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Nutritional carryover effects of the previous plane of nutrition of crossbred Angus steers affects freshwater intake, animal performance, and water and feed efficiency

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ABSTRACT

This study evaluated how the backgrounding diet can affect water intake, animal performance and water and feed efficiency of steers fed finishing diets based on grains or forages. Twenty-four crossbred Angus steers (298 ± 10.2 kg) were fed during backgrounding either a moderate (MP, $n = 12$; triticale hay only, 9.1%crude protein [CP], 1.07 Mcal/kg net energy available for maintenance [NEm], and 0.52 Mcal/kg net energy available for gain [NEg]) or high plane of nutrition (HP, $n = 12$; 85% alfalfa hay and 15% beardless wheat hay, 12.62%CP, 1.23 Mcal/kg NEm, and 0.66 Mcal/kg NEg) during the background phase (85 d). After this period, steers were assigned to two finishing phase groups containing half of the animals from each backgrounding diets. During the finishing phase, animals were fed either a forage-based (Alfalfa hay; CP: 20.8% DM, NEm: 1.47 Mcal/kg, NEg: 0.88 Mcal/kg) or a grain-based diet (80% whole corn and 20% wheat hay; CP: 10.6% DM, NEm: 1.96 Mcal/kg, NEg: 1.31 Mcal/kg). There was no interaction between the effects of the previous plane of nutrition [(moderate (MP) or high (HP)] and finishing diets (forage or grain-fed) on any of the variables studied ($P > 0.05$). Animals backgrounded on MP were lighter and had a lower DMI when compared with HP ($P < 0.01$). However, no differences were observed on the drinking water intake (DWI) between MP and HP ($P > 0.05$). HP animals were more efficient in gross water efficiency ($P < 0.01$), but less efficient on residual feed intake ($P < 0.05$), compared to MP animals. During the finishing phase, forage fed animals had a greater DMI and DWI compared with grain-fed animals ($P < 0.01$), however, no differences were observed on the final BW ($P > 0.05$). Grain-fed animals were more efficient for water and feed intake and had a greater marbling score ($P < 0.01$) compared to forage-fed. Animals fed on HP and finished in a grain-fed diet had the least DWI ($P < 0.05$) and greatest body condition score ($P < 0.05$), marbling score ($P < 0.01$) and rib depth ($P < 0.05$). In the first 20 d of the finishing period, the previous plane affected the variables ADG, DMI, CPi, and DWI (as kg DMI and CP) in the finishing plane. Altogether, our results highlight the individual effects of backgrounding and finishing systems on DWI and the efficiency of finishing animals, as well as the importance of providing adequate nutrition during the earlier stages of life.

LAY SUMMARY

When acquiring stocker cattle at auctions, very limited information is known about the previous plane of nutrition provided to those animals. Previous studies have reported that the backgrounding period can affect cattle performance during the finishing phase. However, more information is needed about the effects of the previous plane of nutrition on the water use by those animals. In this study, we investigated the effect of backgrounding animals on a moderate or high plane of nutrition on water intake, performance, and efficiency of animals finished either on a forage- or grain-fed system. There was no interaction between the effects of the previous plane of nutrition [(moderate (MP) or high (HP)] and finishing diets (forage or grain-fed) on any of the variables studied. However, animals fed a grain-based finishing diet had the lowest requirement for water and the highest carcass quality. Further, when only comparing the differences between the finishing systems, it was observed that the requirements for freshwater of grass/forage-finished cattle almost doubled when compared to grain-finished animals.

Key words: backgrounding, finishing, nitrogen, water

INTRODUCTION

Beef cattle requirements are largely governed by six essential nutrients that ensure proper body function—carbohydrates, lipids, protein, mineral, vitamins, and water. Beef cattle have been documented to survive weeks or months when some of these nutrients are absent; however, in water-deprived environments, the survivability of the animals significantly decreases to a few days, making water the most critical and limiting nutrient (NASEM, 2016; Wagner and Engle, 2021).

Increasing efficiency at backgrounding is an essential factor to consider while attempting to improve animal efficiency at the finishing phase. The period of growth

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significantly impacts the composition of and efficiency of gain during the finishing phase (Roth et al., 2017). This is due to the variability inherent to animal cohorts that arrive at the feedyard. Because of that, upon arrival, animals will typically undergo some level of compensatory gain (Severo et al., 2023). Compensatory gain occurs when animals experience higher-than-normal rates of weight gain following a period of nutritional restriction, during which, their growth is slower-than-normal (Barash et al., 1998; Bezerra et al., 2013).

Besides feeding, drinking water is essential to animal growth. Although water is considered an unlimited resource, freshwater only represents 2.5% of all water resources, with 70% being in the form of glaciers and permanent ice (Thornton et al., 2009). Given that climate change concerns continue to influence policy, adequate monitoring of the environmental footprints of livestock production systems is crucial to accurately quantify the use of natural resources, namely freshwater. Environmental changes, such as water salination, increase in chemical contaminants, and warming climate, will be highly detrimental to any production system, as they will reduce availability to freshwater resources (Nardone et al., 2010). A new focus for the livestock industry will involve their efficiency and use of freshwater resources. Water scarcity and worsening quality of available water sources will require livestock producers to investigate more sustainable production systems and the selection of animals with increased efficiency for both feed and water.

Studies have yet to be conducted on beef cattle examining the factors affecting drinking water intake (DWI) and the efficiency of water use (Ahlberg et al., 2019). According to Wagner and Engle (2021), providing cattle ad libitum access to clean freshwater is imperative to optimize animal health and production efficiency. Moreover, studies have yet to understand how carryover effects from the previous plane of nutrition might affect water efficiency at a later stage. Historically, the beef industry has been highly segmented and operated independently according to the developmental phase of the animal (Drouillard and Kuhl, 1999). However, profitability of each production system is greatly impacted by the interaction with previous segments due to carryover effects of nutrition and management employed during earlier stages of life (Greenwood et al., 2005).

Understanding the relationship between drinking water intake (DWI) and nutritional management during backgrounding is essential for promoting sustainability, improving production efficiency, and ensuring accountability across different sectors of the beef industry. We hypothesize that a moderate plane of nutrition during the backgrounding phase can enhance growth, leading to improved water use efficiency, dry matter intake (DMI), and overall performance in finishing steers. This study aimed to evaluate the effects of backgrounding diets with differing planes of nutrition on DWI, animal performance, and the water and feed efficiency of steers subsequently finished on either grain- or forage-based diets.

MATERIALS AND METHODS

All experimental and animal husbandry procedures conducted were approved by the Institutional Animal Care and Use Committee of the University of Nevada, Reno, NV (protocol #00845).

Experimental Design, Treatments, and Animals

Twenty-four crossbred Angus steers (298 ± 10.2 kg) were housed in two shaded pens at the research feedlot area of the Main Station Field Laboratory at the University of Nevada, Reno. Each pen was equipped with twelve individual Calan gate feeding systems (American Calan, Nothwood, NH) for individual measurement of DMI and four electronic water troughs (Intergado Ltd., Contagem, MG, Brazil) coupled with automatic scale platforms for individual measures of DWI and body weight (BW). The experimental trial lasted 220 d, consisting of two phases: backgrounding (April through June) and finishing (July through November). During the backgrounding phase (85 d), animals were randomly assigned to one of the two treatments (n = 12 per treatment): moderate plane of nutrition (**MP**; 100% Triticale hay) or high plane of nutrition (**HP**; 85% alfalfa hay and 15% beardless wheat hay; Table 1). Following the backgrounding phase, steers were restrictedly-randomized by the previous plane of nutrition (finishing treatments had 50% of animals of each backgrounding) and transitioned to the finishing phase for a 30-d adaptation period. Then, animals were fed to the endpoint for 105-d. The diets were designed to mimic two commonly finishing systems, a forage-fed which consisted of high-quality alfalfa hay only (forage-fed, n = 12), and a grain-fed (80% whole corn grain and 20% alfalfa hay, n = 12; Table 1).

All animals had ad libitum access to water and a balanced mineral mix (Table 1) throughout the experimental period. Steers were fed once during the backgrounding phase at 0800 h, and twice during the finishing phase at 0700 h and 1700 h. Refusals were collected daily before morning feeding and weighed. Feed intake was adjusted daily to ensure up to 10% of refusals.

Water Intake System and Behavior

Before the beginning of the experiment, each animal was fitted with a plastic radio-frequency identification tag (RFID FDX-ISO 11784/11785; Allflex, 104 Joinville, Santa Catarina, Brazil) in the left ear. For each visit to the water trough, the system recorded the number of visits per day, visit duration, time, DWI, and BW of the individual animals by recording the animal's identification tag and bin number. Thus, drinking water behavior data were recorded as the average time spent drinking (min/d), drinking rate as the average daily liters of water drunk per minute (L/min), and the average number of drinking events per day was determined by the frequency of visits to the water troughs. All data were continuously recorded and transferred to the cloud and retrieved for DWI, BW and drinking behavior. The water bins (0.30 × 0.37 × 0.20 m) were programmed to maintain the water temperature at 25 °C and were automatically and continuously filled to a volume of 115 liter after the animals left the weighing platforms. Only one animal was allowed at a time to each individual water trough. A complete description and evaluation of the water system can be found in Oliveira et al. (2018). Each water trough was manually cleaned and disinfected biweekly or as needed to ensure free access to fresh water. Both BW and DWI platforms were calibrated weekly with company-manufactured weights to ensure data accuracy.

