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Grazing behavior, growth performance, carcass yield and economic analysis of steers supplemented with concentrate in an integrated crop-livestock system

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This trial evaluated concentrate supplementation on grazing behavior, growth performance, carcass yield and economic analysis of off-season steer production in an integrated crop-livestock system (ICL). A randomized block design with the pastures (modules) as blocks, with 4 treatments, 4 groups of animals per treatment and 3 animals per group (N=48, 395±16 kg) was used to evaluate increasing levels of concentrate supplementation (1.0, 2.0, 3.0 and 4.0 kg/animal/day) containing 17% crude protein and 76% total digestible nutrients. The steers were kept in "Santa Fé" ICL *Urocloa ruziziensis* pastures during the dry season. Concentrate intake was 0.98, 1.45, 1.86, and 2.02 kg/animal/day, representing 0.23, 0.34, 0.44, and 0.47% of BW. Supplementation did not affect grazing time (P = 0.66); however, linearly decreased rumination time (P = 0.025) and increased idling (P = 0.043) and trough (P = 0.034) times. Average daily gain, carcass weight, dressing percentage and beef productivity linearly increased (P < 0.01) with increasing concentrate in the diets. All the supplementation levels were profitable, but the profit margin was greater in the highest level of concentrate supplementation. Concentrate supplementation to produce off-season Nellore steers in ICL was an efficient and profitable way to enhance growth performance and carcass yield without compromising grazing activity.

Key words: beef cattle, behavior, carcass, intake, performance.

INTRODUCTION

Integrated crop-livestock systems (ICL) have been successfully used for recovering pastures, intensifying land use, enhancing the complementary and/or synergistic effects between plant species and animal

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husbandry, and providing sustainable beef and grain production (Lemaire et al., 2013; Kumar et al., 2019). However, these systems are more complex because involve soil-plant-animal interactions (Sulc and Tracy, 2007; Gil et al., 2016). In this context, “Santa Fé” is a modality of ICL developed to associate crop production, especially corn, sorghum and pearl millet, with forage grasses, mainly *Urocloa* spp. and *Panicum maximum*. Crop and grass are sown intercropped and, after grain harvesting, pasture grows for feeding cattle during the dry season and producing straw for no-till farming, such as soybean and cotton (Kluthcouski et al., 2000).

Beef production in Brazil relies basically on pastures. In Brazilian savannas, where more than 50 million cattle heads are raised, there are two distinct seasons: rainy and dry seasons. During the rainy season, from October to March, cattle typically have a reasonable amount of forage available. Conversely, during the dry season, from April to September, pastures often present restricted forage quantity and quality (Cardoso et al., 2020). Thus, protein and energy supplementation has been used to increase ruminal fiber degradation rate and fermentation efficiency, enhance forage intake and digestibility, and improve cattle performance (Oliveira et al., 2016; Quadros et al., 2016). Supplementation plans must be established based on the different nutrient deficiencies and the producer`s goals (Poppi et al., 2018). However, supplementation involves additional costs, and the lack of information about animal responses has limited its adoption by producers (Bonadimann et al., 2017; Tedeschi et al., 2019).

Although “Santa Fé” ICL propitiates an opportunity to finish cattle during the dry season, there are limited studies about how supplementation could affect the bioeconomy of beef cattle production. We hypothesized that concentrate supplementation can increase the efficiency and profitability of ICL. The objective was to evaluate the effects of concentrate supplementation on grazing behavior, growth performance, beef productivity, carcass yield and economic analysis of finishing steers in “Santa Fé” ICL.

MATERIALS AND METHODS

Animal care

The experimental procedure was approved by the Institutional Animal Care and Use Committee at Bahia State University (0142010).

