 per year (US$ 7.62/month) for maintaining one cow in the production system was considered.

The biological variables used for the development of the production systems were obtained from benchmark data and studies conducted by Embrapa Gado de Corte and are described in Table 1. An equilibrium age distribution for females in the herd was modeled following Leslie (1945; 1948). Calving rates were: 81.4%, 68.6%, and 76.1% for 3, 4, and 5–10 year old cows, respectively. Age-specific survival rates for the cows were also 81.4%, 68.6%, and 76.2% for 3, 4, and 5–10 year old cows, respectively, under the assumption that a cow either produced a calf or was culled for beef in the same year. All of the male calves that were born and 25.8% of the female calves born were destined for slaughter. Thus, the modeled herd of 10,000 reproducing females produced 7325 calves (considering the birth rate, with 50% males and 50% females) each year. The ability to produce three calves by 5 years of age was deemed a positive observation of stayability (STAY).

Carcasses of males (steers) and females (heifers) less than 36 months of age and those of cull cows were simulated separately as having two attributes: weight and fat score or degree of finish, based on USDA cutability formula “yield grade” (Holland & Loveday, 2013). Since steers and heifers were slaughtered at a mean age of either 24 or 32 months, age was not considered a factor that contributes to the degree of finish. The carcass yield, expressed as a percentage of live weight, was 50% for males and 48% for females. The optimal carcass weight window was: 225 ≤ carcass weight ≤ 390 kg for steers and the

Table 1
Performance parameters used to simulate Nellore production systems in the Brazilian Cerrado.

Production and reproduction rates	System 1	System 2
Reproductive parameters	**Means**	
Pregnancy rate of cows with 4 years (%)	68.6	68.6
Pregnancy rate of cows with 5–10 years (%)	79.1	76.1
Pregnancy rate of heifers (%)	81.4	81.4
Age at first calving (months)	36	36
Stayability (%)	50	50
Mortality rates	**Means**	
Weaning mortality rate (%)	1.5	1.5
Death rate after weaning (%)	2.5	2.5
Productive parameters	**Means**	
Calving weight (kg)	33	33
Weight at 240 days of age (kg)	190	190
Postweaning average daily gain of males 1 (kg)[†]	0.235	0.430
Postweaning average daily gain of males 2 (kg)[†]	0.536	0.639
Postweaning average daily gain of males 3 (kg)[†]	0.286	–
Postweaning average daily gain of males 4 (kg)[†]	0.586	–
Postweaning average daily gain of feedlot males (kg)[†]	–	1.18
Postweaning average daily gain of females 1 (kg)[†]	0.212	0.212
Postweaning average daily gain of females 2 (kg)[†]	0.482	0.482
Postweaning average daily gain of females 3 (kg)[†]	0.257	0.257
Postweaning average daily gain of females 4 (kg)[†]	0.522	0.522
Female weight at 600 days of age (kg)	312	312
Male weight at 600 days of age (kg)	340	392
Cow weight at weaning (kg)	475	475
Milk production (kg/day)	3	3
Carcass yield of females (%)	50	50
Carcass yield of males (%)	52	52
Ribeye area (cm^2)[‡]	0.0	0.0
Subcutaneous fat thickness (mm)	2.5	2.5
Average age of sale heifers (months)	31.2	31.2
Average age of young bulls at sale or age at slaughter (months)	31.2	24
Cull cow weight (kg)	455	455
Weight of steers at slaughter/sale (kg)	489	533
Weight of heifers at slaughter/sale (kg)	445	445
Culling and replacement rates	**Means**	
Cull cow rate (%)	27	27
Culling rate of heifers at yearling (%)	22	22
Culling rate of heifers at 2 years of age (%)	21	21
Rate of heifers remaining in the herd (%)	79	79
Culling rate of steers at yearling (%)	1.5	1.5
Culling rate of steers at 2 years of age (%)	100	100
Others	**Means**	
Amount of arroba (US$/15 kg)	42.53	42.53

Abbreviations: System 1 = pasture-based complete cycle production system; System 2 = complete cycle system with feedlot finishing.

[†] The average daily gain after weaning was divided into four periods, 2 dry seasons and 2 rainy seasons, because of the known differences in weight gain between different climatic periods.

[‡] The mean ribeye area was considered null because it is improved by +1 deviation from median of expected progeny differences.

