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Selection indexes for Nellore production system in the Brazilian Pantanal

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ABSTRACT - The objective was to develop selection indexes for Nellore cattle raised
in full-cycle production system in the Brazilian Pantanal. The resulting offspring are
retained as replacements or sold at two years of age. Preliminary analyses explored
effects of scale on economic values (EV). However, given the available data, these effects
were very small. Presented herein are results from a simulated system consisting of
5,000 cows with all animals maintained on pasture as is typical in Pantanal. The EV were
determined by approximating the partial derivatives of the profit function, changing
one trait at a time, by one unit, while keeping the other traits constant. Traits in the
breeding objective were mature cow weight, direct and maternal weaning weight,
postweaning average daily gain, subcutaneous fat depth, *longissimus* muscle area, and
stayability. Economic values were calculated on the basis of number of animals (per
head), number of animal units, and arroba of carcasss weight. Regardless of the basis,
maternal weaning weight and subcutaneous fat depth made negligible contributions to
the breeding objective. Proportions of variation in the breeding objectives (per head, per
animal unit, per arroba) explained by cow weight, direct weaning weight, postweaning
average daily gain, stayability, and *longissimus* muscle area were: 13, 13, 17; 6, 1, 5;
3, 3, 4; 67, 67, 61; and 11, 17, 13, respectively. These indexes may aid Nellore breeders
in their selection decisions, thus facilitating the genetic progress and increased
productivity and profitability of Pantanal herds.

Keywords: beef cattle, bioeconomic model, breeding objectives, genetic gain, selection

1. Introduction

Pantanal is the largest tropical wetland area and largest flooded grassland in the world. It is a gently
sloped basin that receives runoff from Planalto highlands and slowly releases the water through the
Paraguay River and tributaries (Keddy et al., 2009). Pantanal is the smallest biome in Brazil, comprising
about 1.76% of the total area of the country. It is located in southern Mato Grosso and northwestern
Mato Grosso do Sul states, and extends into northern Paraguay and eastern Bolivia (MMA, 2017). The
climate in Pantanal is warm. Winter is dry, and frost may occur in July or August. Rainfall varies between

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1,000 and 1,400 mm per year. About 80% of the precipitation occurs in summer, between November and March, when the river can increase in height by between 2 and 5 m. During the most severe floods, more than 80% of the plains are submerged (Abreu et al., 2010).

Livestock are the main economic enterprise in Pantanal (Abreu et al., 2010) with a cattle population of about 75 million heads (IBGE, 2018). Cattle production is extensive and based almost entirely on pasture with properties ranging in size from 5,000 to more than 20,000 ha (Crespolini et al., 2017). Most of the enterprises are engaged in cow-calf production with the Nellore breed. After weaning, most calves are sent to the plateau region for finishing in cultivated pastures. Finishing in the better environmental conditions of the plateau region increases the throughput of the production system relative to what it would be if the calves were maintained in Pantanal. Due to low productivity and quality of native pastures, which are greatly influenced by drought and flood cycles (Cardoso and Crispim, 2012), metrics describing cattle performance are lower than those for other regions of Brazil.

Because the environment of Pantanal is unique, it was deemed desirable to generate breeding objectives for Nellore cattle specific to that biome. Such breeding objectives would contribute to meeting the need to improve production and enhance the quality of beef, which has been viewed as essential (Moreira et al., 2019). A primary challenge for the implementation of genetic improvement programs in Pantanal is an adequate definition of the ideal type of animal to be reared in the biome (Santos et al., 2008). Animals should be adapted to the environmental conditions, have adequate growth potential, and reproduce regularly. Burrow (2012) concluded that simultaneous genetic improvement of productive and adaptive traits in tropically adapted breeds of beef cattle raised in tropical environments was feasible without serious adverse effects on either adaptation or production. Thus, the breeding objective for cattle to be raised in Pantanal is necessarily complex.

Currently, most Brazilian improvement programs have been using empirical indexes, by considering the traits according to what technicians and producers rule as important within the production system. However, the most efficient way to perform multitrait selections is to use the economic selection index methodology, in which economical relevant traits are weighted according to their effect on the economy of production as defined by a breeding objective. Use of a breeding objective based on a full-cycle production system is desirable because the resulting selection indexes recognize the ultimate value generation from meat that is produced for consumers (after Harris, 1970). Thus, the objective of this paper was to develop selection indexes for Nellore cattle reared in Pantanal based on breeding objectives for a full-cycle production system.

2. Material and Methods

2.1. Breeding objetive

Revenue and costs were attributed to biological variables in simulating production from 5000 cows and their followers. All revenue was generated by selling animals (steers, surplus heifers, and cull cows) for slaughter. Replacement heifers were generated within the herd.