Pasture management under integrated crop-livestock system

The experiment was carried out at Stones Farm, located in Luis Eduardo Magalhaes, Bahia, Brazil. An area of 50 ha, taken from 500 ha under a “Santa Fé” modality of ICL, was used for this trial. Corn was planted intercropped with *Urocloa ruziziensis* in November. After crop harvesting in March, the experimental area was divided by electric fence into four pastures of 12.5 ha (called module), which were subdivided into four paddocks of 2.5 ha. Each module had all four treatments. Feeders and water troughs were placed in the paddocks. Pastures were allowed to grow for approximately 60 days before the first grazing event. The trial lasted 120 days, commonly used to finish cattle during the dry season in “Santa Fé” ICL and get enough straw for the next no-till summer annual crop production season. In order to reduce the influence of the pasture on intake and growth performance, steers were rotated every seven days. Therefore, concentrate supplementation levels were isolated as the unique cause of variance to influence the animal response variables (Quadros et al., 2016). The accumulated rainfall was 957, 124 and 29 mm, during the cultivation period (November to March), grass growth period after corn harvesting (April and May), and experimental period (June to September), respectively.

Diet and feeding

Forty-eight Nellore males with initial body weight (BW) of 395±16 kg, chemically castrated with a commercial product (Bopriva®, Zoetis), were identified, weighed, received an injection of vitamins A, D, and E (ADE-Vetbras®), and treated against parasites (Ivermectin, Genesis Iver Pour-On®, Eurofarma and Albendazole Sulfide, Voss Rico Oral®, Ourofino). The steers were divided into four groups of 12 animals per module. The four pastures (modules) were considered as blocks in a randomized block design. After that, they were subdivided into four subgroups of three animals (N=48) and each group received one of the four daily levels of concentrate: 1.0; 2.0; 3.0; and 4.0 kg/animal/day, corresponding to low, moderate, high, and very high levels, respectively. The concentrate, a mix of corn, sorghum grain, whole cottonseed and soybean cleaning residue, was offered once a day (8:00 h) in a 2 m-long feeder with access from one side. The diet was formulated to meet the requirements of beef cattle (450 kg BW) gaining 600 g/day (NRC, 1996). The proportion and chemical composition of concentrate ingredients, the composition of mixed concentrate and forage are presented in Tables 1 and 2, respectively. Daily supplement intake was calculated by subtracting the refusals (orts) from the amount offered, divided by the number of animals. It was noticed that the animals receiving 3.0 and 4.0 kg/animal/day were far from consuming the entire amount of concentrate offered. After adjustments to allow a maximum of 10% of leftovers, the concentrate daily intakes were: 0.98, 1.45, 1.86, and 2.02 kg/animal/day, representing 0.23, 0.34, 0.44, and 0.47% of BW, respectively, which henceforth will correspond to the treatments.

Samples and chemical analysis

Samples of forage were taken monthly by harvesting above-ground biomass at 10 cm stubble height, using a 0.5 × 0.5 m metal square, in five points per paddock, randomly assigned. The samples were dried in a forced-air oven at 60°C for 72 h to calculate DM content and herbage mass. Three samples of the concentrate ingredients and mixed concentrate were taken, conditioned in plastic bags, identified and frozen at −18°C. At the end of the trial, all samples of the ingredients, mixed concentrate and a composite sample per paddock per period of the forage were ground in a Willey mill using a 1 mm sieve for bromatological analysis. Chemical composition was analyzed to determine dry matter (DM) (Method 967.03), ash (Method 942.05), crude protein (CP) (Method 981.10), and ether extract (EE) (Method 920.29) (AOAC, 1990). Thermostable L-amylase enzyme was used in neutral detergent fiber (NDF)

Table 1. Chemical composition of concentrate ingredients and forage grass.

Item	Chemical composition (%)				
	DM	CP	EE	NDF	ADF
Concentrate ingredients					
Corn	87.7	8.91	4.57	15.3	41.5
Sorghum grain	88.9	12.6	3.55	13.8	61.5
Soybean cleaning residue	91.4	38.5	18.1	20.8	14.5
Whole cottonseed	89.1	13.4	16.9	67.3	58.5
Urea	100	280	-	-	-
Urocloa ruziziensis	26.0	7.03	1.06	80.9	42.9

DM, dry matter; CP, crude protein, EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber.

Table 2. Proportion of ingredients and chemical composition of supplemental concentrate.