Table 2
Premium for carcasses based on the carcass degree of fatness (scores of 1 to 5) and hot carcass weight (HCW) of Nellore cattle.

	Males	Females
Carcass degree of fatness	US$/kg	US$/kg
1	0	0
2	0.38	0.38
3–4	0.95	0.95
5	0	0
HCW	US$/kg	US$/kg
< 225 kg	0	–
> 226 and < 239 kg	0.38	–
> 240 and < 330 kg	0.95	–
> 331 and < 389 kg	0.38	–
> 390 kg	0	–
< 165 kg	–	0
> 195 kg	–	0.95

carcasses of heifers needed to weigh more than 165 kg to potentially receive a premium. The average slaughter price for steers and heifers was obtained from the Center for Advanced Studies in Applied Economics (CEPEA) and was used as the base price for all slaughter animals. The base price for all carcasses was US$ 42.53/arroba, i.e., US $ 2.83/kg. Premiums based on the degree of finish and carcass weight of steers and heifers were obtained from the Nellore Guarantee of Origin Program, developed by the Brazilian Association of Nellore Breeders (ACNB), and are shown in Table 2. Cull cows were subject to a similar grid pricing scheme wherein those cows with carcasses weighing less than 180 kg and those that were either under-finished (fat score = 1) or over-finished (fat score = 5) did not initially merit a premium. However, those cull cows with carcass weight greater than 165 kg and a fat score of 2 received a US$ 0.38/kg premium. As did the cull cows that were denied a premium, the final carcass price for cows was 90% of the base carcass price and the sum of any premiums.

The feed costs were divided into three age categories: mature cows, animals at yearling and animals at 2 years of age. The calculation included intake per animal, pasture rental rate and period. The feed intake of cows was estimated using the prediction equation of relative carrying capacity described by Anderson et al. (1983), where cow's intake was obtained by total digestible nutrient (TDN) per day in kg as: TDN/day = 4.6631 + 0.0030 * cow weight + 0.0127 * (0.022 * milk yield of cow). Feed cost of cows were obtained by equation Cost_feed_Cow = 365 * pasture rental rate * number of cows * cow's intake.

For animals at yearling and 2 years of age, the feed costs was weighted by the metabolic weight of animal in relation to the metabolic cow weight at 5 years old and was calculated as follows: feed_cost_yearling or 2 years = ((weight of animal in the period)$^{0.75}$/metabolic cow weight) * number of animals * pasture rental rate * number of days in period.

Other operating costs for the systems were obtained from the average benchmark data (2016/2017) of Terra Desenvolvimento Agropecuário and included permanent labor, maintenance, equipment, medications, fees, and taxes. These costs were considered fixed while developing the profit equation since they do not vary according to the biological merit of an individual animal, i.e., they do not change with one-unit improvement of the trait (Ponzoni and Newman, 1989). The total cost was calculated as the sum of feed costs (considered 69% of costs) and non-feed costs across all stages of production. Details of the cost calculations are shown in the Appendices. The values were expressed in dollars per total number of cows (10,000), per animal unit (AU) and per arroba (1 arroba = 15 kg). Profit was calculated by subtracting the total cost from the income obtained with the sale of the animals, resulting in total profit and profit per animal unit and per arroba. The economic analysis of the simulated systems is shown in Table 3.

Table 3
Economic analysis of the pasture-based complete cycle production system (System 1) and the complete cycle system with feedlot finishing (System 2) for Nellore cattle raised in the Cerrado.

Economic indicators	System 1	System 2
Total gross revenue (US$)	4,748,197.56	4,987,906.10
Total costs (US$)	2,226,565.67	3,003,577.13
Profit (US$)	2,521,631.83	1,984,325.91
Feed costs (US$)	1,699,668.45	2,292,806.98
Operating costs (US$)	526,897.23	710,770.15
Average profit per head (US$/head)	252.16	198.43
Average profit per animal unit (US$/AU)	132.09	120.63
Average profit per arroba (US$/@)	22.09	16.58

Abbreviations: Total gross revenue comprises the entry of cash relating to the sale of animals obtained as a result of the production process. Total costs are the sum of feed costs and operating costs of the system. Profit is the difference between total gross revenue and total costs.

