# Relationship of efficiency indices with performance, heart rate, oxygen consumption, blood parameters, and estimated heat production in Nellore steers

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**ABSTRACT:** The objective of this study was to examine the relationship of efficiency indices with performance, heart rate, oxygen consumption, blood parameters, and estimated heat production (EHP) in Nellore steers. Eighteen steers were individually lot-fed diets of 2.7 Mcal ME/kg DM for 84 d. Estimated heat production was determined using oxygen pulse ($O_2P$) methodology, in which heart rate (HR) was monitored for 4 consecutive days. Oxygen pulse was obtained by simultaneously measuring HR and oxygen consumption during a 10- to 15-min period. Efficiency traits studied were feed efficiency (G:F) and residual feed intake (RFI) obtained by regression of DMI in relation to ADG and midtest metabolic BW ($RFI_{REG}$). Alternatively, RFI was also obtained based on equations reported by the NRC's *Nutrient Requirements of Beef Cattle* to estimate individual requirement and DMI (RFI calculated by the NRC [1996] equation [$RFI_{NRC}$]). The slope of the regression equation and its significance was used to evaluate the effect of efficiency indices ($RFI_{REG}$, $RFI_{NRC}$, or G:F) on the traits studied. A mixed model was used considering $RFI_{REG}$, $RFI_{NRC}$, or G:F and pen type as fixed effects and initial age as a covariate. For HR and EHP variables, day was included as a random effect. There was no relationship between efficiency indices and back fat depth measured by ultrasound or daily HR and EHP ($P > 0.05$). Because G:F is obtained in relation to BW, the slope of G:F was positive and significant ($P < 0.05$). Regardless of the method used, efficient steers had lower DMI ($P < 0.05$). The initial LM area was indirectly related to $RFI_{REG}$ and $RFI_{NRC}$ ($P < 0.05$); however, the final muscle area was related to only $RFI_{NRC}$. Oxygen consumption per beat was not related to G:F; however, it was lower for $RFI_{REG}$– and $RFI_{NRC}$–efficient steers, and consequently, oxygen volume ($mL \cdot min^{-1} \cdot kg^{-0.75}$) and $O_2P$ ($\mu L\ O_2 \cdot beat^{-1} \cdot kg^{-0.75}$) were also lower ($P < 0.05$). Blood parameters were not related to $RFI_{REG}$ and $RFI_{NRC}$ ($P > 0.05$); however, G:F-efficient steers showed lower hematocrit and hemoglobin concentrations ($P < 0.05$). Differences in EHP between efficient and inefficient animals were not directly detected. Nevertheless, differences in oxygen consumption and $O_2P$ were detected, indicating that the $O_2P$ methodology may be useful to predict growth efficiency.

**Key words:** bioenergetic, feed efficiency of feed utilization, heat rate, oxygen consumption, residual feed intake


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## INTRODUCTION

According to the Brazilian Institute of Geography and Statistics (IBGE, 2014), Brazil has the world's largest commercial cattle herd, with approximately 211 million *Bos indicus* steers accounting for nearly 80% of the total, of which the Nellore breed makes up 90% (ABIEC, 2014). Therefore, feed efficiency is an important factor to reduce feed costs and increase profitability. Different methods have been indicated to measure efficiency, with feed efficiency (G:F) and residual feed intake (**RFI**) being the most common. One difficulty in measuring and incorporating efficiency in beef cattle breeding programs is measuring individual animal feed intake, which is a very laborious task (Herd et al., 2003; Arthur et al., 2004). An alternative would be to identify

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steers with lower requirements of ME for maintenance for the same BW and gain; that is, steers that produce less heat at a certain weight are more efficient at converting feed. Heat loss can represent 70 to 75% of the total energy consumed (Ferrell and Jenkins, 1984; NRC, 1984). Variation of maintenance measures is 10 to 12%, making it an important component of efficiency variance in beef cattle (Hotovy et al., 1991; Swanson and Miller, 2008). The calorimetric chamber is used to estimate heat production (estimated heat production [**EHP**]); however, this methodology is very laborious and expensive. Heat production can be indirectly estimated from heart rate (**HR**) calibrated to oxygen consumed per HR, because most oxygen used by homoeothermic steers is transported to the tissues by the heart. Estimated heat production in humans obtained by this methodology is highly correlated to that obtained by calorimetric chamber ($r = 0.943$; Ceesay et al., 1989). In this context, the objective of this study was to examine the relationships between different efficiency indices and performance, HR, oxygen consumption, blood parameters, and EHP in Nellore steers.