Proportion of ingredients	**%**
Corn	60.0
Sorghum grain	25.5
Soybean cleaning residue	2.00
Whole cottonseed	5.00
Mineral mixture[1)]	5.00
Urea[2)]	2.50
Chemical composition	%
DM	89.0
Ash	2.65
CP	17.0
EE	4.85
NDF	16.5
ADF	9.17
Lignin	5.01
TC	80.4
NFC	37.6
NDIN	2.92
ADIN	0.90
TDN[3)]	76.0
ME (Mcal/kg)[3)]	2.12

DM, dry matter; CP, crude protein, EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; TC, total carbohydrates; NFC, non-fiber carbohydrates; NIDN, neutral detergent insoluble nitrogen; ADIN, acid detergent insoluble nitrogen; TDN, total digestible nutrients; ME, metabolizable energy.[1)] Guaranteed levels (per kg): calcium (max.) - 220 g and calcium (min.) - 209 g; phosphorus - 163 g; sulfur – 12.0 g; magnesium - 12.5 g; copper - 3500 mg; cobalt - 310 mg; iron - 1960 mg; iodine - 280 mg; manganese - 3640 mg; selenium - 32 mg; zinc - 9000 mg; and fluorine (max.) - 1630 mg.[2)] Mixture of urea and ammonium sulfate (9:1).[3)] Estimated according to NRC (1997).

analysis. Both NDF and acid detergent fiber (ADF) were determined in ANKOM 2000 Fiber Analyzer (ANKOM Tech Corp., Fairport, NY, USA). Acid detergent lignin was determined treating the residue is with 72% sulfuric acid (method 973.18) (AOAC, 2002). The NDF and ADF were corrected for ash by digesting the residues in neutral detergent and acid detergent, respectively, and incinerating them in a muffle furnace at 600°C for four hours. Neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen

(ADIN) were obtained by analyzing nitrogen in the NDF and ADF residues, respectively (Method 981.10) (AOAC, 2002). Total carbohydrates (TC) were estimated using the equation:

$$TC = 100 – (\%CP + \%EE + \%ash).$$

Non-fiber carbohydrates (NFC) were calculated according to the equation:

$$NFC = TC – \%NDFap$$

where NDFap is the neutral detergent fiber corrected for ash and protein. Total digestible nutrients (TDN) and metabolizable energy (ME) were calculated (NRC, 1996).

Grazing behavior

Animal behavior was assessed visually by trained observers that stayed on a central watchtower, approximately 250 m distance from the farthest point of the experimental area. The monthly observations were made with the help of binoculars. Each animal was previously marked with colored markers. The behavioral variables were classified into grazing, rumination, idle and time spent at the feed or water trough. To record the diurnal time spent in each activity, the animals were observed every 10 min, from 6:00 to 18:00 h. Behavioral activities were considered mutually exclusive (Pardo et al., 2003). The discretization of time series was performed directly in the data collection worksheets, with the counting of discrete periods of grazing, rumination, idle and trough times. The mean duration of each of the discrete periods was obtained by dividing the daily times of each activity by the number of discrete periods. The influence of circadian rhythm on grazing behavior was graphed to identify the percentage of animals in a certain behavior pattern along the course of the day.

Growth performance and carcass yield

The steers were weighed at 30-day intervals to adjust the amount of concentrate. The initial and final weights were obtained after 16h fasting, and these values were used for calculating average daily gain (ADG). Forage allowance was defined as the herbage mass to average BW ratio. The stocking rate was evaluated by animal unit (AU) that consisted of the average BW divided by 450 kg per hectare. Beef productivity was calculated by dividing the BW gain per stocking rate. Animals were slaughtered in a commercial slaughterhouse (Fribarreiras, Barreiras, Bahia, Brazil), federally inspected, after 16h fasting, with access to water. Slaughter procedures included the utilization of a captive bolt pistol, exsanguination, skinning rack and evisceration without electrical stimulation. After that, the carcasses were divided longitudinally and weighed to obtain hot carcass weight (HCW) and dressing percentage.