Using the method described by MacNeil et al. (1994), the economic values of the traits were determined by approximating partial derivatives of profit at the point of average performance for each driving variable (breeding objective). The model was parameterized and a base profit was calculated. Each driving variable was then changed upward by 1 unit in separate iterations, while keeping the other traits constant. The difference between profits after one variable was changed by 1 unit and its base profit, denominated varian profit (ΔP), was used to determine the economic values for each driving variable. The economic values are expressed as dollars in profit/loss per unit change for each trait. The relative economic value (REV) of each objective trait was estimated as the product between the respective economic value and the genetic standard deviation for this trait. The REV recognizes that the return from a one-standard deviation increase in one trait will not be equal to the same increase in another trait, thus permitting comparison of the economic importance of traits and their relative emphasis (RE) in percentage.

2.4. Calculation of selection index coefficients

The method of Schneeberger et al. (1992) was used to calculate the vector of index coefficients (*b*) for indices based on expected progeny differences (EPD). In this case, in addition to the economic values, the only information necessary are the genetic (co)variances between the selection criteria present in the index and the genetic covariances between the selection criteria and objective traits. This method allows to compare animals within and outside the contemporary groups since the EPDs are adjusted for environmental effects that can influence animal performance (Campos et al., 2014; Kluyts et al., 2007). Thus, for the index whose notation is $I = b'_n\, EPD_n$, the following equation is used to estimate the index coefficients (*b*):

$$b = \mathrm{G}_{11}{}^{-1}\mathrm{G}_{12}v$$

where *b* is the regression coefficients vector (weighting factor); G_{11} is a 7 × 7 matrix of genetic (co)variances between 7 selection criteria; G_{12} is a 7 × 5 matrix of genetic (co)variances between 7 selection criteria and 5 objective traits, and *v* is a 5 × 1 vector of economic values for all objective traits.

The variances and covariances for the growth, reproductive and carcass traits of Nellore cattle used to calculate the breeding values and to obtain G_{11} and G_{12} were estimated by restricted maximum-likelihood method under multi-trait analyses by using the Misztal programs (Misztal, 2002) in database of Geneplus beef cattle breeding program of Embrapa. The estimates are shown in Table 4. It was ensured that a positive defined (co)variance matrix existed.

2.5. Estimation of index accuracy

For indices that utilize EPDs as the selection criterion, the following equation was used to calculate the accuracy of the indices:

$$r_{HI} = \frac{b'G_{12}v}{\sqrt{(b'G_{11}b)(v'Cv)}}$$

where $b'G_{12}v$ represents the covariance between the index and aggregate genotype; $b'G_{11}b$ represents the variance of the index, and $v'Cv$ represents the variance of the aggregate genotype. When presenting index coefficient equations using EPD as the selection criterion, Schneeberger et al. (1992) explained that G11 is the genetic (co)variance matrix of the selection criteria and it is assumed that the accuracy of each EPD included in the index for each animal was unity.

Predicted response in aggregate genotype (S_H) (US$) was calculated as:

$$S_H = \frac{b'G_{12}v}{\sqrt{b'G_{11}b}}$$

Response in a given objective trait (S_g) was calculated as:

$$S_{g_t} = i\frac{\mathbf{b'G}_{12}}{\sqrt{\mathbf{b'G}_{12}\mathbf{v}}}$$

where *i* is selection intensity defined = 1.

2.6. Estimation of index sensitivity

The coefficients of economic selection indexes are rarely known without error because of the wrong estimates in the (co)variances and economic values. One approach to determine the sensitivity of indices to changes in the (co)variances and economic values assumed is to calculate the efficiency of the index, which is given as:

$$E_u = \frac{R_{H_u}}{R_{H_t}} = \frac{b'_u G_{12_t} v}{\sqrt{b'_u G_{11_t} b_u}} * \frac{1}{\sqrt{b'_t G_{12_t} v}}$$

where b_u are coefficients derived from “used” values and b_t are “true” coefficients of the index. The “used” index coefficients are arbitrary, while the “true” index coefficients are considered to be optimal. In reality, index coefficients considered to be optimal may not always be accurate. It is therefore important to calculate the efficiency and to determine the impact of unadvisedly using incorrect index coefficients.

A sensitivity to absolute changes in the genetic correlations between objective traits and selection criteria of ± 0.2 and ± 0.4 was calculated. These changes in the genetic correlations are similar to those reported by Simm et al. (1986). In some cases, adding or subtracting these values resulted in a change of sign. In cases in which these changes would have

Table 4
Genetic variance (diagonal), covariance (above diagonal), genetic correlation (below diagonal) and heritability for growth, reproductive and carcass traits of Nellore cattle.