Water Quality Analysis

Water samples were collected monthly throughout the experimental trial, and a composite sample was shipped for chemical analysis at the Cumberland Valley Analytical Services (CVAS;

Table 1. Ingredient and nutrient composition of the backgrounding and finishing phases for crossbred Angus steers fed a moderate (n = 12) or a high plane (n = 12) of nutrition

Item	Backgrounding		Finishing	
	Moderate (MP)	High (HP)	Forage	Grain
Ingredient, % of dry matter				
Alfalfa hay (21% CP)	–	85	100	–
Alfalfa hay (16% CP)			–	20
Beardless wheat hay	–	15		–
Triticale hay	100	–		–
Corn grain, whole			20	80
Mineral Mix[a]	Ad libitum		Ad libitum	
Chemical analysis[b], % of dry matter				
Dry matter, % as-is	93.70	93.88	94.00	90.28
Organic matter	90.28	92.38	96.44	90.80
Crude protein	9.10	12.62	21.3	10.80
Soluble protein	4.80	5.78	8.20	3.50
Soluble protein, % CP	52.80	45.62	38.4	30.46
Rumen degradable protein	7.00	9.20	14.7	5.07
Rumen degradable protein, % CP	76.40	72.81	69.2	41.82
Acid detergent fiber	29.28	39.97	26.2	11.02
NDICP	1.28	1.52	1.93	0.746
aNDFom	47.78	46.92	32.2	17.12
apNDFom	46.50	45.40	30.27	16.37
Lignin	4.07	6.91	5.72	3.176
Sugar	12.80	7.46	9.5	3.26
Starch	0.40	0.98	2.2	56.92
Ash	9.72	7.62	9.2	3.56
Ca	0.35	1.20	1.82	0.34
P	0.19	0.21	0.19	0.28
Mg	0.15	0.32	0.32	0.16
K	1.41	1.49	1.62	0.75
Na	0.08	0.16	0.2	0.09
Fe, ppm	297	112	387	1283
Mn, ppm	35.0	27.3	47.0	33.4
Zn, ppm	22.0	21.4	34.0	1107.2
Cu, ppm	11.00	11.55	13.00	9.60
Total digestible nutrients	53.00	57.59	64.80	80.52
Net energy for maintenance, Mcal/kg	1.07	1.23	1.47	1.96
Net energy for gain, Mcal/kg	0.52	0.66	0.88	1.31
Non-fiber carbohydrates	25.99	30.40	36.6	65.12

[a]Mineral mix composition: 18% Ca, 6% P, 18% NaCl, 4% Mg, 0.5% K, 0.36% Mn, 0.36% Zn, 0.12% Cu, 6 ppm I, 27 ppm Se, 12 ppm Co.
[b]NDICP: Neutral detergent insoluble crude protein; aNDFom: Neutral detergent fiber (NDF) assayed with a heat stable amylase and expressed exclusive of residual ash; apNDFom: NDF assayed with a heat stable amylase and expressed exclusive of residual ash and protein.

Waynesboro, PA). The chemical analysis performed followed the recommendations of Rice et al (2017) for pH (method # 4500-H), nitrate (method #4500 NO3-), total dissolved solids (method # 2540), sulfates (method # 4500-SO42), minerals (Ca, P, Mg, Na, I, Mn, Zn, Cu; method #3500), carbonate hardness (method #2340), and total coliform and *E. coli* (method #9223). The results of the chemical analysis of the water are described by Macias-Franco et al. (2021).

Feedstuff Chemical Analysis

Feed samples were collected weekly for bromatological analysis. Feedstuffs were composited into one representative sample for each experimental phase, and a 200 g subsample was shipped to Cumberland Valley Analytical Services (CVAS; Waynesboro, PA). The samples were analyzed for dry matter (**DM**; method #930.15 AOAC, 2000), crude protein (**CP**; method # 990.03; AOAC, 2000), soluble protein (Krishnamoorthy et al., 1982), rumen degradable protein (**RDP**; Krishnamoorthy et al., 1983), acid detergent fiber (**ADF**; method # 973.18; AOAC, 2000), acid detergent insoluble CP using ADF residue in a Leco FP-528 Nitrogen Combustion Analyzer (Leco Corporation, St. Joseph, MO), neutral detergent fiber (**NDF**; Van Soest et al., 1991) corrected for protein (Leco Corporation, St. Joseph, MO) and ash (**apNDFom**; method # 942.05; AOAC, 2000), lignin (Goering and Van Soest, 1970), sugar (Dubois et al., 1956), starch (Hall, 2009), crude ash (method # 942.05; AOAC, 2000) and a complete mineral panel (method# 985.01; AOAC, 2000) in a Perkin Elmer 5300 DV ICP (Perkin Elmer, Shelton, CT). Values for total digestible nutrients were calculated according to Weiss (1998), while net energy values were derived from the empirical equations recommended by NASEM (2016), based on the NRC (1984) equations.

Efficiency and Performance Traits

Performance and biometric measures (**BM**) were taken throughout the experimental trial. On days 0, 28, 56, and 85 of the backgrounding, and on days 0, 28, 56, 84, and 105 of the finishing phases. Body weights were obtained automatically daily and regressed to obtain the estimate for the average daily gain (**ADG**) discounting differences in rumen fill. The feed efficiency (**FE**) and gross water efficiency (**GWE**; Pereira et al., 2021) were estimated as the ratio of average ADG to DMI and ADG to average DWI, respectively.

Residual drinking water (**RDWI**) and feed (**RFI**) intake were calculated as the difference between observed and predicted DMI, and DWI required to meet net energy requirements for maintenance and growth (Koch et al., 1963). Predicted DMI and DWI were estimated as a function of ADG and mid-point metabolic BW (MidBW0.75) using the following model recommended by Koch et al. (1963):

$$RFI; RDWI = Y_{12} = \beta_0 + \beta_1 \times MidBW^{0.75} + \beta_2 \times ADG + \varepsilon_{12}$$

Where Y represents the expected values for DMI and DWI measures to be regressed, β_0 represents the intercept, β_1 represents the partial regression coefficient of $MidBW^{0.75}$, β_2 represents the partial regression coefficient for ADG, and ε is the respective residuals for the adjusted model.

Additionally, RDWI was also estimated as a function of observed DMI (**RDWI$_{DMI}$**). Expected DWI based on DMI was estimated as the regression of observed DMI and $MidBW^{0.75}$ using the following model recommended by Ahlberg et al. (2019):

$$RDWI_{DMI} = Y_{12} = \beta_0 + \beta_1 \times MidBW^{0.75} + \beta_2 \times DMI + \varepsilon_{12}$$

Where Y represents the expected values for DWI based on observed DMI to be regressed, β_0 represents the intercept, β_1 represents the partial regression coefficient of $MidBW^{0.75}$, β_2 represents the partial regression coefficient of DMI, and ε is the respective residuals.

For BM, animals were normally positioned in a squeeze chute, and the same trained technician was responsible for taking the BM using anatomical locations as reference points. The measurement points were determined by palpation as described by Fonseca et al. (2017) and were taken with the aid of a large caliper (Hipometro type Bengala with 2 bars, Walmur, Porto Alegre, Brazil) and a graduated plastic flexible tape. The BM included hook bone width (**HBW**) as the distance between the two ventral points of the tuber coxae (large calipers); pin bone width as the distance between the two ventral tuberosities of the tuber ischia (large calipers); abdominal width (**AW**) measured as the widest horizontal width of the abdomen (paunch) at right angles to the body axis (large calipers); body length (**BL**) as the distance between the dorsal point of the scapulae and the ventral point of the tuber coxae (tape); rump height as measured from the ventral point of the tuber coxae, vertically to the ground (large calipers); scapula as the measure from the humeroscapular joint to the end of the scapula; height at withers measured from the highest point over the scapulae, vertically to the ground (large calipers); pelvic girdle length as the distance between the ventral point of the tuber coxae and the ventral tuberosity of the tuber ischii (large calipers); rib depth (**RD**) measured vertically from the highest point over the scapulae to the end point of the rib, at the sternum (large calipers); rump depth measured as the vertical distance between the ventral point of the tuber coxae and the ventral line (large calipers); body diagonal length measured as the distance between the ventral projection of the tuber coxae and the cranial point of shoulder (tape); and thorax width (**TW**) as the widest horizontal width across shoulder region, at the back (large calipers). On those same days, visual assessments of body condition score (**BCS**) were also performed only during the finishing phase.