A full-cycle production system of Nellore beef cattle reared in the Pantanal region was considered in defining the breeding objective. Net merit was defined by the profitability of a stereotypical pasture-based enterprise, in which calves and their dams were pastured until weaning at 240 days of age. After weaning, calves were kept on pasture, with protein and mineral supplementation, until they reached slaughter age (32 months). Estimates of phenotypic levels of cattle performance were provided by the Centro de Pesquisa Agropecuária do Pantanal (Table 1).

Economic data pertinent to production cost in Pantanal was based on a 2016-2017 survey of over 150 farms raising Nellore cattle by Terra Desenvolvimento Agropecuário. We admit that the use of data from clients of a technical consulting firm may introduce a degree of bias relative to a stereotypical producer. However, data from the latter type of producer were not readily available. The direction and magnitude of any such bias are unknown.

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Table 1 - Performance parameters used to simulate Nellore production system in the Brazilian Pantanal

Productive and reproductive rates	
Reproductive parameter	Mean
Pregnancy rate of four-year-old cows (%)	68.6
Pregnancy rate of 5-12-year-old cows (%)	76.1
Pregnancy rate of heifers (%)	81.4
Age at first calving (months)	40
Stayability (%)	50
Mortality rate	Mean
Weaning mortality rate (%)	1.5
Death rate after weaning (%)	4
Productive parameter	Mean
Calving weight (kg)	33
Weight at 240 days of age (kg)	155
Postweaning average daily gain of males 1 (kg)[1]	0.235
Postweaning average daily gain of males 2 (kg)[1]	0.536
Postweaning average daily gain of males 3 (kg)[1]	0.286
Postweaning average daily gain of males 4 (kg)[1]	0.586
Postweaning average daily gain of females 1 (kg)[1]	0.159
Postweaning average daily gain of females 2 (kg)[1]	0.362
Postweaning average daily gain of females 3 (kg)[1]	0.193
Postweaning average daily gain of females 4 (kg)[1]	0.392
Female weight at 600 days of age (kg)	246
Male weight at 600 days of age (kg)	311
Cow weight at weaning (kg)	350
Milk production (kg/day)	3
Carcass yield of females (%)	50
Carcass yield of males (%)	52
Ribeye area (cm²)[2]	0.0
Subcutaneous fat thickness (mm)	2.5
Average age of heifers at sale (months)	31.2
Average age of young bulls at sale or age at slaughter (months)	31.2
Cull cow weight (kg)	336
Weight of steers at slaughter/sale (kg)	460
Weight of heifers at slaughter/sale (kg)	346
Culling and replacement rates	Mean
Cull cow rate (%)	25
Culling rate of yearling heifers (%)	13
Culling rate of two-year-old heifers (%)	12
Rate of heifers remaining in the herd (%)	88
Culling rate of yearling steers (%)	1.5
Culling rate of two-year-old steers (%)	100
Others	Mean
Amount of arroba (US$/15 kg)	42.53

[1] Average daily gain after weaning was divided into four periods, two dry seasons, and two rainy seasons, because of the known differences in weight gain between different climatic periods.
[2] Mean ribeye area was considered null because it is improved by +1 deviation from median of expected progeny differences.

Production costs were summarized as feed and non-feed costs. The cost of grazing in Pantanal was 50% of the cost in the Cerrado, wherein the rental rate for pasture was US$ 7.62/month. For the base cow, this value was $0.125 per day. For the different animal classes, this cost was prorated relative to body weight. Non-feed costs were 31% of feed cost. Slaughter prices for steers and heifers were obtained from the Centro de Estudos Avançados em Economia Aplicada. The monetary calculations were done in Reais (R$) in 2017 and converted to US dollars (US$), using the average exchange rate of 2017 (US$ 1.00 = R$ 3.28). The base carcass price was US$ 2.87/kg. Price discrimination was implemented,

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adjusted by a system of premiums and discounts that were based on fat cover and carcass weight, which were derived from the "Programa Nelore Garantia de Origem", developed by the Associação dos Criadores de Nelore do Brasil (ACNB). Carcasses from steers in fat cover classes 1 and 5 were discounted US$ 0.04/kg as they were weighed less than 225 kg or more than 390 kg. Steer carcasses weighing between 240 and 330 kg and falling into fat cover classes 3 and 4 were awarded a premium of US$ 0.061. For heifers, carcasses weighing more than 195 kg and falling into fat cover classes 3 and 4 were likewise awarded a premium of US$ 0.061/kg. Carcasses from heifers weighing less than 165 kg or falling into fat cover classes 1 or 5 were discounted US$ 0.04/kg. Carcasses from cull cows had a base price of US$ 2.15/kg. Carcasses from cull cows weighing less than 180 kg or falling into fat cover classes 1 or 5 were discounted US$ 0.03/kg, except those of cull cows weighing more than 165 kg and falling into fat class 2, which received a premium of US$ 0.03/kg.