Trait	WW	MWW	ADG	YW	SC	REA	FAT	AFC	CW	STAY
WW	**103.86**	−4.24	173.4	131.38	6.55	15.72	0.25	−33.96	102	0.66
MWW	−0.07	**36.04**	116.1	21.87	2.96	−5.62	0.08	−25.34	−28.79	−0.34
ADG	0.40	0.45	**1806**	403.1	7.19	45.02	0.22	−741.8	139.4	−0.4
YW	0.83	0.23	0.61	**238.29**	5.58	26.27	0.33	−159.2	141.7	1.30
SC	0.51	0.39	0.13	0.28	**1.60**	1.41	0.003	−29.23	12.28	0.08
REA	0.44	−0.27	0.30	0.49	0.32	**12.12**	0.10	−34.78	−2.29	0.10
FAT	0.17	0.09	0.04	0.15	0.16	0.20	**0.02**	−1.61	0.39	0.03
AFC	−0.08	−0.11	−0.45	−0.26	−0.59	−0.26	−0.29	**1505**	−290.9	−0.12
CW	0.48	−0.23	0.16	0.44	0.46	−0.03	0.13	−0.35	**434.7**	0.04
STAY	0.24	−0.21	−0.04	0.32	0.23	0.11	0.74	−0.01	0.01	**0.07**
h^2	0.21	0.08	0.22	0.25	0.28	0.32	0.32	0.12	0.36	0.23

Abbreviations: WW = weaning weight (kg); MWW = maternal weaning weight (kg); ADG = postweaning weight gain (g/day); YW = yearling weight (kg); SC = scrotal circumference at yearling (cm); REA = ribeye area (cm^2); FAT = fat thickness (mm); AFC = age at first calving (days); CW = cow weight (kg); STAY = stayability (%).

Table 5
Additive standard deviation (σ_α), variant profit (ΔP), economic value (EV), relative economic value (REV) and relative emphasis (RE) of individual objective traits for the pasture-based complete cycle production system (System 1) and for the complete cycle system with feedlot finishing (System 2) of Nellore cattle.

System 1			Per head			Per animal unit			Per arroba		
Trait (unit)	σ_α	ΔP (US$)	EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)
CW (kg)	20.85	6,681.2	0.67	13.93	17	0.28	5.78	19	0.04	0.76	26
WW (kg)	10.19	4,123.2	0.41	4.20	5	0.01	0.14	0	0.01	0.08	3
MWW (kg)	6.00	−1,544.0	−0.15	−0.93	1	−0.07	−0.43	1	0.00	−0.02	1
ADG (kg)	42.50	917.7	0.09	3.90	5	0.03	1.27	4	0.00	0.13	4
FAT (mm)	0.14	−1,715.3	−0.17	−0.02	0	−0.09	−0.01	0	−0.02	0.00	0
STAY (%)	0.26	6,398.7	187.64	49.65	60	67.25	17.79	59	5.89	1.56	53
REA (cm^2)	3.48	69,103.2	2.72	9.47	12	1.43	4.96	16	0.11	0.39	13

System 2			Per head			Per animal unit			Per arroba		
Trait (unit)	σ_α	ΔP (US$)	EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)
CW (kg)	20.85	4,685.4	0.47	9.77	14	0.44	9.25	9	0.09	1.82	19
WW (kg)	10.19	4,488.8	0.45	4.57	6	0.36	3.71	4	0.06	0.58	6
MWW (kg)	6.00	−11.2	0.00	−0.01	0	0.09	0.56	1	0.03	0.16	2
ADG (kg)	42.50	2,823.0	0.28	12.00	17	0.52	22.10	21	0.05	1.98	21
FAT (mm)	0.14	−5,900.4	−0.59	−0.08	0	−1.18	−0.17	0	−0.16	−0.02	0
STAY (%)	0.26	5,369.7	157.47	41.66	59	237.25	62.77	61	17.36	4.59	48
REA (cm^2)	3.48	7,344.2	0.73	2.56	4	1.46	5.10	5	0.12	0.42	4

Abbreviations: CW = cow weight; WW = weaning weight; MWW = maternal weaning weight; ADG = postweaning weight gain; FAT = fat thickness; STAY = stayability; REA = ribeye area.

resulted in a correlation higher than unity, the genetic correlation was assumed to be 1.