Slaughter

Once the animals reached an average of 560 kg, all steers were transported approximately 600 km to a USDA inspected commercial abattoir (CS Beef Packers, Kuna, Idaho), where all the animals were slaughtered by trained technicians stunning the animals using a penetrating captive bolt rendering the animal unconscious, followed by exsanguination through the jugular vein. Hot carcass weight (**HCW**) was obtained immediately after evisceration, and dressing percentage was obtained by dividing HCW by final BW. All carcasses were chilled for 24 h, and qualified personnel measured longissimus dorsi area via direct grid reading between the 12th and 13th rib, and USDA marbling score (**MS**) and yield grades (USDA, 1997).

Statistical Analysis

Prior to the trial, we performed a power analysis based on a previous database's variability around the mean for the variables analyzed herein. Upon completion of the trial, the observed was used for a second power analysis to guarantee that the number of experimental units would be able to depict significant differences when existed. Based on the error variance of our data, assuming a power of 95%, with 6 experimental units we would be able to detect differences in DMI at 160 g/d and WI at 270 mL/d. The average difference in DMI and DWI at backgrounding was 2.12 kg/d and 2.09 liters/d, respectively (or 13.25 and 7.74-fold of the threshold for detecting significant differences). The average difference in DMI and DWI at finishing was 1.93 kg/d and 28.06 liters/d (12.06 and 103.93-fold of the threshold for detecting significant differences).

Then, data were analyzed as linear mixed models using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC) adopting a $P \le 0.05$ as significant and $0.05 < P \le 0.10$ as tendencies. The data collection followed a 2×2 factorial arrangement of treatments with backgrounding as previous plane of nutrition (moderate or high) and finishing (forage or grain-finished) as the following phase:

$$Y_{ijk} = \mu + B_i + F_j + (BF)_{ij} + \varepsilon_{ijk}$$

Where Y_{ij} is the k-th response that received the i-th level of factor B and the j-th level of factor F; μ is a constant (average)

Table 2. Interaction or individual effect of backgrounding nutritional plane phase [moderate (MP) or high nutritional plane (HP)] and subsequently finished on grain or forage-fed finishing nutritional plane on nutrient intake of crossbred Angus steers

Daily intake, kg/d[a]	Backgrounded Plane (BP)		Finishing Plane (FP)		SEM[b]	*P*-value[c]		
	Moderate	High	Grain-fed	Forage-fed		BP	FP	BP × FP
Dry matter	7.58	9.70	10.98	12.91	0.331	<0.0001	0.0005	0.5617
Organic matter	6.84	8.97	10.60	11.73	0.318	<0.0001	0.0207	0.5728
Crude protein	0.69	1.22	1.19	2.75	0.040	<0.0001	<0.0001	0.4267
RDP	0.53	0.89	0.56	1.90	0.022	<0.0001	<0.0001	0.3577
ADF	2.22	3.88	1.21	3.38	0.044	<0.0001	<0.0001	0.3911
apNDFom	3.52	4.41	1.80	3.91	0.060	<0.0001	<0.0001	0.4397
Lignin	0.31	0.67	0.35	0.74	0.012	<0.0001	<0.0001	0.4450
Sugar	0.97	0.72	0.36	1.23	0.014	<0.0001	<0.0001	0.3569
Starch	0.03	0.09	6.26	0.28	0.180	<0.0001	<0.0001	0.7795
NFC	1.97	2.95	7.16	4.73	0.209	<0.0001	<0.0001	0.6512
TDN	4.02	5.59	8.85	8.37	0.262	<0.0001	0.2119	0.5995
NEm, Mcal/d	4.24	5.44	21.52	18.95	0.837	<0.0001	0.0450	0.6056
NEg, Mcal/d	1.74	2.23	14.40	11.35	0.210	<0.0001	0.0020	0.6160
Ca, g/d	22.45	31.42	29.95	30.21	0.213	<0.0001	0.4046	0.2929
P, g/d	8.04	8.67	13.68	4.69	0.093	<0.0001	<0.0001	0.6297
Mg, g/d	5.54	7.48	4.80	5.62	0.062	<0.0001	<0.0001	0.4337
K, g/d	11.24	15.00	15.12	21.11	0.290	<0.0001	<0.0001	0.4111
Na, g/d	8.40	9.38	4.36	5.22	0.035	<0.0001	<0.0001	0.4078
Fe, g/d	0.22	0.11	1.59	0.50	0.041	<0.0001	<0.0001	0.7125
Mn, g/d	0.42	0.42	0.21	0.19	0.001	0.9867	<0.0001	0.4954
Zn, g/d	0.42	0.41	1.39	0.18	0.035	<0.0001	<0.0001	0.7816
Cu, g/d	0.15	0.14	0.07	0.06	0.001	<0.0001	<0.0001	0.5032

[a]Intake is expressed as kg/d unless otherwise specified; RDP: Rumen degradable protein; ADF: Acid detergent fiber; apNDFom: neutral detergent fiber assayed with a heat-stable amylase and expressed exclusive of residual ash and protein; NEm: Net energy maintenance; NEgain: Net energy gain.
[b]SEM: Standard error of the mean of the full model.
[c]*P*-value: < 0.1 = trend; < 0.05 = significant comparing backgrounded nutritional plane (BP), finishing nutritional plane (FP), and interaction between BP and FP.

common to all observations; B_i is the effect of the $_i$-th level of factor B with $_i$ = (moderate and high plane); F_j is the effect of the $_j$-th level of factor F with $_j$ = (grain and forage-fed); BF_{ij} is the effect of the interaction of the i-th level of factor α with the effect of the j– I same level of factor β; εijk is the experimental error associated with the observation y_{ijk} with k = 1,…,r.

Data collection days were considered repeated measures. For the finishing phase, data were analyzed following a randomized complete block design, where the previous treatment is considered the block. Identification of outliers and influential points was performed by plotting the studentized residuals against the predicted values as well as by Cook's distance. Coefficients exceeding 2.5 studentized t distributions were considered outliers and removed from the data (Neter et al., 2004). Mean comparisons were computed using the LSMEANS statement and compared using Tukey-Kramer adjustment. Data from different time points were included as repeated measures in the statistical model, where day was considered the repeated variable. The fixed effect of time and its interactions with treatments was analyzed using the covariance structure that yielded the lowest Bayesian Information Criteria. Plots of effect of previous plane of nutrition data were analyzed using ggplot2 from the Tidyverse package in R version 4.1.2. (R Development Core Team, Vienna, Austria).

RESULTS

Intake of Water and Nutrients

There was no interaction between the effects of the previous plane of nutrition [(moderate (MP) or high (HP)] and finishing diets (forage or grain-fed) for both water and nutrient intake, behavior variables, performance and feed and water efficiency. Hence, the factors were presented separately ($P < 0.05$).

No effects in the previous plane of nutrition were observed on nutrient intake from the feed of the animals ($P > 0.05$). Intake of nutrients during the background phase (Table 2) was greater for animals fed HP ($P < 0.0001$), except for sugars, Fe, Zn, and Cu, which were greater for the MP diet ($P < 0.0001$). Regarding the concentration of energy available for maintenance and gain, intake was also greater for the HP diet ($P < 0.0001$). For the finishing phase, DMI differed between treatments ($P = 0.0053$), with forage-fed animals presenting the greatest DMI. Forage-fed animals had a higher intake of organic matter (OM), CP, RDP, ADF, apNDFom, lignin, sugars, Mg, K and Na ($P < 0.0001$). However, the intake of net energy for maintenance ($P = 0.0171$) and gain ($P = 0.0002$) was higher for the grain-fed animals.

Water intake during the backgrounding phase (Table 3) when corrected for DMI ($P = 0.0010$), CP intake (**CPi**; $P < 0.0001$) and RDP intake ($P < 0.0001$) animals was higher on the MP treatment when compared to HP treatment. When ADG was corrected by DWI, animals from HP treatment also had higher gains ($P < 0.0001$). Although MP animals drank more water, they spent less time drinking water ($P = 0.0054$) and visited less water troughs ($P = 0.0185$). For the finishing phase, DWI was higher for the forage-fed treatment ($P < 0.0001$), even when corrected for DMI ($P < 0.0001$). However, when corrected for CPi ($P < 0.0001$), the water intake was greater for animals fed a grain-based diet compared with forage fed animals. Furthermore, it was observed that forage-fed animals visited more water troughs ($P = 0.0016$) and had a higher DWI rate ($P = 0.0115$) and time spent DWI ($P = 0.0016$) compared to grain-fed animals. Interestingly, no effect was observed for nutrient intake from the diet, although the previous plane of nutrition affected the DWI during the finishing phase when corrected for hot carcass weight (HCW; $P = 0.0294$), DMI ($P = 0.0375$), and tended to influence DWI corrected for CPi ($P = 0.0581$). When BW ($P < 0.0001$) was corrected for DWI, forage-fed animals had higher BW when compared to grain-fed animals. However, when ADG was corrected for DWI ($P < 0.0001$), the opposite was observed.