Economic analysis

All costs involved in the beef production process were recorded and the expenses were divided into variable and fixed costs. The variable costs included animal purchase, feed, labor, veterinary products, freight and other expenses. The production infrastructure was computed as fixed costs, using the depreciation values (that is, original value minus salvage value, divided by the useful life span) of fences, troughs, feed mixer, pens and scale. A land area of 500 ha was considered in these calculations because part of the structure (e.g. pens, scale) and labor used in the experimental area (50 ha) also served the entire production area (500 ha). Machinery was not considered in the calculations because the farm used a double seeder (corn and grass) when they planted the crops; and therefore, had no additional costs. All values in Brazilian national currency were converted to American dollars (USD) using the exchange rate from October 2011 (https://economia.uol.com.br/cotacoes/cambio/). The cattle price was $ 1.72 per kg of BW to purchase and $ 3.40 per kg of carcass to sell. The income per hectare considered the gain by each group of animals multiplied by the stocking rate. Return on investment (ROI) was calculated by the formula:

$$ROI = [(\text{sale price} - \text{cost})/\text{cost}] \times 100.$$

Profit margin (profit) was calculated by the formula:

$$Profit = [(\text{sale price} - \text{cost})/\text{sale price}] \times 100.$$

Statistical analysis

Pasture measurements (herbage mass and forage allowance) were not subjected to the effect of supplementation level due to the grazing rotation, therefore the data were analyzed by analysis of variance (ANOVA) for a completely randomized design to test paddock as a cause of variance with repeated measures in time, using PROC GLM of the Statistical Analysis System (SAS® 9.22), and considered statistically equal when the p-values were greater than 0.05 in F-test.

Intake, grazing behavior, growth performance, stocking rate, beef yield and carcass data were analyzed in a randomized block design with the four pastures (modules) being the blocks, with four treatments (levels of supply of concentrate supplement), four groups (experimental units) and three animals per group (N=48). After the ANOVA, treatments were compared employing orthogonal decomposition of the sum of squares of the treatments in linear, quadratic, and cubic degree order effects related to the effect of level of supplementation, with subsequent adjustment of the linear regression equations, using PROC REG of SAS (SAS® 9.22). Statistical procedures conducted utilizing PROC GLM of SAS (SAS® 9.22) adopted 0.05 as the critical level of probability of type I error and used initial BW as a covariate. The economic analysis evaluated financial indicators and data were not submitted to statistical analysis.

RESULTS AND DISCUSSION

Pasture evaluation

The herbage mass was not affected by paddock or month, with an average of 3,892 ± 325 kg/ha of DM (Table 3). “Santa Fé” ICL was a good option to provide forage for cattle during the dry season, enabling considerable carrying capacity to reach the forage allowance of 8 kg DM/100 kg BW (8%), which seems reasonable for balancing gain per animal and per area (Euclides et al., 2018). Pastures must have at least 2,500 kg/ha of herbage mass in order to maximize supplementation results (Brandao et al., 2018); thus, there were no forage intake restrictions in this trial. Additionally, at the end of the experimental period, there

Table 3. Evaluation of *Urocloa ruziziensis* pasture in “Santa Fé” integrated crop-livestock system.

Item	Paddock				Mean	CV[1)] (%)	P-value
	1	2	3	4			
Herbage mass (kg DM/ha)	4335	3646	3600	3988	3892	16.7	0.57
Forage allowance (kg DM/100 kg BW)	9.00	7.50	7.35	8.18	8.01	2.65	0.36

[1)] CV = Coefficient of variation (%).

was enough straw for the next no-till cultivation season, which provides important environmental services (Sulc and Tracy, 2007; Lemaire et al., 2013; Kumar et al., 2019).

In this study, based on herbage mass and concentrate intake results, it seems the carrying capacity of “Santa Fé” ICL was underestimated. The initial and final stocking rates of 0.9 and 1.0 AU/ha, respectively, based on average national values (Dias et al., 2016), could have been increased. Taking into account the herbage mass, the theoretical DM intake of 12 kg DM/day for cattle weighing 450 kg BW (NRC, 1996), and grazing efficiency of 50%, it can be inferred that carrying capacity would be 1.5 AU/ha. The relationship between optimal concentrate level and stocking rate is worth further investigation.

No fertilizer was applied on the pastures, taking advantage of residual nutrients from the previous crop. After the grazing season, livestock manure serves as a source of nutrients for the next crop in rotation, thereby cycling nutrients from the crops through the animals and back out onto the land (Sulc and Tracy, 2007). The chemical composition of *U. ruziziensis* (Table 1) was considered good compared to a regular condition of low nutritive value stockpiled grasses in the dry season commonly used for beef cattle production in Brazilian savannas (Quadros et al., 2016).