The sensitivity to a 50% increase or decrease in the magnitude of the economic value of each trait in the breeding objective was calculated as described by Simm et al. (1986).

3. Results

3.1. Economic values

The average total profit per head was US$252.16 and US$198.43 in S1 and S2, respectively. Although the slaughter of males occurs earlier in S2, the system was less profitable because of the higher feed cost in order to reach the slaughter weight at 24 months. The economic values, REV, and RE for each trait are shown in Table 5 for S1 and S2 per head, animal unit (AU) and arroba (@).

The REV for CW, WW, ADG, STAY and REA were positive. The CW influenced both the expenses component of the profit equation since a higher CW results in increased feed intake, and the income given that cull cows are sold and their value is determined based on live weight. The WW exerts a direct effect on income through the value of the calf when sold at weaning. Stayability will increase the profitability of the operation through additional calves to be sold and lower replacement rate. The REA had the highest variant profit (ΔP) due to the premium received for carcass quality (carcass degree of fatness and hot carcass weight). The MWW was negative because of the increase in feed costs associated with higher milk production of the cow and, in this case, the additional cost of feeding the cow does not pay the extra kg of the calf, because animals are not sold at weaning. The FAT was characterized by a negative REV since the increase in FAT also increases the degree of finish and consequently reduces the carcass value when the score is higher than 4.

Stayability received the greatest emphasis in both systems, demonstrating the importance of including the reproductive trait in selection indices. On the other hand, the RE was zero or 1 for MWW and FAT in the systems evaluated. In addition, differences were observed in the weight given to the traits of each system. In S1, in addition to STAY, CW and REA were the traits with the highest impact, demonstrating the importance of dam characteristics for the pasture-finished carcass. In S2, the traits of highest impact were STAY, ADG and CW since males are feedlot finished and will respond positively to ADG due to the diet applied. Thus, CW, WW, ADG, STAY and REA, which had a RE of 5 to 60% (per head, AU or arroba) in the production systems evaluated, were used as breeding objectives to calculate the indexes and response to selection.

3.2. Index coefficients

The selection criteria to compose the indices for S1 and S2 were CW, WW, ADG, YW, SC, AFC and REA since these traits are related to the breeding objective.

Table 6 shows the regression coefficients (*b*), responses to selection in US dollars (S_H), and genetic gains in trait unit (S_g) expected for the indices proposed for S1 and S2 of Nellore cattle raised in the Cerrado. As can be seen, the regression coefficients for ADG, YW, SC and AFC were positive and those for WW, REA and CW were negative in S1. On the other hand, in S2, the regression coefficients for YW, SC and AFC were positive and those for WW, ADG, REA and CW were negative, due

Table 6
Regression coefficient (*b*), genetic gain (S_g), response in the aggregate genotype (S_H) and accuracy (r_{HI}) expected for the indices proposed for the pasture-based complete cycle production system (System 1) and for the complete cycle system with feedlot finishing (System 2) of Nellore cattle.

	System 1		System 2	
Trait	*b*	S_g (trait unit)	*b*	S_g (trait unit)
WW	−5.27	6.99	−4.32	7.22
ADG	0.28	8.99	−0.03	17.43
YW	5.32	–	4.46	–
SC	39.26	–	32.95	–
REA	−1.12	1.45	−2.49	1.21
AFC	0.73	–	0.62	–
CW	−0.23	8.25	−0.28	8.19
STAY	–	0.15	–	0.14
S_H (US$)	41.94		35.82	
r_{HI}	0.85		0.86	

Abbreviations: WW = weaning weight; ADG = postweaning weight gain; YW = yearling weight; SC = scrotal circumference at yearling; REA = ribeye area; AFC = age at first calving; CW = cow weight, STAY = stayability.

to adjustment the selection of the different traits simultaneously. The gains in trait unit for REA and CW were higher in S1, while those for WW, ADG and STAY were higher in S2. In US dollars, the gain was US $41.94 in S1 and US$35.82 in S2, that is, it is expected that 1 standard deviation of selection in the index will generate this profit for each system.

3.3. Index accuracy

The accuracy of the indices was 0.85 (S1) and 0.86 (S2).