Performance, Efficiency, and Biometric Measurements

Regarding performance and efficiency among treatments during the background phase (Table 4), animals on the HP treatment had higher final BW ($P = 0.0071$), final MidBW ($P = 0.0074$), ADG ($P < 0.0001$), RFI ($P = 0.0408$), and GWE ($P < 0.0001$). High plane animals had the highest FE ($P = 0.0463$). For the finishing phase (Table 4), the only differences observed were related to efficiency traits, where grain-fed animals were more efficient for RFI ($P = 0.0007$), RDWI ($P < 0.0001$), $RDWI_{DMI}$ ($P = 0.0062$), and GWE ($P < 0.0001$). The previous plane of nutrition only showed effects on the initial BW ($P = 0.0116$) and $MidBW^{0.75}$ ($P = 0.0169$), where animals backgrounded on the HP treatment and finished on a grain-fed diet were the heaviest in the beginning, but as animals reached the midpoint of the trial, only animals coming from a moderate plane of nutrition and finished on grain had the lightest weight. Regarding the carcass data, there was only a difference for the MS ($P = 0.0005$), where animals in the grain-fed treatment had a higher score when compared to the forage fed animals. The previous plane of nutrition also affected the MS ($P = 0.0013$), where animals fed HP followed by grain-fed diets had the highest score among all the treatments.

Biometric measurements for the backgrounding phase (Table 5) only differed for the HBW ($P = 0.0426$), TW ($P = 0.0193$) and scapula ($P = 0.0163$); where animals on the HP treatment had larger HBW and TW, but smaller scapula when compared to the animals on MP treatment. For the finishing phase, AW ($P = 0.0373$), BL ($P = 0.0372$) and diagonal ($P = 0.0365$) were the only variables that were different among treatments, where grain-fed animals were larger than forage-fed animals. The previous plane of nutrition affected BCS ($P = 0.0038$) and RD ($P = 0.0171$) of animals, where animals fed HP followed by grain-based diets had the highest values.

Interaction and breakdown effect of the previous nutrition plane on the finishing nutritional plane, depending on the diet and the number of days in the finishing phase on the ADG, final body weight gain, DMI, CPI, and DWI are presented in Table 6. In the first 20 d of the finishing period, the previous plane affected the variables ADG, DMI, CPI, and tended to affect DWI (as kg DMI and CP) in the finishing plane (Table 6). For the other periods (40, 60, 80, and 100 d), the previous nutrition plane did not influence the animals at the finishing phase.

For the first 20 d of the finishing phase, there was a strong positive correlation (0.9) between DWI and CPi of cattle (Figure 1). This correction remained at 40 d and reduced a little (0.8) between 60 and 100 d of termination. The correlation between DWI and ADG was negative for all finishing periods and reduced (0.5 to 0.3) as the finishing period advanced. In other words, DWI reduced as the crossbred Angus steers gained more weight. There was also a medium-high negative correlation (0.6) between DMI and DWI (/g CPI) in all termination periods.

Table 3. Interaction or individual effect of backgrounding nutritional plane phase [moderate (MP) or high nutritional plane (HP)] and subsequently finished on grain or forage-fed finishing nutritional plane on drinking water intake and behavior of crossbred Angus steers

Variables[a]	Backgrounded Plane (BP)		Finishing Plane (FP)		SEM[b]	*P*-value[c]		
	Moderate	High	Grain-Fed	Forage-Fed		BP	FP	BP × FP
DWI, kg	36.53	38.62	39.75	67.81	2.158	0.2583	<0.0001	0.5985
DWI, kg DMI	4.82	4.00	3.60	5.24	0.125	0.0010	<0.0001	0.7984
DWI, kg CPi	53.03	31.74	33.40	24.63	0.935	<0.0001	<0.0001	0.6642
Time DWI, min/d	16.58	21.00	34.42	45.17	2.842	0.0054	0.0146	0.5018
DWI rate, liters/min	2.23	1.92	1.20	1.55	0.089	0.0115	0.0115	0.6702
Water trough visits, events/d	5	6	5	6	0.276	0.0016	0.0016	0.4502
DWI, g CCW	–	–	127.70	223.60	7.137	–	<0.0001	0.5042
BW, kg DWI	9.18	9.17	13.70	7.57	0.581	0.9851	<0.0001	0.0708
$BW^{0.75}$, kg DWI	2.15	2.12	2.47	2.07	0.228	0.7380	0.3255	0.6802
ADG, g DWI	22.72	32.26	22.54	37.77	1.690	<0.0001	<0.0001	0.9280

[a]DWI: drinking water intake; BW: body weight; $BW^{0.75}$: metabolic body weight; CCW: hot carcass weight; ADG: average daily gain; DMI: dry matter intake; CPi: crude protein intake; RDPi: Rumen degradable protein intake.
[b]SEM: Standard error of the mean of the full model.
[c]*P*-value: < 0.1 = trend; < 0.05 = significant comparing backgrounded nutritional plane (BP), finishing nutritional plane (FP), and interaction between BP and FP.

Table 4. Interaction or individual effect of backgrounding nutritional plane phase [moderate (MP) or high nutritional plane (HP)] and subsequently finished on grain or forage-fed finishing nutritional plane on performance, carcass traits, and feed and water efficiency of crossbred Angus steers

Variables[a]	Backgrounded Plane (BP)		Finishing Plane (FP)		SEM[b]	*P*-value[c]		
	Moderate	High	Grain-fed	Forage-fed		BP	FP	BP × FP
Initial BW, kg	293.84	302.19	385.94	383.60	10.79	0.5673	0.8796	0.7289
Final BW, kg	362.81	405.97	569.95	572.11	8.970	0.0071	0.8669	0.4324
Final BW, kg $BW^{0.75}$	83.05	90.39	116.61	116.95	1.376	0.0084	0.8658	0.4379
Average daily gain, kg	0.821	1.235	1.786	1.830	0.0842	<0.0001	0.7179	0.6998
Midpoint BW, kg $BW^{0.75}$	77.39	81.34	107.23	108.07	1.468	0.1525	0.6927	0.3394
Feed efficiency	0.11	0.13	0.11	0.10	0.009	0.0463	0.2977	0.0787
Residual feed intake	−0.36	0.36	−0.79	0.79	0.281	0.0408	0.0007	0.6377
Residual DWI	0.08	−0.08	−13.30	13.30	2.355	0.9265	<0.0001	0.6234
Residual DWI (as DMI)	0.33	−0.33	−4.72	4.72	2.179	0.6955	0.0062	0.9404
Gross water efficiency	0.023	0.032	0.046	0.027	0.002	<0.0001	<0.0001	0.9242
Hot carcass weight, kg	–	–	312.89	304.01	6.249	–	0.3269	0.7454
Dressing percentage, %	–	–	54.95	53.19	0.974	–	0.2181	0.7565
Rib eye area, cm^2	–	–	11.57	10.98	0.323	–	0.2097	0.9048
Marbling score[3]	–	–	457.16	367.79	15.21	–	0.0005	0.1099
Yield grade	–	–	3.05	3.07	0.070	–	0.8416	0.4467

[a]BW: body weight; $BW^{0.75}$: metabolic body weight; DWI: drinking water intake; DMI: dry matter intake; Feed efficiency: ratio of average daily gain to dry matter intake; Residual feed intake: difference between observed and predicted dry matter intake required to meet growth and maintenance energy requirements; Residual drinking water intake: difference between observed and predicted water intake required to meet growth and maintenance energy requirements; Gross water efficiency: ratio of average daily gain to average water intake; –: Animals from the first phase were not slaughtered.
[b]SEM: Standard error of the mean.
[c]*P*-value: < 0.1 = trend; < 0.05 = significant comparing backgrounded nutritional plane (BP), finishing nutritional plane (FP), and interaction between BP and FP.