An equilibrium age distribution for females in the simulated herd was modeled following Leslie (1945; 1948). Birth rates were: 81.4, 68.6, and 76.2% for cows aged three, four, and 5-12 years, respectively. Age-specific survival rates for cows were also 81.4, 68.6, and 76.2% for cows aged three, four, and 5-12 years, respectively. Cows were required to calve annually or they were culled. All male calves and female calves that were surplus to the need for replacement females were destined for slaughter. After weaning, the young stock continued to graze through two subsequent wet and dry seasons. Average daily gain achieved by steers was 0.23525 kg/d during the five-month dry season immediately after weaning, 0.56325 kg/d during the following seven-month wet season, 0.28625 kg/d in the second dry season, and 0.58625 kg/d for 180 days of the second wet season. Corresponding average levels of performance by heifers were: 0.15925, 0.36225, 0.19325, and 0.39225 kg/d, respectively. Final weight was weaning weight plus the sum of products of average daily gain and number of days in each of the seasonal periods.

Mean carcass weight was modeled as the product of final weight and dressing percentage (DP), which had means of 50% for heifers and 52% for steers. Individual phenotypes for carcass weight and subcutaneous fat cover ($\bar{x}$ = 2.5) were drawn from the bivariate normal distribution defined by means, coeficients of variation of 0.06 and 0.46, respectively, and correlation of 0.14.

The baseline feed intake for cows was estimated following Anderson et al. (1983) as TDN intake per day = 4.6631 + 0.0030 × cow weight + 0.0127 × (0.022 × annual milk production), in which TDN = total digestible nutrients. Feed intake for yearling and two-year-old animals was estimated using the predicted feed intake by a cow multiplied by the ratio of metabolic weights for the young stock and mature cow.

Cow weight, weaning weight, milk production as indicated by maternal weaning weight (MacNeil and Mott, 2006), postweaning weight gain, carcass fat thickness, stayability, and ribeye area (REA) were considered to be the economically relevant traits (ERT). In the simulation, effects of cow weight were multi-faceted, influencing both the salable production from cull cows and feed required for maintaining the cowherd. Likewise, effects of maternal weaning weight influenced not only weaning weight of calves that were produced, but also the feed required by cows for milk production. Weaning weight and postweaning gain affected final weight because time from weaning to slaughter was held constant. Finally, the economic weight of REA was manifest through its effect on DP (DP = $\overline{DP}$ + .29REA).

A baseline simulation of full-cycle production in Pantanal as described above was conducted. The difference between simulated revenue and costs was estimated and used throughout as the baseline estimate of profitability from the system. The economic values (EV) for the breeding objective were obtained with the finite difference approximatation of the partial derivatives of simulated profit with respect to each of the ERT. Thus, the difference in profitability from the baseline simulation and a simulation in which the ERT was perturbed estimated the EV for that trait. The EV were then expressed per cow, per animal unit, and per arrobas (15 kg carcass weight). Relative EV (REV) were calculated as the product of the EV and genetic standard deviation for the ERT from the Programa Embrapa Geneplus genetic evaluation system. The transformation of EV to REV produces values that can be compared directly in determining the relative emphasis that is being applied to each trait in the breeding objective.

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Net merit was defined as a linear function of cow weight (CW) at five years of age, direct and maternal weaning weight (WW and MWW, respectively), postweaning average daily gain (ADG), subcutaneous fat thickness (FAT), REA, and stayability (STAY). Stayability was defined as a binary trait that indicates whether a cow was successful or not in producing three calves before attaining the age of six years. Because age at first calving was set to three years, this is equivalent to calving annually at three, four, and five years of age.

2.2. Selection criteria

The expected progeny differences (EPD) used as selection criteria were obtained in the Programa Embrapa Geneplus genetic evaluation system. Of the 15 productive, reproductive, and carcass traits evaluated in that system, seven were selected for use in this study. The choice of direct effects on WW in kg, ADG in kg, yearling weight (YW) in kg, scrotal circumference (SC) at 450 days in cm, REA in cm², age at first calving (AFC) in days, and CW in kg was made considering the direct correspondence with traits in the breeding objective as well as the genetic correlations between these traits and those that were modeled in developing the breeding objective (Table 2).