3.4. Index sensitivity

An error of ± 0.2 in the genetic correlations resulted in selection efficiencies of 0.76 to 1.00. For errors of ± 0.4, efficiencies ranged from 0.58 to 1.00 for subtraction and addition, respectively. Efficiency was lower for the correlations between STAY and WW (0.4 and 0.42) and between STAY and YW (0.24 and 0.3) in S1 and S2, indicating possible uncertainty in the genetic correlations between these traits. For changes of 50% in the economic values, the efficiency ranged from 0.85 to 1.00. These results demonstrate that the indices are somehow sensitive to erros in the genetic relationships between the traits used and less sensitive to changes in the systems studied in order to obtain economic values.

4. Discussion

Feed costs account for about 65 to 75% of the expenses of a beef cattle production system; 70% of the total feed costs of the herd in complete cycle systems refer to females, including cows that remain for various cycles and part of the heifers that are kept for herd replacement (Bittencourt et al., 2006). These costs are even higher in production systems with feedlot finishing due to the diet supplied to the animals, resulting in lower profitability of the system. In this respect, Peripolli et al. (2016) observed a lower net present value and internal rate of return for the feedlot system compared to 100% pasture-based systems.

In the present study, the average profit per head was lower for the feedlot system. The same was reported by Simões et al. (2019) for Brangus cattle raised in pasture- and feedlot-finished complete cycle systems. The authors observed higher feed costs for the cow category because these animals remained in the herd for various production cycles. In addition, the authors suggested that feedlot systems will only be more profitable than pasture-based systems if the growth traits were genetically improved without an increase in production costs, a rather complex task because of the negative correlation with feed intake (MacNeil et al., 2011). An alternative to this economic increase in feedlots systems would be the inclusion of feed efficiency traits of the herd in selection indices (Koots and Gibson 1998, Wolfová et al. 2005). However, in view of the difficulties and costs of collecting these data individually, traits such as residual feed intake, feed conversion and feed intake are still rarely used as selection criteria.

In our study, a premium was paid per animal when the animals met the carcass specifications, which generated a difference in economic importance even for the CW, which had a positive EV because the sale of cull cows generated income in the systems. Fernandes et al. (2018) evaluated cow-calf and complete cycle production systems of Angus x Nellore cattle, comparing systems with and without premiums for carcass quality. The authors observed that the costs of the complete cycle system were 50% higher than those of the cow-calf system because of the longer time the animals stayed in the herd. Regarding the premium payment for carcass quality, the authors suggested that feedlot systems can be efficient if there is price differentiation since the animals would remain less time in the herd and the use of pasture area would be reduced, factors that contribute positively to the profit of the system and permit producers to improve the efficiency of their production system.

Direct comparison of the results of different studies investigating economic values and selection indices is difficult because of the particularities of the breeds and production systems evaluated, the adoption of different objective traits, and differences between the models used for the calculations (Phocas et al., 1998; Wolfová et al., 2005). However, general considerations regarding objective traits and selection criteria can be made in order to contribute to future studies.

Economic values are expressed as dollars in profit/loss per unit change for each trait, while keeping the other traits constant. The REV, in turn, provides an objective measure of the potential of economic change in each trait considered for selection compared to other traits, taking into account the additive genetic variance of each trait (Koots and Gibson, 1998). In our study, since part of the heifers are kept as replacements and because of the larger number of animals in the dam category, greater importance of STAY and CW was observed in the systems studied. In addition, in S2 in which males were feedlot finished, ADG and REA were more important because of the improvement in the carcasses of males.

The ability of a cow to stay in the herd, a trait called stayability, is defined as the probability of the cow to remain in the herd until a specific age, provided that the animal has the chance to reach this age (Hudson and Van Vleck, 1981). This trait is evaluated as a categorical variable, i.e., failure or success of the cow. Its direct heritability is low (0.11–0.16) and the trait is therefore not commonly used as a selection criterion in beef cattle (Santana Jr. et al., 2012; Kluska et al., 2018; Bonamy et al., 2019). In our study, the heritability for STAY was considered 0.23, indicating that direct selection for the trait will result in slow progress. Thus, selection should be performed in combination with other correlated traits to obtain genetic gain through correlated responses. In an attempt to improve the sexual precocity of Nellore animals raised on pasture in the tropics, Brumatti et al. (2011) concomitantly evaluated heifer pregnancy when exposed to bulls at 14 months of age, stayability, weaning and yearling weight, and postweaning weight gain. The authors reported that these traits are already applied in genetic evaluations and highlighted the need for the simultaneous use of traits related to fertility, sexual precocity and productive performance for the selection of breeding animals in Brazilian herds.