Table 5. Interaction or individual effect of backgrounding nutritional plane phase [moderate (MP) or high nutritional plane (HP)] and subsequently finished on grain or forage-fed finishing nutritional plane on body weight, body condition score, and biometric measurements of crossbred Angus steers

Variables	Backgrounded Plane (BP)		Finishing Plane (FP)		SEM[a]	*P*-value[b]		
	Moderate	High	Grain-fed	Forage-fed		BP	FP	BP × FP
Body weight, kg	330.26	346.55	504.16	510.82	9.768	0.1048	0.6349	0.4871
Shrunk body weight, kg	317.05	335.56	484.00	490.39	9.38	0.1049	0.6350	0.4874
Body Condition Score, 1 to 9	5.5	6.0	6.12	6.09	0.146	0.0038	0.8732	0.1400
Girth circumference, cm	155.79	160.04	183.88	185.18	0.146	0.2038	0.8732	0.1329
Hook bone width, cm	37.02	38.61	44.39	44.60	0.520	0.0426	0.7822	0.8936
Pin bone width, cm	8.20	8.45	10.70	10.69	1.960	0.2239	0.6463	0.2355
Pelvic girdle length, cm	39.04	39.65	44.20	43.90	0.109	0.1101	0.9153	0.5424
Rump depth, cm	56.44	57.15	63.26	62.16	0.445	0.2494	0.6296	0.3931
Rib depth, cm	56.30	57.96	65.23	64.20	0.689	0.0101	0.2690	0.9396
Thorax width, cm	33.34	35.69	43.73	43.17	0.614	0.0606	0.2479	0.1674
Abdomen width, cm	47.31	46.29	59.19	56.90	0.705	0.0909	0.5815	0.0639
Scapula, cm	33.26	29.79	34.99	34.66	0.727	0.3150	0.0373	0.6953
Rump height, cm	121.38	123.01	131.63	129.55	0.453	0.3820	0.6173	0.8926
Height at withers, cm	115.01	114.00	126.05	123.18	0.877	0.2685	0.1225	0.6883
Body length, cm	55.96	57.31	65.46	62.39	1.044	0.1344	0.0665	0.2188
Diagonal, cm	93.56	93.84	104.13	101.40	0.974	0.0811	0.0372	0.1435

[a]SEM: Standard error of the mean of the full model.
[b]*P*-value: < 0.1 = trend; < 0.05 = significant comparing backgrounded nutritional plane (BP), finishing nutritional plane (FP), and interaction between BP and FP.

DISCUSSION

A positive correlation between DMI and DWI has previously been observed regardless of the diet (Meyer et al., 2004; Kume et al., 2010). However, this might not apply to all feeding systems. In this study, even though MP steers have presented lower DMI, they still have the same or higher DWI—when corrected for DMI and CPi—when compared to HP, which might be associated with the composition of the ingested

Table 6. Interaction or individual effect of backgrounding nutritional plane phase [moderate (MP) or high nutritional plane (HP)] and subsequently finished on grain or forage-fed finishing nutritional plane on performance, dry matter and drinking water intake (DWI) of crossbred Angus steers depending on the number of days in the finishing phase

Variables[a]	Finishing Plane		SEM[b]	P-value[c]		
	Grain	Forage		BP	FP	BP × FP
100 d of Finishing Nutrition Plane						
Final body weight, kg	565.82	543.29	9.700	0.0183	0.1162	0.3616
Average daily gain, kg	1.59	1.21	0.084	0.2899	0.0051	0.2890
Dry matter intake, kg	12.43	13.81	0.288	0.3835	0.0030	0.4047
Crude protein intake, kg	1.33	2.91	0.037	0.4739	<0.0001	0.5166
Drinking water intake, kg	40.91	69.19	2.213	0.1115	<0.0001	0.5142
Drinking water intake, kg DMI	3.55	5.11	0.131	0.0189	<0.0001	0.8574
Drinking water intake, kg CPi	32.84	23.98	0.993	0.0324	<0.0001	0.5537
Body weight, kg DWI	10.61	9.04	0.951	0.2911	0.2543	0.6901
Metabolic body weight, kg DWI	2.26	1.94	0.200	0.2691	0.2640	0.6993
Average daily gain, g DWI	39.28	17.64	1.895	0.9288	<0.0001	0.4545
80 d of Finishing Nutrition Plane						
Final body weight, kg	528.30	522.60	7.831	0.0054	0.6124	0.2857
Average daily gain, kg	1.51	1.25	0.168	0.5661	0.2972	0.5282
Dry matter intake, kg	11.84	13.72	0.348	0.3729	0.0010	0.2777
Crude protein intake, kg	1.26	2.89	0.045	0.5209	<0.0001	0.3363
Drinking water intake, kg	40.84	69.96	2.162	0.1614	<0.0001	0.4565
Drinking water intake, kg DMI	3.73	5.19	0.141	0.0368	<0.0001	0.9308
Drinking water intake, kg CPi	34.52	24.39	1.064	0.0496	<0.0001	0.4583
Body weight, kg DWI	12.02	6.85	0.465	0.0769	<0.0001	0.8621
Metabolic body weight, kg DWI	2.60	1.48	0.097	0.1360	<0.0001	0.9992
Average daily gain, g DWI	37.77	18.88	3.646	0.7339	0.0015	0.7339
60 d of Finishing Nutrition Plane						
Final body weight, kg	492.83	492.37	9.091	0.0131	0.9717	0.3646
Average daily gain, kg	1.43	1.17	0.095	0.2053	0.0759	0.1536
Dry matter intake, kg	11.14	13.47	0.313	0.1727	<0.0001	0.0857
Crude protein intake, kg	1.18	2.82	0.041	0.3523	<0.0001	0.1302
Drinking water intake, kg	39.03	69.62	1.876	0.2419	<0.0001	0.2550
Drinking water intake, kg DMI	3.86	5.26	0.144	0.0438	<0.0001	0.8530
Drinking water intake, kg CPi	35.73	24.71	1.120	0.0612	<0.0001	0.4336
Body weight, kg DWI	9.98	8.78	0.903	0.1931	0.3603	0.8386
Metabolic body weight, kg DWI	2.16	1.91	0.195	0.2089	0.3682	0.7625
Average daily gain, g DWI	37.13	16.94	2.463	0.5467	0.0001	0.5761
40 d of Finishing Nutrition Plane						
Final body weight, kg	454.57	467.08	10.164	0.0064	0.3945	0.4847
Average daily gain, kg	1.18	1.12	0.116	0.7786	0.7423	0.1317
Dry matter intake, kg	10.50	13.09	0.299	0.1082	<0.0001	0.1164
Crude protein intake, kg	1.13	2.79	0.045	0.2529	<0.0001	0.2760
Drinking water intake, kg	37.44	67.66	1.737	0.6334	<0.0001	0.3416
Drinking water intake, kg DMI	4.03	5.22	0.208	0.1037	<0.0001	0.5548
Drinking water intake, kg CPi	37.35	24.55	1.210	0.1233	<0.0001	0.3387
Body weight, kg DWI	9.98	8.78	0.903	0.1931	0.3603	0.8386
Metabolic body weight, kg DWI	2.18	1.94	0.200	0.1804	0.3981	0.8682
Average daily gain, g DWI	32.27	16.72	3.183	0.9836	0.0025	0.4255
20 d of Finishing Nutrition Plane						
Final body weight, kg	430.32	446.27	10.476	0.0047	0.2944	0.5030
Average daily gain, kg	1.16	1.21	0.161	0.7402	0.7853	0.0364
Dry matter intake, kg	10.86	12.56	0.379	0.0108	<0.0001	0.0097
Crude protein intake, kg	1.17	2.67	0.058	0.0650	<0.0001	0.0569

Table 6. Continued

Variables[a]	Finishing Plane		SEM[b]	*P*-value[c]		
	Grain	Forage		BP	FP	BP × FP
Drinking water intake, kg	38.95	65.66	1.644	0.8429	<0.0001	0.2899
Drinking water intake, kg DMI	4.18	5.30	0.179	0.0354	0.0003	0.0692
Drinking water intake, kg CPi	38.69	24.88	1.595	0.0257	<0.0001	0.0381
Body weight, kg DWI	9.64	8.45	0.793	0.1776	0.3023	0.8507
Metabolic body weight, kg DWI	2.11	1.87	0.175	0.1691	0.3439	0.8800
Average daily gain, g DWI	30.24	18.56	4.020	0.6095	0.0538	0.1228

[a]CCW: hot carcass weight, DMI: dry matter intake, CPi: crude protein intake.
[b]SEM: Standard error of the mean of the full model.
[c]*P*-value: < 0.1 = trend; < 0.05 = significant comparing backgrounded nutritional plane (BP), finishing nutritional plane (FP), and interaction between BP and FP.

feed. The forage provided for MP animals was bulkier and required more water for feed particle hydration. Furthermore, MP animals also visited less water troughs and spent less time drinking water, so they tended to drink water faster than HP animals. For most mammals, water is mostly consumed during or shortly before or after feeding events, and in rats, food-related drinking can account for almost 70% of the daily DWI (Kraly, 1983). For MP animals, the faster drinking rate might be associated with the lower DMI due to lower passage rate, caused by the lower CP content in the diet that potentially limited microbial growth (Köster et al., 1996), and consequently led to fewer feeding events, whereas animals on HP would eat more constantly during the day and visit the water troughs more often. This observation is potentially important for management of grazing animals in arid and semi-arid environments that must walk long distances in search of feed and water. Animals on low-quality feed would be willing to walk longer distances when compared to animals grazing a higher quality feed, since they would be drinking water more constantly throughout the day.