The selection index weights (b) for EPD were calculated following Schneeberger et al. (1992), where:

$$b = G_{11}^{-1}G_{12}v,$$

in which G_{11} is the 7×7 matrix of the genetic (co)variances of the seven selection criteria, G_{12} is the 7×5 matrix of the genetic (co)variances of the seven selection criteria and five selection objectives, and v is a 5×1 vector of economic values for ERT. Variances and covariances for growth, reproduction, and carcass traits in Nellore cattle used to calculate genetic values and obtain G_{11} and G_{12} were estimated by the restricted maximum likelihood method in multitrait analyses of data in Embrapa's beef cattle genetic improvement program database (Table 2). The matrix G_{11} was positive-definite.

Table 2 - Genetic variances (*), covariance (above diagonal), genetic correlations (below diagonal) and heritabilities (h²) 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*
h²	0.21	0.08	0.22	0.25	0.28	0.32	0.32	0.12	0.36	0.23

WW - weaning weight (kg); MWW - maternal weaning weight (kg); ADG - postweaning average daily gain (g/day); YW - yearling weight (kg); SC - scrotal circumference at yearling (cm); REA - ribeye area (cm²); FAT - fat thickness (mm); AFC - age at first calving (days); CW - cow weight (kg); STAY - stayability (%).

2.3. Index accuracy

The equation $r_{HI} = \dfrac{b'G_{12}v}{\sqrt{(b'G_{11}b)(v'Cv)}}$ (in which $b'G_{12}v$ is the covariance between the index and the aggregate genotype, $b'G_{11}b$ is the variance of the index, and $v'Cv$ is the variance of the breeding objective) is similar to the one described by Van Vleck (1993) for accuracy of indexes that use phenotypic information, with G_{11} replacing the phenotypic covariance matrix P. Schneeberger et al. (1992) explained that G_{11} is the genetic (co)variance matrix of the selection criteria that is assumed to be known without error, which is equivalent to all EPD having unit accuracy.

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The predicted response in the aggregate genotype (S_H) was calculated as: $S_H = \dfrac{b'G_{12}v}{\sqrt{b'G_{11}b}}$ in dollars. The

expected change in additive genetic value (S_g) of each trait was calculated as $S_{g_t} = i\,\dfrac{b'G_{12}}{\sqrt{b'G_{12}v}}$, wherein i is the selection intensity set to 1.

2.4. Index sensitivity

Results of the analysis of index sensitivity were expressed as relative efficiency of the index (E_u), given by $E_u = \dfrac{b'_u G_{12_t} v}{\sqrt{b'_u G_{11_t} b_u}} * \dfrac{1}{\sqrt{b'_t G_{12_t} v}}$, wherein b_u are perturbed coefficients and b_t are the corresponding "true" values. In conducting the sensitivity analyses, genetic correlations were perturbed by 0.2 and 0.4, and the EV from the breeding objective were perturbed by 50%. In addition, sensitivity of the breeding objective to production costs and product prices was assessed by incrementing the cost of grazing and carcass base price by 50% in separate analyses. The EV that resulted from these analyses were compared to the results from the base simulation as percentages.

2.5. Rank

Rank correlations were used to evaluate the relationship between the indexes calculated in the present study and the Índice de qualificação genética (IQG) that is currently produced by Embrapa's Geneplus Program. The IQG is an empirical index that considers the total maternal genetic effects on calf weight at 120 days of age (MW120) and at MWW, and direct genetic effects on WW, YW, ADG, yearling carcass conformation score (YCCS), yearling scrotal circumference (SC), and AFC, as follows: IQG = 0.05MW120 + 0.15WW + 0.15MWW + 0.15YW + 0.20ADG + 0.10YCCS + 0.10SC + 0.10AFC. For this analysis, a set of reference sires were extracted from the 2018 ABCZ Index/Geneplus genetic evaluation database. The database catalogs more than 10 million phenotypes from 2,003,130 animals born between 1991 and 2018. These animals were the offspring of 57,868 sires and 2,636,335 dams. The selected sires were required to have a genomic EPD for WW with accuracy greater than 60%, and minimum estimates of EPD accuracy of 30% for YW, ADG, STAY, REA, and FAT. These criteria produced a dataset of 865 bulls.

3. Results

3.1. Economic values

Gross revenue for the baseline system was US$ 1,607,572.53 against a production cost of US$ 541,778.87, yielding a gross profit of US$ 1,065,793.63. Average profits per cow, per animal unit (AU), and per arrobas were, US$ 213.16, US$ 152.92, and US$ 25.92, respectively.