Bittencourt et al. (2006) emphasize that the maintenance cost of a cow that does not produce one calf per year is practically the same as that of a cow that does, which made the STAY the trait most economically important within the evaluated systems, since it generated a greater number of calves produced. Furthermore, in view of the economic importance of reproductive traits, increasing the reproductive efficiency of the herd is essential even if the genetic progress in the individual trait is slow.

Wolfová et al. (2005) calculated the economic values of 16 direct and maternal traits of Charolais cattle raised in three different productions systems (purebred and crossing with beef or dairy breeds) and suggested that greater attention should be given to the longevity of cows as this trait, together with calving difficulty, was the most important trait in the systems studied. In addition, the authors highlighted the importance of evaluating and selecting CW, which had a negative economic value because of the size of Charolais cows in this case.

On the other hand, some studies have reported positive economic values for CW, as observed here due to the sale value of cull cows. Koots and Gibson (1998) calculated the economic values for growth and reproductive traits in a Hereford herd. However, by evaluating CW, the authors ignored the greater energy requirements of heavier females because the supply of feed is separated by animal category to calculate residual feed intake, a trait also evaluated in the herd, a fact that resulted in a positive economic value. Hirook et al. (1998) obtained positive economic values for CW in Black Japanese cattle, which are due to a lower rate of dystocia and a lower percentage of calf loss among heavier cows, as well as a relatively high price per kg slaughter weight.

In Nellore cattle, Carvalho and Bittencourt (2015) observed a positive economic value for CW and 25% importance in the system evaluated. However, the authors commented that this result might be due to the market price of cows during the years of evaluation.

The mature size of Nellore cows has been the focus of studies in recent years as a result of the practice of selecting for weight at younger ages and its positive correlations with mature weight (Boligon et al., 2010; Lacerda et al., 2018; Koetz Jr. et al., 2019), which can increase production costs due to higher nutritional requirements. Using complete cycle and cow-calf production systems for Nellore cattle, Jorge Jr et al. (2006) observed that CW discretely affected profit because of the low cost of pasture maintenance and the price paid for cull cows, resulting in a positive economic value close to zero, i.e., an increase in cow weight would not negatively affect profit. The authors emphasized that these results should be analyzed with caution since the system used had additional areas available for heavier cows on the farm, which may not be a reality under other conditions.

Weaning weight had the lowest REV in both systems studied. A similar finding was reported by Carvalho and Bittencourt (2015) who evaluated a cow-calf system of Nellore cattle and calculated economic values for weaning and yearling weight, mature weight, weaning rate, and cumulative productivity, the last expressed as kg of weaned calf/cow/year. The authors observed that the economic value of WW, as well as its relative importance, was the lowest among the traits studied, demonstrating that WW contributes positively to profit despite its low economic weight. The authors concluded that, since the estimate of cumulative productivity encompasses the other traits, its effectiveness is significant to indirectly select for calf weight and female reproductive performance.

EV negative, almost zero, to MWW observed in this work was also obtained by Pravia et al. (2014) identifying breeding objectives for beef cattle in Uruguay. The authors comment that this result is due to the objective of the selection index being general and not a maternal index or even due to the complete production system and not a cow-calf system. In addition, as calves were not sold at weaning, they did not generate revenue during this period, which resulted in the fact that they did not compensate for the cost of nutrition for the cow to increase the calf's weight. Another important point of the work is that the authors determined a premium for the carcass quality and also had positive CW and the second most important trait in the index, as in our study, showing that both the signal and the economic importance of EV's depend on the evaluated system.

We observed some negative coefficients (*b*) in our indices; however, the sign of the coefficients does not indicate gain or loss in selection but rather the adjustment of each trait in the index, which is composed of several simultaneously analyzed traits, since the coefficients are obtained using the economic values of objective traits and the (co)variances and correlations between objective traits and selection criteria. For both systems, the highest regression coefficient was obtained for SC, a trait a trait easy to measure and correlated to the growth of the animals and sexual precocity of herd (Terakado et al., 2015).