Grazing behavior

Grazing time was not affected (P = 0.66) by concentrate supplementation levels (Table 4), in contrast to the observations of Pardo et al. (2003). The substitution coefficient, when supplement reduces forage intake, did not affect the grazing time, similarly to what was observed by Mendes et al. (2015) testing up to 0.8% BW in concentrate to finish crossbred steers on *U. brizantha* cv. Marandu pastures. Supplemental feed decreases voluntary forage intake when TDN consumption from the supplement surpasses 0.7% of BW (Moore et al., 1999); that was not the case in this trial.

Increasing concentrate in the diet resulted in a linear decrease in rumination time (P = 0.025); conversely, it linearly increased idling (P = 0.043) and trough (P = 0.034) times. Increasing energy and protein in the cattle diets reduced rumination time and increased idling time since the behavioral activities are mutually exclusive (Pardo et al., 2003). In some cases, the reduction of rumination time may be associated with substitutive effects on forage by concentrate, which restricts rumination by lowering NDF concentration in the diet (Mendes et al., 2015). Another reason for reduced rumination and increased idling times, which seems more applicable to this trial, is that satiety was reached faster when the concentrate level in the diets was increased. This occurrence may result in improvements in energy balance since the animal spends less energy to search for forage (Kilgour et al., 2012).

The percentage of time spent on grazing (34%) and rumination (31 to 35.3%) were lower than those observed by Quadros et al. (2016), testing low intake self-fed supplement for stocker Zebuine males on stockpiled *U. brizantha* in the dry season, that varied from 49 to 54% and 42.5 to 46.3%, respectively. “Santa Fé” ICL pastures provided adequate forage availability and quality that requires less grazing and rumination than high-fiber and low-digestibility stockpiled grasses. Grazing, rumination and idling relative times were in the normal range for cattle, that is, (28.3-54.2%, 19.5-50.0% and 15.0-42.9%, respectively) (Kilgour, 2012). As expected, trough time increased by increasing concentrate level in the diet, which is positively correlated with ADG (Dias et al., 2016).

There was an influence of circadian rhythm on animal ethology (Figure 1). Independent of concentrate supplementation level, circadian rhythm affected grazing behavior. There was a peak of grazing activity between 14h and 16h, with higher intensity when supplement intake was up to 0.34% BW (Figure 1, a and b). In all treatments, the animals ruminated and rested preferentially in the morning. Other behaviors were similar, highlighting the ethologic characteristics of the animals. Cattle present certain plasticity in their behavior, developing many times an individual circadian behavior model to adapt to the current environment (Pardo et al., 2003; Quadros et al., 2016).

Concentrate intake, growth performance and carcass yield

Concentrate intake linearly increased (P < 0.001)

Table 4. Diurnal grazing behavior of Nellore steers supplemented with concentrate in “Santa Fé” integrated crop-livestock system (in minutes).

Activity	Concentrate intake (% BW)				SEM[1)]	P-value	Regression equation[2)]
	0.23	0.34	0.44	0.47			
Grazing	243	244	247	245	18.6	0.66	ns[3)]
Rumination	255	251	226	223	11.8	0.03	Y = -11.8x + 268
Idling	170	167	187	187	9.87	0.04	Y = 7.21x + 160
Feeder trough	52.4	57.8	59.6	64.8	4.85	0.03	Y = 3.9x + 48.9

[1)] Standard error of the mean.
[2)] The regression equations represent the relation between concentrate supplementation and the different response variables.
[3)] ns = nonsignificant (P > 0.05).