The EV, REV, and proportional magnitude of the REV (RE) were calculated for the system (Table 3). The REV of STAY was positive and was the most important component of all three indexes (per cow, per AU, per arroba). Its importance results from change in the net calf crop, a shift in age distribution of the cow herd toward more mature cows, and a reduction in the number of females that must be retained as replacements to maintain herd size. Ribeye area and CW have somewhat similar REV with CW being more important per cow and per arrobas, and REA being more important per AU. The positive EV of CW is obvious and derived for the increased beef that is sold when the trait is perturbed upward, ceterus paribus. Likewise, the upward perturbation of REA increases the amount of beef that is sold through its effect on dressing percentage. The growth traits, WW and ADG, had still smaller REV with each of them individually accounting for less than 6% of breeding objective. Weaning weight constitutes less than 50% of final weight, but the direct effects were manifest at no cost. In contrast, the effects of ADG were expressed over almost two years with the benefit from increased growth rate being partly offset

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by the feed required to produce that increase in weight. The effects of MWW and FAT on the breeding objective were negligible. The value of increased weight due to MWW was offset by the cost of feed required to support milk production. Subcutaneous fat has an intermediate optimum in the simulated situation, with the mean level specified in the simulation being close to that optimum.

Table 3 - Additive standard deviation (σ_a), 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 of Nellore cattle

Trait (unit)	σ_a	ΔP (US$)	Per head			Per animal unit			Per arroba		
			EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)	EV (US$)	REV (US$)	RE (%)
CW (kg)	16.22	2,559.51	0.51	8.30	13	0.23	3.77	13	0.03	0.42	17
WW (kg)	8.31	2,105.46	0.42	3.50	6	0.03	0.25	1	0.01	0.12	5
MWW (kg)	4.90	73.96	0.01	0.07	0	0.01	0.03	0	0.00	0.00	0
ADG (kg)	23.83	454.63	0.09	2.17	3	0.04	0.97	3	0.00	0.11	4
FAT (mm)	0.16	−1,142.71	−0.23	−0.04	0	−0.16	−0.03	0	−0.03	0.00	0
STAY (%)	0.20	29,825.52	208.07	41.78	67	99.36	19.95	67	7.62	1.53	61
REA (cm²)	3.48	9,890.37	1.98	6.89	11	1.42	4.94	17	0.09	0.32	13

CW - cow weight; WW - weaning weight; MWW - maternal weaning weight; ADG - postweaning average daily gain; FAT - fat thickness; STAY - stayability; REA - ribeye area.

3.2. Index coefficients

Regression coefficients (b), responses to selection in dollars (S_H), and genetic gains in the trait unit (S_g) expected for the indexes proposed were calculated for the system (Table 4). For indexes calculated per cow and per AU, regression coefficients for YW, SC, and AFC were positive, and for WW, ADG, REA, and CW, they were negative. For the index selection calculated per arroba, all regression coefficients were positive.

In index per cow, the largest gains were the ADG, CW, and WW. In animal unit, REA, WW, and ADG obtained the greatest responses. Finally, in arrobas, REA and WW were the traits with the highest genetic gain by using the selection index. In dollars, the responses to the selection were US$ 42.95 (per cow), US$ 19.97 (per UA), and US$ 11.53 (per arroba).

Table 4 - Regression coefficients (b), genetic gains (S_g), relative importance of selection criteria (RI), responses in the aggregate genotype (S_H), and accuracies (r_{HI}) expected for the indices proposed for the pasture-based complete cycle production system per cow, per animal unit (AU), and per arroba

	Cow			AU			Arroba		
	b	S_g	RI (%)	b	S_g	RI (%)	b	S_g	RI (%)
WW	−5.77	6.51	22	−2.93	5.47	23	0.07	18.16	4
ADG	−0.33	7.27	5	−0.16	6.07	5	0.11	6.97	29
YW	5.85	-	34	2.79	-	34	0.04	-	4
SC	42.83	-	20	20.45	-	20	0.31	-	2
REA	−2.28	1.26	3	−0.61	6.69	2	0.29	25.29	6
AFC	0.80	-	12	0.38	-	12	0.01	-	2
CW	−0.49	6.54	4	−0.25	0.16	4	0.41	0.01	52
STAY	-	0.16	-	-	1.44	-	-	0.86	-
S_H (US$)		42.95			19.97			11.53	
r_{HI}		0.84			0.83			0.99	

WW - weaning weight; ADG - postweaning average daily gain; YW - yearling weight; SC - scrotal circumference at yearling; REA - ribeye area; AFC - age at first calving; CW - cow weight; STAY - stayability.
1 AU = 450 kg; 1 arroba = 15 kg carcass weight.