During the finishing phase, grain-fed steers presented a lower DMI compared to forage-fed animals, probably due to the higher concentration of energy in the diet. Voluntary intake of ruminants is mainly constrained by intake capacity of the rumen or by chemostatic mechanisms, where the animal only consumes enough DM to supply its physiological demand for energy (Montgomery and Baumgardt, 1965; Dulphy and Demarquilly, 1994). Water intake was the greatest for forage-fed steers, which goes back to the diet composition between treatments, where forage-fed animals did not only have a bulkier diet but also double CP content in the diet. Once the CP reaches the rumen, it is degraded into ruminal NH3-N, and whatever is in excess is converted into urinary and fecal nitrogen to be excreted out of their bodies (Xia et al., 2018). Although not analyzed in this study, we postulate that the increase of DWI of forage-fed animals is due to the high supply of CP through the diet, leading to an increase in urinary nitrogen excretion. However, none of the current equations for DWI prediction take into consideration the dietary levels of CP (Hicks et al., 1988; Meyer et al., 2006; Arias and Mader, 2011; Sexson et al., 2012; Ahlberg et al., 2018; Zanetti et al., 2019).

No carryover effect of feed intake during the previous phase was observed on the subsequent finishing phase. However, a carryover effect was observed for drinking DWI of animals during the backgrounding phase when DWI was corrected for HCW and DMI. In general, animals finished with a grain-fed diet drink less water than forage-fed animals, with the lowest DWI being observed for animals previously fed HP. This remark is of high significance. As freshwater sources continue to decrease, and the policy around them becomes more stringent, these animals could serve as a unique opportunity for producers to maintain production levels while utilizing less water (Cantonati et al., 2020).

According to Godde et al. (2021), the potential impacts of climate change on current livestock systems worldwide constitute a significant concern. However, the topic is covered to a limited extent in global reports such as the ones produced by the Intergovernmental Panel on Climate Change. The risks of climate-related impacts are highly context-specific but expected to be higher in already hot environments with limited socio-economic and institutional resources for adaptation. Diet choices for cattle aimed at lower water consumption could benefit public and natural resource use policies.

It is hypothesized that grass-fed production systems—equivalent to our forage-fed treatment—carry less environmental burden due to the absence of large and confined animal operations, intense use of grains in the diet, reduction in water usage and air pollution (Gwin, 2009); which has increased consumer interest in grass-fed beef often paid with a premium at the grocery store. However, this can vary significantly depending on region, resource availability, and forage quality. For example, Klopatek et al. (2022) compared the environmental impact of grass-fed beef for 20 and 25 months on a kg of HCW basis. According to her research, animals fed for 20 months used 2.7 times less water than animals fed for 25 months, mainly due to irrigation requirements due to decreased forage quality for the extra 5 months. With that, animals finished with 20 months could reduce their water footprint by 63%. In this current study, we show that forage quality can affect the environmental impact of forage-finished beef. When comparing forage-fed vs grain-fed animals, our data shows that forage-fed animals double their water requirements compared to grain-fed animals when their diet is associated with a higher CP intake. Furthermore, high CP intake can increase environmental impacts due to increased NH_3-N excretion. NH_3-N is volatized from animal waste, which is a major global air quality concern (Burgos et al., 2007; Dong et al., 2014).

According to Ahlberg et al. (2019), DWI has no genetic correlation with ADG, a moderate correlation with RFI, and a strong correlation with water efficiency measurements. Therefore, selecting animals by DWI should not inhibit the production or efficiency of steers in the feedlot. This

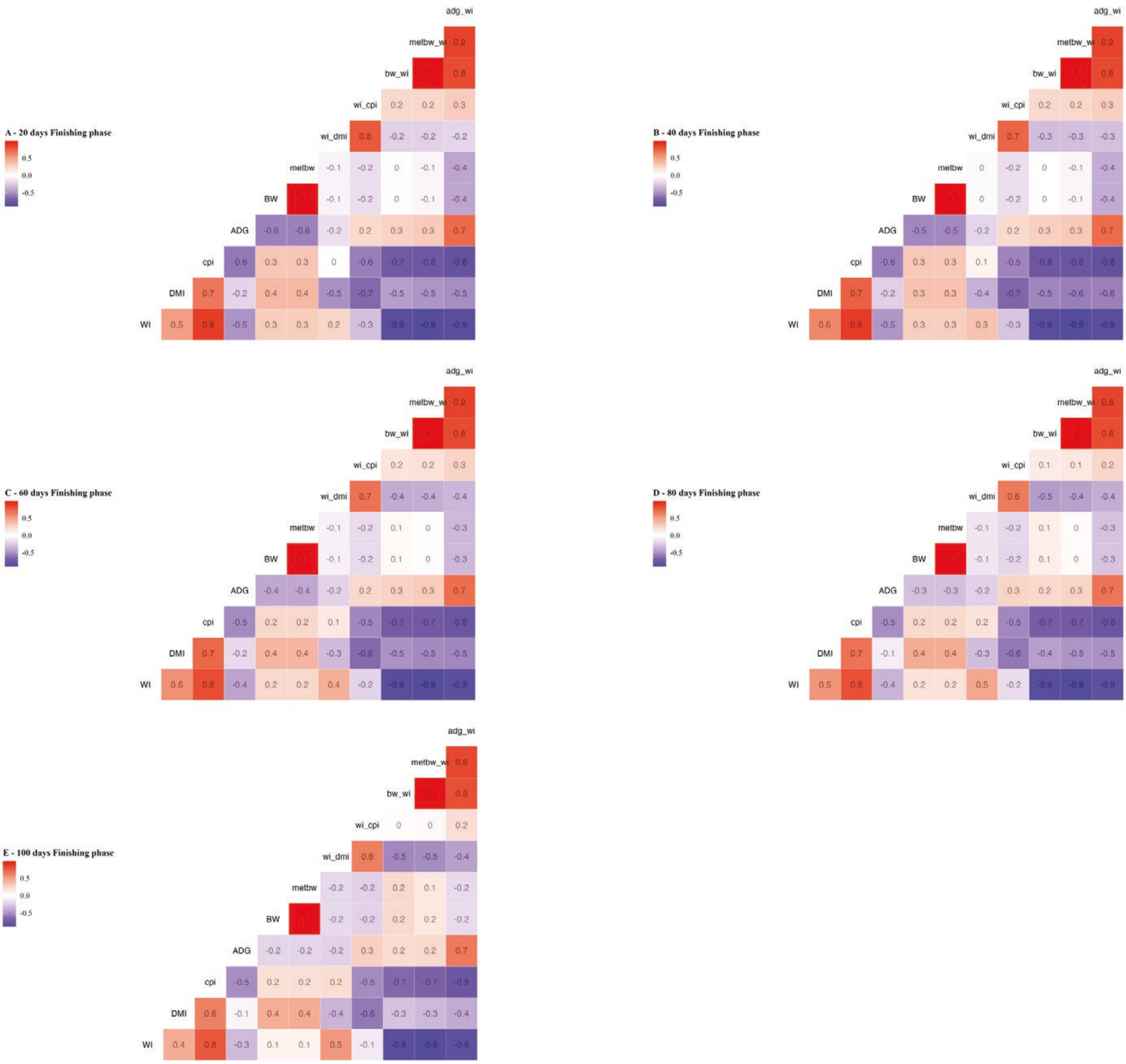

Figure 1. Heat graph demonstrating interaction between variables average daily gain (ADG), final body weight (BW), dry matter intake (DMI), crude protein intake (CPI), drinking water intake (WI), water intake as function of /kg DMI and /kg CPI, and body weight, metabolic body weight (METBW), and average daily in gain as function of /kg WI depending on the diet and the number of days (20, 40, 60, 80 and 100 d) of the finishing phase.

is important since cattle are usually sold after background priced on weight, so heavier steers often generate more revenue. Our results show that although animals from MP had a lower RFI, animals on HP had higher ADG, drank less water (when corrected for DMI and CPi), and were more water efficient based on GWE. On the other hand, even though no differences were observed on ADG, animals on grain-fed diets were more feed and water efficient than forage-fed animals. Therefore, selecting those animals based on lower DWI would be an excellent opportunity to sustainably reduce water utilization by cattle.

The inverse relationship between DMI and DWI/g CPI can be explained by the high concentration of CP in Alfalfa supplied in the finishing plane. The high concentration of CP in the diet during the finishing phase causes animals to reduce DMI to avoid energy losses in protein metabolism, mainly urinary losses. The ratio between CP dietary concentration, DMI, and DWI could be proven in the study by Silva et al. (2024). When the animals came from MP and finished with forage, the relative abundance of aquaporins in the kidney increased compared to animals fed a grain-based diet. The authors also explained that the previous nutritional plane could impact the expression of genes associated with water and urea metabolism during the finishing phase, confirming from aquaporins and UT-B in the rumen, with a more significant impact observed in changes in gene expressions investigated in the termination phase. According to Michalek (2016), among the crucial cellular components associated with water that can be altered by water stress are aquaporins, a specialized group of channels that facilitate the movement of water and small molecules between the cytosol and the cellular environment.