The accuracy for the S1 and S2 was high. In literature, Oschner et al. (2017) obtained much lower values and conclude that this occurred because some indicator traits used as selection criteria were little related to objective traits. What did not occur in our work, where most of the traits were objectives and selection criteria.

The sensitivity to changes in the genetic correlations is the efficiency of the index after the addition or subtraction of 0.2 or 0.4 from the genetic correlations between the traits used as objective traits and selection criteria, one at a time. In the present study, higher sensitivity of STAY to changes in its correlation with WW and YW was observed. This finding might be explained by the higher REV of the trait compared to the other traits, as also reported by Ochsner et al. (2017) for mature weight.

In conclusion, the increase in STAY, CW, REA, WW and ADG would increase the profitability of the two production systems proposed. Cow STAY is the most important trait in complete cycle production systems in the Cerrado. Well-estimated genetic correlations are important in the process to avoid sensitivity in selection indices. The indices proposed can be applied by producers who use production systems similar to that of the present study in order to increase the profitability of their operation.

CRediT authorship contribution statement

Juliana V. Portes: Conceptualization, Methodology, Software, Formal analysis, Validation, Investigation, Data curation, Writing - original draft, Project administration. **Gilberto R.O. Menezes:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing - review & editing, Supervision. **Michael D. MacNeil:** Conceptualization, Methodology, Software, Formal analysis, Software, Validation, Data curation, Writing - review & editing. **Luiz O.C. da Silva:** Validation, Resources, Data curation, Writing - review & editing. **Andrea Gondo:** Software, Resources, Data curation, Writing - review & editing. **José Braccini Neto:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that there is no conflict of interest associated with this publication.

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Supplementary materials

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Appendices

The description of calculation and variables used to obtain the costs of systems is presented below:

Variables used:

CW = Cow weight

MP = milk yield of cow

Day_rent = pasture rent by year for base cow

Cows = number of cows

Intake_cow = 4.6631 + 0.0030*CW + 0.0127*(0.022*MP)

Ccap (feed requirement) = Intake_cow/(4.6631 + 0.0030*CW + 0.0127*(0.022*MP))

WTm = weight cow at 5 years old calculated by growth curve for cows

MWT = $WTm^{0.75}$

sDn and hDn = postweaning period in "n" part, the postweaning period was divided into 4 parts due to climatic differences in the region (dry and rainy season) for steers and heifers

sADGn and hADGn = postweaning gain in "n" period for steers and heifers

WTs0 = weaning weight of steers

WTh0 = weaning weight of heifers

yrst = number of yearling steers held for haverst

yrhf = number of yearling replacement heifers

yrhh = number of yearling heifers held for harvest

Thus:

WTs1 = WTs0 + sD1*sADG1;
WTs2 = WTs1 + sD2*sADG2;
WTs3 = WTs2 + sD3*sADG3;
WTs4 = WTs3 + sD4*sADG4;
WTh1 = WTh0 + hD1*hADG1;
WTh2 = WTh1 + hD2*hADG2;
WTh3 = WTh2 + hD3*hADG3;
WTh4 = WTh3 + hD4*hADG4
Cost_cows = 365*day_rent*cows/ccap
cost_yearling = ((0.5*(WTs0 + WTs1)$^{0.75}$)/MWT)*yrst*day_rent*sD1 + (0.5*(WTs1 + WTs2)$^{0.75}$)/MWT)*yrst*day_rent*sD2 + ((0.5*(WTh0 + WTh1)$^{0.75}$)/MWT)*(yrhf + yrhh)*day_rent*hD1 + ((0.5*(WTh1 + WTh2)$^{0.75}$)/MWT)*(yrhf + yrhh)*day_rent*hD2
cost_2_years = ((0.5*(WTs2 + WTs3)$^{0.75}$)/MWT)*y2st*day_rent*sD3 + ((0.5*(WTs3 + WTs4)$^{0.75}$)/MWT)*y2st*day_rent*sD4 + ((0.5*(WTh2 + WTh3)$^{0.75}$)/MWT)*(yrhf + yrhh)*day_rent*hD3 + ((0.5*(WTh3 + WTh4)$^{0.75}$)/MWT)*(yrhf + yrhh)*day_rent*hD4
cost_feed = cost_cows + cost_yearling + cost_2_years
non_feed_cost = ccap*(cost_feed*(1–0.69))
Total_cost = cost_feed + non_feed_cost

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