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3.3. Index accuracy

The accuracy for the indexes were 0.84 (per cow), 0.83 (per AU), and 1.00 (per arroba).

3.4. Sensitivity analyses

Changes of ±0.2 in genetic correlations resulted in efficiencies from 0.74 to 1. In changes of ±0.4, the efficiency was from 0.33 to 1. There was lower efficiency in correlation between STAY and WW (0.33), when genetic correlations with an increase of 0.40 were used, which indicated a possible uncertainty in the genetic correlations in these traits. In changes of ±50% in the economic values, efficiency was from 0.84 to 1. These results demonstrate that the indexes are sensitive to changes in the genetic relationships in the traits, and less sensitive in the systems used to obtain the EV.

As studied by Simm et al. (1986), the sensitivity to absolute changes in genetic correlations between the objectives and selection criteria of ±0.2 and ±0.4 was calculated. In some cases, adding or subtracting these values resulted in a sign change. In cases where these alterations would have resulted in a correlation greater than the unit, the genetic correlation was assumed to be equal to the unit. In addition, sensitivity was calculated as increasing or decreasing 50% in the magnitude of the EV of each trait in the selection objective.

Some authors have argued for the use of long-run production costs and product prices in the construction of breeding objectives (e.g., Ochsner et al., 2017; Barron Lopez, 2013) rather than the use of one of the values from a single point in time as was done in this study. Because CW and STAY impact the inputs and outputs and were major contributors to the breeding objectives, the sensitivity of their economic values to changes in prices was evaluated in this study. A 50% increase in the cost of grazing decreased the simulated profit per cow, per AU, and per arrobas by 25.4%, but increased the EV for CW by 10.7, 30.8, and 62.0%, respectively. A similar 50% increase in the base carcass price increased simulated profits by 74.5% and altered the EV of CW by 36.2, 14.8, and −26.1%, per cow, per AU, and per arrobas, respectively. A 50% increase in the cost of grazing reduced the EV for STAY by −7.8% per cow, but increased its EV by 1.0 and 32.7%, per AU and per arrobas, respectively. The 50% increase in the base carcass price altered the EV of STAY by 70.7, 47.28, and −12.2%, per cow, per AU, and per arrobas, respectively.

3.5. Spearman correlation

Spearman correlations between indexes and IQG were 0.78 (IQG × index per cow), 0.77 (IQG × index per AU), and 0.55 (IQG × index per arroba). Correlations between the indexes calculated were equal to 0.99 (cow and AU), 0.22 (AU and arroba), and 0.25 (cow and arroba).

4. Discussion

Although most properties in Pantanal adopt production systems only for the cow-calf phase, that is, calves are produced and sold after weaning, it is necessary to assess the full-cycle production system to perform the selection of individuals. The selection index favors the improvement of the herd's traits from reproduction to the final product.

Although the average profit in the different bases assessed (per animal, per AU, and per arroba) were similar, that is, regardless of the production scale adopted in the property, the EV and selection indexes found for the different bases pointed out some particularities in the economic and relative importance of the same traits.

The ability of the cow to stay in the herd, called stayability, mainly refers to the reproductive life of a matrix. It indicates its ability to remain in the herd, producing one calf per year, with no failures, up to a certain age (Snelling et al., 1995). In the literature, STAY presents estimates of heritability coefficients with low to moderate magnitude (0.03 to 0.23) (Santana Jr. et al., 2012; Kluska et al., 2018;

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Bonamy et al., 2019), similarly to the magnitude used in this study (0.23), which indicates that the direct selection for the trait results in slow genetic progress. However, STAY presents favorable genetic correlations with other traits, such as age at first calving (−0.15 to −0.69; Buzanskas, et al., 2010; Rizzo et al., 2015; Schmidt et al., 2018), scrotal circumference (0.19 and 0.45; Buzanskas, et al., 2010; Van Melis et al., 2010), post-weaning weight gain (0.19; Rizzo et al., 2015), and adult weight (0.66; Schmidt et al., 2018), also considered in the present study as selection criteria, enabling genetic gain through correlated response.

The selection for STAY and other reproductive traits is of great importance, due to the economic impact on production systems. After all, the cost of keeping a cow that does not produce a calf per year is almost the same as that of the female that does, which makes the selection for increasing the reproductive efficiency of the herd fundamental. As the reproduction rate of the herd increases, the amount of cull cows decreases; consequently, the herd becomes more productively long-lived, and the sale of surplus heifers is viable (Bittencourt et al., 2006; Brumatti et al., 2011; Silva et al., 2015).