Carcass characteristics were similar between groups, except for MS. Beef with higher marbling produces higher sensory traits, including tenderness, juiciness, flavor, and overall acceptability of beef samples (Hunt et al., 2014). An increase in net energy intake is essential for depositing intramuscular fat in the carcass (Park et al., 2018). Interestingly, in this study, the only treatment that reached MS close to 460 were the animals that were backgrounded on an HP diet and subsequently finished on a grain-fed diet. In beef cattle, adipocytes in the visceral depot occur during the mid-fetal stage to early postnatal stage (Robelin, 1981); formation of subcutaneous adipocytes occurs between mid- to late fetal stage and the early weaning stage (Hood and Allen, 1973); and formation of intramuscular adipocytes (marbling) is estimated to happen at 250 d of age. As a result, there is a "marbling window" where the requirements of animals need to be supplied to enhance adipogenesis, and later adipocyte hypertrophy and high marbling (Du et al., 2013). In this study, all animals were between the "marbling window" during the backgrounding phase. Our results suggest that animals backgrounded on an HP diet and finished on a grain-fed diet had the highest MS score. Therefore, heavier animals at the end of the backgrounding phase will not only generate more revenue for the backgrounder but also for feedlot during finishing. Altogether, if paired with a lower DWI, they would allow a more sustainable and economically relevant selection tool for the beef cattle industry.

Although growth typically is measured as the change in live weight, BM is an important tool to help us understand how the growth pattern and tissue pools can change. In this study, during the backgrounding phase, the only detectable differences were between HBW, TW, and scapula treatments. HP animals had higher measurements for HBW and TW, and MP had higher values for scapula measurements. In the finishing phase, however, a previous plane of nutrition effect was only observed for RD, while a trend was noticed for TW, AW and body diagonal. In a study to access body fat composition through BM, Fonseca et al. (2017) observed that among the BM, HBW, RD, AW and TW were the variables with the highest positive correlations with body fat composition, indicating their importance on fat deposition. Furthermore, BCS can also be used to assess body reserves of animals as a predictor of fat deposition (Apple et al., 1999). According to the BCS obtained in our finishing phase, animals fed HP during backgrounding and finished with a grain-based diet reached the highest scores. Together with the MS data, we can observe how important the plane of nutrition is in the earlier stages of life to ensure adequate fat deposition of animals at later life stages. Furthermore, as body fat increases, body water decreases (Kraybill et al., 1952), decreasing the animal requirements for water. As previously mentioned, an effect of previous plane of nutrition was also observed for DWI of animals, which can indicate a decrease on water requirements of steers coming from a HP due to an increase in fat deposition in earlier stages of life.

Both background plans with HP and finishing nutrition plane with forage-fed promoted higher nutrient intake. However, in the background nutrition plane, the diets did not influence water intake. Furthermore, in the finished nutrition plane, cattle on forage-fed diets consumed more water than animals on grain-fed diets. As expected, animals with an HP background showed more accelerated growth than MP.

There was a compensatory gain in the finishing nutrition plane, confirmed by the residual feed and drinking water intake, and the cattle showed similar ADG. In the first 20 d of the finishing period, the previous plane affected the variables ADG, DMI, CPI, and tended to affect DWI (as kg DM and CP) in the finishing plane. This may have occurred because the nutritional plans of the previous period were not sufficiently different to allow for a greater incidence of the compensatory gain to occur up to 100 d after finishing.

This study highlights the importance of early-life nutritional management and finishing strategies on water intake, nutrient efficiency, and carcass characteristics in crossbred Angus steers. While backgrounding diets with higher planes of nutrition promoted accelerated growth and better water efficiency during the finishing phase, grain-fed diets further enhanced feed and water efficiency, ultimately improving carcass marbling scores. These findings are applicable to the development of strategic nutritional interventions to reduce water requirements and enhance the sustainability of beef production systems. The lack of significant interactions between backgrounding and finishing phases suggests that these effects operate independently and require further investigation to fully understand their combined implications and the correct point at which differences prevail. Future research should focus on elucidating the mechanisms driving water metabolism and nutrient utilization across production phases to optimize resource use and mitigate environmental impacts in livestock systems.

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Conflict of Interest Statement

The authors declare no perceived conflicts of interest

Author Contributions

Aghata Silva (Formal analysis, Investigation, Writing—original draft, Writing—review & editing), Arturo Macias-Franco (Formal analysis, Investigation), Felipe De Moura (Investigation), Aaron Norris (Methodology, Writing—review & editing), Kelli Noelle Bangert (Formal analysis, Investigation), Leilson Bezerra (Visualization, Writing—review & editing), Lucas Mota (Writing—review & editing), and Mozart Fonseca (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—review & editing)

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Literature Cited

Ahlberg, C. M., K. Allwardt, A. Broocks, K. Bruno, L. McPhillips, A. Taylor, C. R. Krehbiel, M. S. Calvo-Lorenzo, C. J. S. Richards, E. Place, et al. 2018. Environmental effects on water intake and water intake prediction in growing beef cattle. J. Anim. Sci. 96:4368–4384. doi:10.1093/jas/sky267

Ahlberg, C. M., K. Allwardt, A. Broocks, K. Bruno, A. Taylor, L. McPhillips, C. R. Krehbiel, M. Calvo-Lorenzo, C. J. Richards, S. E. Place, et al. 2019. Characterization of water intake and water efficiency in beef cattle. J. Anim. Sci. 97:4770–4782. doi:10.1093/jas/skz354

AOAC. 2000. Official methods of analysis. 17th ed. Arlington (VA): Association of Official Analytical Chemists.

Apple, J. K., J. C. Davis, J. Stephenson, J. E. Hawkins, J. R. Davis, and S. L. Beaty. 1999. Influence of body condition score on carcass characteristics and subprimal yield from cull beef cows. J. Anim. Sci. 77:2660–2669. doi:10.2527/1999.77102660x

Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. J. Anim. Sci. 89:245–251. doi:10.2527/jas.2010-3014

Barash, H., Y. Aharoni, A. Brosh, and Z. Holzer. 1998. Effects of low energy diets followed by a compensatory diet on body weight gain and plasma hormone concentrations in bull calves. J. Dairy Sci. 81:250–254. doi:10.3168/jds.S0022-0302(98)75573-0

Bezerra, L. R., R. L. Oliveira, S. Gonzaga Neto, J. L. R. Sarmento, N. R. O. Paula, and W. M. F. Rego. 2013. Residual feed intake: a nutritional tool for genetic improvement. Trop. Anim. Health Prod. 45:1649–1661. doi:10.1007/s11250-013-0435-y

Burgos, S. A., J. G. Fadel, and E. J. DePeters. 2007. Prediction of ammonia emission from dairy cattle manure based on milk urea nitrogen: relation of milk urea nitrogen to urine urea nitrogen excretion. J. Dairy Sci. 90:5499–5508. doi:10.3168/jds.2007-0299

Cantonati, M., S. Poikane, C. M. Pringle, L. E. Stevens, E. Turak, J. Heino, J. S. Richardson, R. Bolpagni, A. Borrini, N. Cid, et al. 2020. Characteristics, main impacts, and stewardship of natural and artificial freshwater environments: consequences for biodiversity conservation. Water 12:260. doi:10.3390/w12010260

Dong, R. L., G. Y. Zhao, L. L. Chai, and K. A. Beauchemin. 2014. Prediction of urinary and fecal nitrogen excretion by beef cattle. J. Anim. Sci. 92:4669–4681. doi:10.2527/jas.2014-8000

Drouillard, J. S., and G. L. Kuhl. 1999. Effects of previous grazing nutrition and management on feedlot performance of cattle. J. Anim. Sci. 77:136–146. doi:10.2527/1999.77suppl_2136x

Du, M., Y. Huang, A. K. Das, Q. Yang, M. S. Duarte, M. V. Dodson, and M. J. Zhu. 2013. Meat science and muscle biology symposium: manipulating mesenchymal progenitor cell differentiation to optimize performance and carcass value of beef cattle. J. Anim. Sci. 91:1419–1427. doi:10.2527/jas.2012-5670

Dubois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350–356. doi:10.1021/ac60111a017

Dulphy, J. P., and C. Demarquilly. 1994. The regulation and prediction of feed intake in ruminants in relation to feed characteristics. Livest. Prod. Sci. 39:1–12. doi:10.1016/0301-6226(94)90147-3

Fonseca, M. A., L. O. Tedeschi, S. C. Valadares Filho, N. F. De Paula, F. A. C. Villadiego, J. M. Silva Junior, D. C. Abreu, and M. L. Chizzotti. 2017. Assessment of body fat composition in crossbred Angus × Nellore using biometric measurements. J. Anim. Sci. 95:5584–5596. doi:10.2527/jas2017.1840

Godde, C. M., D. Mason-D'Croz, D. E. Mayberry, P. K. Thornton, and M. Herrero. 2021. Impacts of climate change on the livestock food supply chain; a review of the evidence. Glob. Food. Secur. 28:100488. doi:10.1016/j.gfs.2020.100488

Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). Agric. Handbook 379. Washington, DC: ARS, USDA.