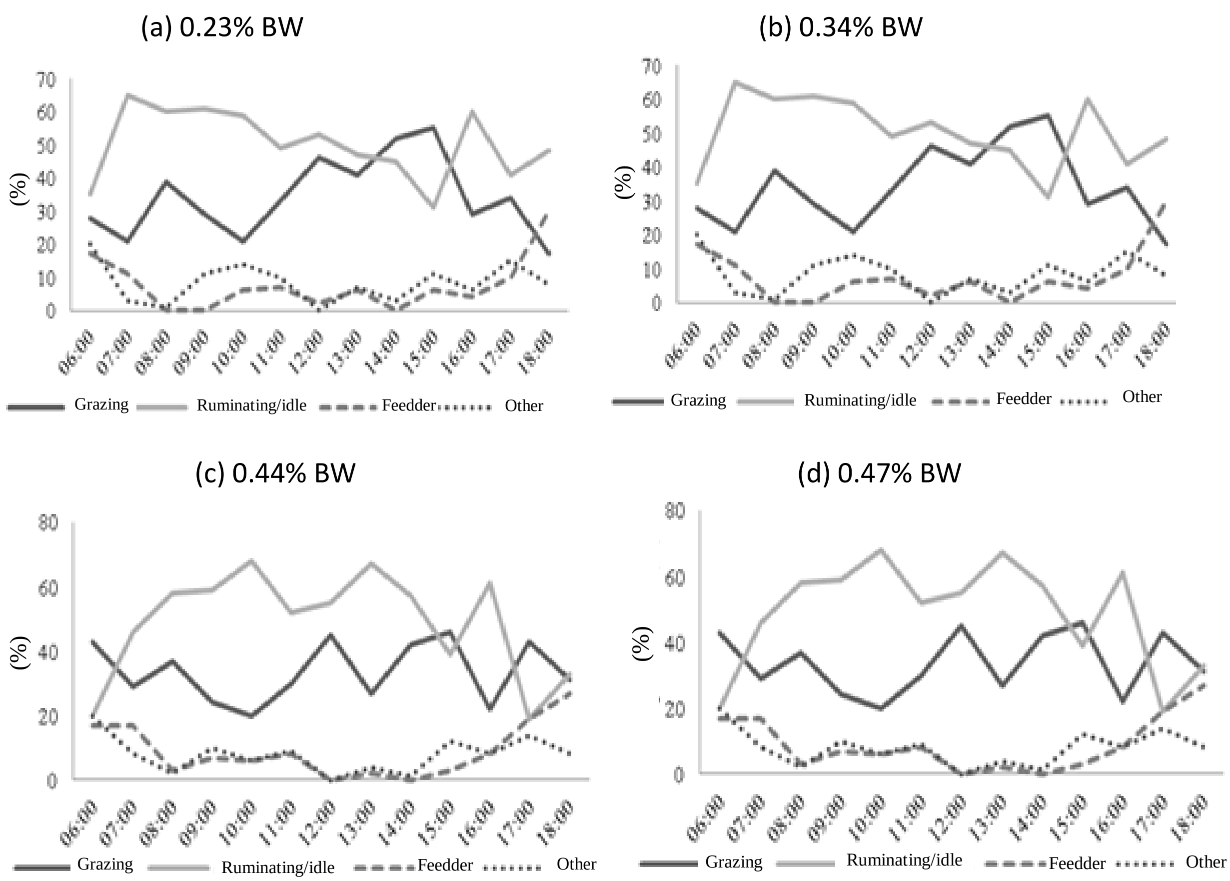

Figure 1. Influence of circadian rhythm on grazing behavior of Nellore steers supplemented with concentrate (a, 0.23% BW; b, 0.34% BW; c, 0.44% BW; d, 0.47% BW) in “Santa Fé” integrated crop-livestock system.

according to the amount offered (Table 5). However, steers receiving more than 3 kg of concentrate daily did not consume as much as expected, probably as a consequence of the availability of forage with reasonable quality and previous history (i.e. raised exclusively on pastures) and genetic traits of those Zebuine steers. The supplemental concentrate provided an extra 0.15, 0.22, 0.28 and 0.31 kg of CP; 0.66, 0.98, 1.26 and 1.37 kg of TDN or 1.85, 2.74, 3.50 and 3.81 kcal of ME, for the consumption of 0.23, 0.34, 0.44 and 0.47% of BW of concentrate, respectively.

The initial BW did not vary (P = 0.84), but final BW (P < 0.01) and ADG (P < 0.01) linearly increased in consequence of the larger amounts of digestible nutrients

Table 5. Supplement intake, growth performance, beef productivity, dressing percentage and hot carcass weight of Nellore steers supplemented with concentrate in "Santa Fé" integrated crop-livestock system.