As the cows' stayability in the herd influences both the revenues, with the production of a greater number of calves, and the expenses, due to the increase in their maintenance costs, STAY and similar traits related to permanence, longevity, and productivity of the matrices have been included as selection objectives (Formigoni et al., 2005; Wolfová et al., 2005; Brumatti et al., 2011). These traits have the highest EV in the operation, regardless of the base assessed (cow, AU, or arroba).

Similarly, in our study, as part of the heifers were retained for herd replacement and also due to the greater number of animals in the category of matrices, STAY was the most important in all bases studied. The relative importance of STAY was around seven times higher than the other traits assessed. In parallel, Hill (1998) and Phocas et al. (1998) observed that reproduction traits have an economic impact up to ten times greater than those associated with growth and carcass in full-cycle production systems.

Another trait linked to matrices that has been assessed as a selection objective was CW, due to the high genetic correlations between weights at different ages (0.44 to 0.95; Boligon et al., 2010; Regatieri et al., 2012; Portes et al., 2020a). This is because most beef cattle perform selection for weaning and/or yearling weight, due to the relationship between the traits and the final product, which inevitably results in changes in mature cow weight.

Most EV for the CW is negative, according to several studies (Wolfová et al., 2005; Ochsner et al., 2017; Simões et al., 2020). Larger animals are not always the most suitable and profitable to production systems, due to the high energy required for their maintenance and the consequent increased feeding costs. In Pantanal, Silva et al. (2015) assessed the productive efficiency of Nellore cows at weaning and found that selecting medium-sized cows (379 to 461 kg) is more advantageous for the region. They generate lower maintenance costs than larger cows and produce heavier calves than smaller cows.

In our study, CW presented a positive EV and was the second and third most important trait in our different bases, as a large volume of cows remained in the herd for several productive cycles, even though this generated extra feeding costs. As there was a greater number of cull animals for slaughter, profit was generated due to the payment related to the final weight of cows. A positive EV for CW was also obtained by Jorge Jr. et al. (2007) in a herd of 10,000 cows—the authors justified the possibility of expanding the pasture area of the property to accommodate animals with higher nutritional requirement—, and by Moreira et al. (2019), who pointed out the prices of dry matter and the sale price of cows for slaughter at the time of the study as factors involved in the result. Both studies demonstrated that CW is a trait that varies according to each system and market.

Although CW and WW are usually reciprocally antagonistic in relation to selection objectives, i.e., it is ideal to increase WW without raising CW, as the correlation assumed between them is not equal to the unit, it is possible to have progress in both traits simultaneously in a balanced way in the selection index (Ochsner et al., 2017). The selection for the direct effect of WW is relevant in the production of beef cattle because it represents the individual growth capacity. In the case of Pantanal, where most systems are cow-calf, this trait is interesting for a better economic return to calf producers.

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Several studies include WW as a selection objective (MacNeil et al., 1994; Wolfová et al., 2005; Bittencourt et al., 2006; Matjuda et al., 2014; Ochsner et al., 2017). The RE weighting is variable, according to the systems adopted and the final product. In studies that simulated the sale of calves at weaning, WW presented a higher RE than when they remained in the system until slaughter, because there was an increase in revenue during the weaning period, related to the sale of animals. However, those authors emphasized the importance of this trait in herd profit, even in those systems that presented a small RE, because the higher the WW, the faster the animal reaches the slaughter weight, which increases the precocity of herd finishing (Bittencourt et al., 2006).

The selection for the maternal effect for weaning weight (MWW) demonstrates the cow's maternal ability, that is, the efficiency of the female in producing milk for the calf (Silva et al., 2015). The EV for MWW were close to zero in this study, a result that can be explained by increased feeding costs due to the cow's higher nutritional requirement to produce milk and to result in increased calf weight, as described in the literature with null or even negative values (Pravia et al., 2014; Ochsner et al., 2017).

In addition to the direct and maternal importance, WW is correlated with other important traits that influence profit in production systems. Phocas et al. (1998) assessed different reproduction, growth, and carcass traits as selection objectives in Limousin cattle, by addressing the link between WW and other postweaning growth traits used as selection objectives and in the management strategy for sale at a certain age or final weight for slaughter. The authors explained that, by including the ADG and setting a slaughter age in the selection objective, a 1-kg increase of WW would also imply the increase of 1 kg in the final weight for slaughter, as ADG and the period of gain for finishing are kept constant in obtaining EV related to WW.

In our study, with pasture systems, ADG showed less relative emphasis than WW. On the other hand, Portes et al. (2020b) observed that, in systems where there is feedlot finishing, greater importance is given to this trait, aiming to accelerate the early finishing of animals.