Greenwood, P. L., L. M. Café, H. Hearnshaw, and D. W. Hennessy. 2005. Consequences of nutrition and growth retardation early in life for growth and composition of cattle and eating quality of beef. Proc. Recent Adv. Anim. Nutr. Aust. 15:183–195.

Gwin, L. 2009. Scaling-up sustainable livestock production: innovation and challenges for grass-fed beef in the U.S. J. Sustain. Agric. 33:189–209. doi:10.1080/10440040802660095

Hall, M. B. 2009. Analysis of starch, including maltooligosaccharides, in animal feeds: a comparison of methods and a recommended method for AOAC collaborative study. J. AOAC Int. 92:42–49. doi:10.1093/jaoac/92.1.42

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasia. 1988. Water intake by feedlot steers. Okla. Anim. Sci. Rep. MR 125:208.

Hood, R. L., and C. E. Allen. 1973. Cellularity of bovine adipose tissue. J. Lipid Res. 14:605–610. doi:10.1016/s0022-2275(20)36840-1

Hunt, M. R., A. J. Garmyn, T. G. O'Quinn, C. H. Corbin, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2014. Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. Meat Sci. 98:1–8. doi:10.1016/j.meatsci.2014.04.004

Klopatek, S. C., E. Marvinney, T. Duarte, A. Kendall, X. Yang, and J. W. Oltjen. 2022. Grass-fed vs. grain-fed beef systems: performance, economic, and environmental trade-offs. J. Anim. Sci. 100:skab374. doi:10.1093/jas/skab374

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486–494. doi:10.2527/jas1963.222486x

Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgadir, and G. St-Jean. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim. Sci. 74:2473–2481. doi:10.2527/1996.74102473x

Kraly, F. S. 1983. A probe for a histaminergic component of drinking in the rat. Physiol. Behav. 31:229–232. doi:10.1016/0031-9384(83)90124-5

Kraybill, H. F., H. L. Bitter, and O. G. Hankins. 1952. Body composition of cattle. II. Determination of fat and water content from measurement of body specific gravity. J. Appl. Physiol. 4:575–583. doi:10.1152/jappl.1952.4.7.575

Krishnamoorthy, U., T. V. Muscato, C. J. Sniffen, and P. J. Van Soest. 1982. Nitrogen fractions in selected feedstuffs. J. Dairy Sci. 65:217–225. doi:10.3168/jds.s0022-0302(82)82180-2

Krishnamoorthy, U., C. J. Sniffen, M. D. Stern, and P. J. Van Soest. 1983. Evaluation of a mathematical model of rumen digestion and an in vitro simulation of rumen proteolysis to estimate the rumen-undegraded nitrogen content of feedstuffs. Br. J. Nutr. 50:555–568. doi:10.1079/bjn19830127

Kume, S., K. Nonaka, T. Oshita, and T. Kozakai. 2010. Evaluation of drinking water intake, feed water intake and total water intake in dry and lactating cows fed silages. Livest. Sci. 128:46–51. doi:10.1016/j.livsci.2009.10.012

Macias-Franco, A., A. E. M. Silva, F. H. Moura, K. Van den Broek, M. Valcheck, A. B. Norris, A. S. de Mello, and M. A. Fonseca. 2021. Effects of lipid and starch supplementation as water intake mitigation techniques on performance and efficiency of nursing Holstein calves trans. Anim. Sci. 5:1–15. doi:10.1093/tas/txab103

Meyer, U., M. Everinghoff, D. Gädeken, and G. Flachowsky. 2004. Investigations on the water intake of lactating dairy cows. Livest. Prod. Sci. 90:117–121. doi:10.1016/j.livprodsci.2004.03.005

Meyer, U., W. Stahl, and G. Flachowsky. 2006. Investigations on the water intake of growing bulls. Livest. Sci. 103:186–191. doi:10.1016/j.livsci.2006.02.009

Michalek, K. 2016. Aquaglyceroporins in the kidney: present state of knowledge and prospects. J. Physiol. Pharmacol. 67:185–193.

Montgomery, M. J., and B. R. Baumgardt. 1965. Regulation of food intake in ruminants. 1. Pelleted rations varying in energy concentration. J. Dairy Sci. 48:569–574. doi:10.3168/jds.s0022-0302(65)88286-8

Nardone, A., B. Ronchi, M. S. Ranieri, and U. Bernabucci. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livest. Sci. 130:57–69. doi:10.1016/j.livsci.2010.02.011

National Academies of Sciences, Engineering, and Medicine (NASEM). 2016. Nutrient requirements of beef cattle. 8th rev. ed. Washington, DC: The National Academies Press.

National Research Council (NRC). 1984. Nutrient requirements of beef cattle. 6th rev. ed. Washington, DC: The National Academies Press.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Li. 2004. Applied linear regression models. 4th rev. ed. New York (NY): McGraw-Hill.

Oliveira, B., M. Ribas, F. Machado, J. Lima, L. Cavalcanti, M. Chizzotti, and S. Coelho. 2018. Validation of a system for monitoring individual feeding and drinking behaviour and intake in young cattle. Animal 12:634–639. doi:10.1017/s1751731117002002

Park, S. J., S. H. Beak, D. J. S. Jung, S. Y. Kim, I. H. Jeong, M. Y. Piao, H. J. Kang, D. M. Fassah, S. W. Na, S. P. Yoo, et al. 2018. Genetic, management, and nutritional factors affecting intramuscular fat deposition in beef cattle - a review. Asian-Australas. J. Anim. Sci. 31:1043–1061. doi:10.5713/ajas.18.0310

Pereira, G. M., A. A. Egito, R. D. Gomes, M. N. Ribas, R. T. Junior, J. F. Junior, and G. D. Menezes. 2021. Water requirements of beef production can be reduced by genetic selection. Animal 15:100142. doi:10.1016/j.animal.2020.100142

Rice, E. W., R. B. Baird, and A. D. Eaton. 2017. Standard methods for the examination of water and waste water. 23nd ed. Washington, DC: American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF).

Robelin, J. 1981. Cellularity of bovine adipose tissues: developmental changes from 15% to 65% mature weight. J. Lipid Res. 22:452–457. doi:10.1016/S0022-2275(20)34959-2

Roth, M. T. P., F. D. Resende, I. M. Oliveira, R. M. Fernandes, L. Custódio, and G. R. Siqueira. 2017. Does supplementation during previous phase influence performance during the growing and finishing phase in Nellore cattle? Livest. Sci. 204:122–128. doi:10.1016/j.livsci.2017.08.019

Severo, M. M., L. F. G. de Menezes, F. Kuss, W. Paris, R. C. Haveroth, G. B. Souto, and A. C. Sanches. 2023. Effect of the gain rate during growing phase on the performance and characteristics of carcass and meat of super precocious steers. Anim. Sci. J. 94:e13803. doi:10.1111/asj.13803

Sexson, J. L., J. J. Wagner, T. E. Engle, and J. Eickhoff. 2012. Predicting water intake by yearling feedlot steers. J. Anim. Sci. 90:1920–1928. doi:10.2527/jas.2011-4307

Silva, A. E. M., A. Macias Franco, B. S. Ferguson, and M. A. Fonseca. 2024. Influence of previous plane of nutrition on molecular mechanisms regulating the expression of urea and water metabolism related genes in the rumen and kidney of finishing crossbred Angus steers. Anim. Nutr. 17:232–243. doi:10.1016/j.aninu.2023.12.011

Thornton, P. K., J. Van de Steeg, A. Notenbaert, and M. Herrero. 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Sys. 101:113–127. doi:10.1016/j.agsy.2009.05.002

United States Department of Agriculture (USDA). 1997. Official United States standards for grades of carcass beef. [accessed October 10, 2022]. https://www.ams.usda.gov/grades-standards/carcass-beef-grades-and-standards.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Wagner, J. J., and E. E. Engle. 2021. Invited review: water consumption, and drinking behavior of beef cattle, and effects of water quality. Appl. Anim. Sci. 37:418–435. doi:10.15232/aas.2021-02136

Weiss, W. P. 1998. Estimating the available energy content of feeds for dairy cattle. J. Dairy Sci. 81:830–839. doi:10.3168/jds.S0022-0302(98)75641-3

Xia, C., M. Aziz Ur Rahman, H. Yang, T. Shao, Q. Qiu, H. Su, and B. Cao. 2018. Effect of increased dietary crude protein levels on production performance, nitrogen utilization, blood metabolites and ruminal fermentation of Holstein bulls. Asian-Australas. J. Anim. Sci. 31:1643–1653. doi:10.5713/ajas.18.0125

Zanetti, D., L. F. Prados, A. C. B. Menezes, C. B. Silva, M. V. C. Pacheco, F. A. S. Silva, L. F. Costa E Silva, E. Detmann, T. E. Engle, and S. C. Valadares Filho. 2019. Prediction of water intake to *Bos indicus* beef cattle raised under tropical conditions. J. Anim. Sci. 97:1364–1374. doi:10.1093/jas/skz003