Item	Supplementation (% BW)				SEM[1]	P-value	Regression equation[2)]
	0.23	0.34	0.44	0.47			
Concentrate intake (kg/day as fed)	0.98	1.45	1.86	2.02	0.70	0.001	Y = 4.28x - 0.006
Initial BW (kg)	396	398	394	393	2.32	0.84	ns[3)]
Final BW (kg)	476	484	490	507	6.16	0.01	Y = 106.6x + 450.0
BW gain (kg/animal)	80.4	86.4	96.0	114	21.8	0.01	Y = 120.7x + 49.6
ADG (kg/day)	0.67	0.72	0.80	0.95	0.03	0.01	Y = 1.02x + 0.41
Stocking rate (AU/ha)	0.92	0.93	0.94	0.95	0.01	0.91	ns
Beef productivity (kg BW/ha)	74.2	80.7	89.8	109	0.03	0.01	Y = 122.4x + 43.0
Dressing percentage (%)	52.1	52.7	53.2	54.5	1.46	0.03	Y = 8.45x + 50.0
HCW (kg)	248	255	261	276	19	0.01	Y = 98.1x + 223.8

BW, body weight; ADG, average daily gain; HCW, hot carcass weight.
[1)] Standard error of the mean.
[2)] The regression equations represent the relation between concentrate supplementation and the different response variables.
[3)] ns = nonsignificant (P > 0.05).

as the levels of concentrate in the diets were increased corroborating the finds of Detmann et al. (2014) and Machado et al. (2019).

Growth performance observed in this study was greater than that observed in the literature (Detmann et al., 2004; Detmann et al., 2014) for supplemented beef cattle of the same category raised on pastures. Increasing concentrate levels in the diets resulted in up to 42% additional ADG. Conversely, the weight gain:kg supplement ratio, decreased 0.20 when comparing a concentrate intake of 0.23% BW to the other levels (0.70 vs. 0.50). Increasing the supplement from the range 0.5-1.0 kg/day to 1.0-2.0 kg/day reduced the weight gain/kg supplement ratio (Cabral et al., 2014). The response of supplementation in weight gain is positive in the beginning and tends to stabilize as the supplement supply level is increased, probably limited by the genetic potential of the animals and the interaction between pasture and supplement regarding TDN intake (Moore et al., 1999). Another factor that may influence performance is the negative effect of starch-rich concentrate feedstuffs on fiber digestibility because high amounts of NFC with rapid fermentation can decrease rumen pH and inhibit cellulolytic bacteria growth (Rotger et al., 2006). In fact, depending on the cost of supplement and live weight cattle prices, it could be feasible to allow a certain reduction of weight gain:kg supplement ratio to achieve greater ADG and beef productivity, resulting in shorter harvest time and increased efficiency of beef production based on pastures (Barbero et al., 2015). As the stocking rate was kept constant (P = 0.91) because the experimental protocol used a fixed number of animals per area, maximizing ADG with increased concentrate levels in the diets linearly increased (P < 0.01) beef productivity, corroborating Cardoso et al. (2020). The consumption of 0.47% of BW in supplemental concentrate resulted in 46.4% more beef per unit area than 0.23% of BW, in consequence of increased weight gain per cattle, intensifying land utilization.

In 120 days, depending on concentrate level, beef productivity was from 165 to 241% greater than the annual Brazilian average of 45 kg/ha (Martha Junior et al., 2011). Strategic supplementation at moderate levels can promote individual BW gain and gain per area attributed to associative effects, which elevates growth performance and productivity simultaneously (Oliveira et al., 2016). Carcass dressing percentage was improved from 52.1 to 54.5% by increasing concentrate in the diets (P = 0.026). These values are greater than the 45 to 51.1% observed by Carvalho et al. (2017) evaluating Nellore steers raised on rangelands and cultivated tropical pastures, probably in virtue of better nutrition of ICL pasture plus concentrate. The HCW linearly increased with concentrate supplementation level (P < 0.01). When the concentrate intake was increased from 0.23 to 0.47% of BW, HCW improved 11.3%. Thus, concentrate supplementation was an important tool to increase HCW (Rutherford et al., 2020).