## MATERIALS AND METHODS

### Steers and Diet

Steers were handled and managed according to the Institutional Animal Care and Use Committee Guidelines (Brazilian Agricultural Research Corporation [EMBRAPA], São Carlos, SP, Brazil). Eighteen Nellore steers of 20 mo of age and 281 ± 22 kg were used in this study. Steers were randomly distributed in individual pens (sheltered or unsheltered) where they were given excess feed twice daily to result in 5% orts for 84 d with diet containing 15% CP and 2.7 Mcal ME/kg DM (Table 1).

Samples of diet and individual orts were collected weekly, dried in forced ventilation oven (55°C ± 5°C/72 h), and then ground in a 1 mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA, USA) to obtain composite samples at the end of the experimental period. Samples were then analyzed with an Ankom fat analyzer (model XT20; Ankom Technology Corp., Macedon, NY) DM at 105°C (method 930.15; AOAC, 1986); ash (method 942.05; AOAC, 1986); CP Kjeldahl N (method 984.13; AOAC, 1986), NDF, ADF, and lignin (Van Soest et al., 1991); NDIN and ADIN (Licitra et al., 1996); and ether extract with an fat analyzer (Ankom XT20, method 2, 01–30–09, Ankom Technology Corp., Macedon, NY).

Total digestible nutrients were obtained using the equation proposed by Weiss et al. (1992); afterward, TDN was converted to DE, considering that 1 kg of TDN corresponds to 4,409 Mcal of DE, and finally, DE was converted to ME, where ME corresponds to 0.82 of the DE, according to the NRC (1984; Table 1).

**Table 1.** Ingredients and composition of experimental diet

| Ingredient | Rate, % DM | |
|---|---|---|
| Corn silage | 44.03 | |
| Grounded corn grain | 29.45 | |
| Soybean hull | 9.25 | |
| Cotton seed | 7.76 | |
| Soybean meal 45% | 8.17 | |
| Limestone | 0.45 | |
| Urea | 0.23 | |
| Mineral premix[1] | 0.63 | |
| Monensin[2] | 0.03 | |
| Composition[3] | Diet | Corn silage |
| DM[4] | 59.19 | 38.50 |
| Ash | 4.19 | 5.25 |
| CP | 15.73 | 8.43 |
| NDIN[4] | 16.65 | 17.31 |
| ADIN[5] | 7.95 | 15.77 |
| EE | 4.22 | 4.90 |
| NDF | 43.39 | 47.54 |
| NDFp | 40.78 | 46.07 |
| ADF | 31.14 | 30.26 |
| Lignin | 3.76 | 4.60 |
| NFC | 35.09 | 35.35 |
| TDN[6] | 71.03[7] | 65.73 |
| ME[8] | 2.63 | 2.51 |

[1]Composition by kilogram: 85 g phosphorus, 130 g calcium, 5 g magnesium, 25 g sulfur, 156 g sodium, 240 g chlorine, 5,000 mg zinc, 1,500 mg copper, 1,700 mg iron, 1,250 mg manganese, 120 mg cobalt, 120 mg iodine, and 15 mg selenium.

[2]28 mg/kg of DM.

[3]NDIN = neutral detergent insoluble nitrogen; ADIN = acid detergent insoluble nitrogen; EE = ether extract; $NDF_p$ = NDF corrected for protein; NFC = non-fibrous carbohydrate.

[4]Percent DM basis.

[5]Percent CP basis.

[6]Estimated according to Weiss et al. (1992).

[7]Processing factor (0.95) used according to Van Soest et al. (1991).

[8]Megacalories per kilogram of DM, in which 1 kg of TDN = 4.409 kcal DE and ME = DE × 0.82 (NRC, 1984).

### Performance and Intake

Body weight was measured every 2 wk in the morning before feeding (no food or water restriction). Initial BW (kg) and final BW (kg) of the RFI evaluation period as well as preslaughter weight were taken after a 16-h period of feed and water fasting. Midtest metabolic BW was calculated as the average of initial BW and final BW.

Average daily gain (kg/d) was estimated for the period of RFI evaluation by regression between BW and days on feed using PROC REG (SAS Inst. Inc., Cary, NC), where the slope represents the growth rate.

Individual DMI (kg/d) was obtained as the difference between offer and refusal DM. The DM content of the diet and orts was determined weekly. At the end of the experimental period, DM was corrected to definitive DM (105°C) using individual composite samples of refusals and diet samples.