Of the traits related to the final product, REA presented the highest RE, from 10 to 13%, in the systems studied. This is because this trait is linked to the amount of meat in the carcass, and the simulated systems presented bonus payment for the carcass quality, which directly influenced the profit. A similar result was observed by Fernandes et al. (2018) in production systems for crossbred Nellore × Angus, where a greater carcass uniformity benefited the marginal profit.

In our study, we observed some negative coefficients (*b*) for the different indexes in WW, ADG, REA, and CW in cow and AU bases. In the three indexes formed, the regression coefficient of highest value was for SC, a trait linked to animals' growth and herd's sexual precocity (Terakado et al., 2015). Positive coefficients were obtained for YW and AFC. It is important to point out that the coefficient sign does not mean gain or loss in the selection, but rather the importance of each trait in the index composed of several traits analyzed simultaneously, since the coefficients are obtained by using EV of the objectives, (co)variances, and correlations between objectives and selection criteria.

The accuracy calculated for the three bases assessed was high. Unlike our results, Ochsner et al. (2017) obtained much lower values in their indexes. They concluded that this happened because some indicator traits used as selection criteria were little related to the objective traits. In our case, most traits were objective traits and selection criteria simultaneously, which resulted in the high values observed.

The sensitivity to changes in genetic correlations is the index efficiency after the addition or subtraction of 0.2 or 0.4 in the genetic correlations between the traits used as objectives and selection criteria, one at a time. The value shows the importance of using well-estimated genetic parameters for the formation of selection indexes. In the present study, we observed greater sensitivity of STAY to its genetic correlations with WW and YW, which may have occurred due to the higher REV of STAY in relation to the other traits, a behavior also seen by Ochsner et al. (2017) for CW. The observed sensity of the economic values to production costs and product prices indicates the need for some care in determining appropriate values for the economic inputs. This is made even more challenging, because the truly relevant economic inputs are those that occur in the future at the time the progeny of the selected animals are produced and marketed. However, changes of 50% in the EV produced

little sensitivity in the breeding objective as indicated by the genetic correlations between the base objective and objectives that contained perturbed EV. Thus, the indexes developed here should be relatively robust to improve the profitability in various production environments.

Spearman rank-order correlations between the selection indexes and Geneplus's IQG were high (0.55 to 0.78). However, there was a non-coincidence between the classification of bulls, considering IQG and indexes obtained here. The results show that, when using IQG, most bulls selected as the best would not be the same as those selected by means of the indexes per cow, per AU, and per arroba. This is because IQG prioritizes the improvement of growth and finishing traits (weights, weight gain, and carcass conformation score) and gives less emphasis to reproductive traits (scrotal circumference and age at first calving).

5. Conclusions

The results indicate that the selection of stayability, cow weight, ribeye area, weaning weight, and postweaning average daily gain traits increases profitability in the production systems assumed. The cow's permanence in the herd is the most important trait in full-cycle production systems in Pantanal, regardless of the number of cows in the herd. In those systems where there is a bonus, the selection of traits related to finishing precocity and carcass quality are important for greater profitability. Well-estimated genetic correlations are important in the process to avoid sensitivity problems in selection indexes. The classification of animals is changed by applying different selection indexes with different selection objectives. Therefore, the indexes developed in this paper may be used only in production systems that are similar to the ones studied here. They may help producers to select sires that will contribute to greater profitability in their systems.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: J.V. Portes, G.R.O. Menezes, L.O.C. Silva, M.D. MacNeil, U.G.P. Abreu and J. Braccini Neto. Data curation: J.V. Portes, M.D. MacNeil and U.G.P. Abreu. Formal analysis: J.V. Portes and M.D. MacNeil. Funding acquisition: G.R.O. Menezes, L.O.C. Silva and U.G.P. Abreu. Investigation: J.V. Portes and V.V. Lacerda. Methodology: J.V. Portes, M.D. MacNeil, U.G.P. Abreu and V.V. Lacerda. Project administration: G.R.O. Menezes, L.O.C. Silva and J. Braccini Neto. Supervision: G.R.O. Menezes and J. Braccini Neto. Validation: J.V. Portes and M.D. MacNeil. Visualization: J.V. Portes, G.R.O. Menezes, M.D. MacNeil, U.G.P. Abreu, V.V. Lacerda and J. Braccini Neto. Writing-original draft: J.V. Portes and V.V. Lacerda. Writing-review & editing: J.V. Portes, G.R.O. Menezes, L.O.C. Silva, M.D. MacNeil, U.G.P. Abreu, V.V. Lacerda and J. Braccini Neto.

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