Economic analysis

Although the technical results have shown the advantages of supplementing steers with concentrate (that is, increased ADG, beef productivity, and carcass yield), to be extensively adopted by producers the system needs to be profitable. In the cost analysis, cattle purchase represented 89.1 to 92.7% and 88.2 to 91.7 % of variable and total costs, respectively, for 0.47% and 0.23 of BW concentrate intake (Table 6). The considerable sum of

Table 6. Economic analysis of concentrate supplementation for fattening Nellore steers in "Santa Fé" integrated crop-livestock system (in US$).

Item	Supplementation (% BW)			
	0.23	0.34	0.44	0.47
Variable costs				
Cattle purchase price (per head)	672.68	672.68	672.68	672.68
Concentrate	27.08	40.19	51.55	55.99
Labor	6.97	6.97	6.97	6.97
Vet medicine/Drugs	4.92	4.92	4.92	4.92
Freight[1)]	8.77	8.77	8.77	8.77
Other expenses[2)]	5.32	5.32	5.32	5.32
Fixed costs				
Depreciation[3)]	7.98	7.98	7.98	7.98
Costs				
Total variable costs	725.74	738.86	750.22	754.65
Total costs	733.72	746.83	758.20	762.63
Unitary costs (per 100 kg carcass weight)	295.61	292.56	290.85	276.00
Gross return				
Cattle sale (per head)	810.21	823.83	834.04	862.98
Net income				
Income over variable cost per head	84.47	84.97	83.83	108.33
Income over total cost per head	76.49	77.00	75.85	100.35
Net income per hectare	70.61	71.90	70.95	95.57
Economic indicators				
ROI (%)	10.4	10.3	10.0	13.2
Profit margin (%)	9.5	9.3	9.1	11.6

ROI, return on investment.
1) Feeding and cattle transportation.
2) Energy, grass seeds and other minor expenses.
3) Electric fences, feeders and water troughs, mixer, pens and scale.

capital, particularly for animal acquisition, has been one of the main restrictions for the broad adoption of ICL systems (Martha Junior et al., 2011). Concentrate expenses corresponded to 3.7, 5.4, 6.9 and 7.4% of variable costs for 0.23, 0.34, 0.44 and 0.47% of BW of concentrate intake, respectively. However, when we excluded cattle purchase from the variable costs, these percentages rose to 51 to 68.3%. All the supplementation strategies were profitable. However, the unitary costs decreased with increasing concentrate levels in the diet (Table 6). The positive effect in weight gain with increased levels of supplement and the prices of carcass/supplement overcame the slight reduction in feed efficiency. Beef costs of finishing steers with concentrate supplementation in the "Santa Fé" ICL was competitive ($ 276-296/100kg of carcass weight) compared to the costs in Europe, Oceania, and North America, of $ 350-450, 400-410, 290-340/100 kg of carcass weight, respectively, in the same year when the trial was conducted (Hocquette et al., 2018).

Cattle production generated income from $ 76-100 and $ 70-95 per head and per hectare, respectively, justifying the implementation of "Santa Fé" ICL plus concentrate supplementation. The ICL can reduce financial risks, increase productivity, diversify production, and enhance the resiliency of the land (Kumar et al., 2019; Vinholis et al., 2021). The total income over variable and total costs, net income per hectare, ROI and profit margin were higher when concentrate intake was 0.47% of BW compared to lower supplementation levels. The income over total cost per head and net income per area of 0.47% of BW of concentrate intake resulted in an additional $ 23.90 and $ 24.4, respectively, greater than the average of the three lower levels of supplementation. The ROI and profit margin slightly reduced from 0.23 to 0.44% of BW but increased when 0.47% of BW of concentrate was consumed reaching 13.2 and 11.6%, respectively. The biggest drivers of profitability are BW gain and stocking rate as well as the balance between these two factors (Poppi et al., 2018).

In conclusion, increasing concentrate supplementation to finish Nellore steers in a "Santa Fé" ICL enhanced growth performance and carcass yield without compromised grazing activity. All levels of supplementation consumption were feasible, and in the short term resulted in 1.7 to 2.4 times more beef per hectare than the Brazilian national annual average. Steers consuming daily 2 kg (0.47% of BW) of supplemental concentrate per day resulted in the greatest growth performance, beef productivity and carcass yield, thus increasing the efficiency and profitability of ICL.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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