### *Efficiency Indices*

Feed efficiency and RFI were evaluated as efficiency parameters. Feed efficiency was calculated by the ratio between ADG (kg) and DMI (kg/d), and RFI was obtained by 2 different approaches. The first is a classical approach computed by regression of DMI, $BW^{0.75}$, and ADG (Koch et al., 1963) using the MIXED procedure (SAS Inst. Inc.). The difference between observed and predicted DMI by the regression was denominated $\mathbf{RFI_{REG}}$ (RFI obtained by regression of DMI in relation to ADG and midtest metabolic BW).

The second approach is based on equations to predict DMI proposed by the NRC, taking into account the amount of energy and feed required for both gain and maintenance (NRC, 1996). Net energy for maintenance per kilogram of shrunk BW and $NE_g$ per kilogram of shrunk body gain were also determined using equations indicated by the NRC. Those values were then divided by the concentration of NEm (Mcal/kg) and NEg (Mcal/kg) of the diet to determine the feed required to meet maintenance and energy gain requirements. The difference between actual and expected DMI, according to requirements, was denominated $\mathbf{RFI_{NRC}}$ (RFI calculated by the NRC [1996] equation) in agreement with Fan et al. (1995).

### *Body Gain Composition*

Back fat (**BF**) depth and LM area between the 12th and 13th ribs were measured by ultrasound (Aquila; Pie Medical, Inc., Maastricht, The Netherlands) at the beginning (the first day of the trial period), middle (42 d after the beginning of the trial period), and end of the trial period (84 d after the beginning of the trial period). Images were collected, processed, and interpreted by ODT Eview software (Pie Medical, Inc.).

### *Heat Production Estimated by Oxygen Pulse Methodology*

Heat production was estimated according to Brosh et al. (1998b). To obtain average beats per minute (**bpm**) and total daily beats, HR per minute was recorded using heart monitors (POLAR RS400; Kempele, Finland) for at least 4 consecutive days, between 42 and 52 d after the beginning of the trial period. Electrodes were fitted to steers with stretch belts. To calculate oxygen pulse ($\mathbf{O_2P}$), oxygen consumption and HR were simultaneously measured for 10 to 15 min. Oxygen consumption was collected by an EXHALYZER (ECOMedics, Zurich, Switzerland) on different days and periods using an open respiratory system (Taylor et al., 1982) consisting of a facemask connected to the gas analyzer, previously calibrated with gases with a known oxygen concentration and a syringe of known volume (3 L).

Because $O_2P$ is constant only under stress-free conditions, calibration of oxygen consumption per beat was taken only when HR was up to 20% greater than the HR previously obtained under normal conditions (4 d) to avoid biased results.

Daily oxygen consumption was calculated by multiplying the volume of $O_2$ per beat by total daily beats. The result was multiplied by constant 4.89 kcal/L of $O_2$ (Nicol and Young, 1990) to estimate daily heat production in relation to metabolic BW ($kcal.kg_{-1}\ BW^{0.75}\cdot d^{-1}$). Daily EHP was determined as follows:

$$\text{EHP} = (\text{TDB} \times O_2 \text{ per beat} \times 4.89 \text{ kcal/L } O_2)/\text{kg BW}^{0.75}, \quad [1]$$

in which EHP is expressed in kilocalories/kilogram $BW^{0.75}$, TDB = total daily beats, and $O_2$ per beat is liters of $O_2$ per beat).

### *Blood Parameters*

To analyze hematocrit and hemoglobin, blood samples (5 mL) were collected using vacuum tubes with EDTA, between 42 and 52 d after the beginning of the trial period. The blood sample was partially transferred into a capillary tube and centrifuged using a micro hematocrit centrifuge at 1,077 × *g* for 5 min at ambient temperature. The packed cell volume as percentage of each specimen was determined using a graduated scale in millimeters. Hemoglobin was determined by colorimetric methodology using commercial kits (Labtest Diagnóstica, Lagoa Santa, Brazil) and spectrophotometer (UV-1601PC, Shimadzu, Japan) at 525 nm.

### *Statistical Analysis*

Average daily gain was estimated by regression between BW and days on feed using PROC REG (SAS, Inst. Inc.), where the slope represents growth rate. Regression of DMI, $BW^{0.75}$, and ADG was computed as $RFI_{REG}$ (Koch et al., 1963) considering pen type as a fixed effect using the MIXED procedure (SAS Inst. Inc.). Variables were analyzed by multiple linear regression in which studied traits were considered dependent or response variables (*y*) and $RFI_{REG}$, $RFI_{NRC}$, or G:F as independent variables (*x*) using the PROC MIXED function of

SAS. Initial age was considered a covariate and pen type and $RFI_{REG}$, $RFI_{NRC}$, or G:F were considered fixed effects according to the statistical model described below:

$$y_{ijkt} = \mu + \beta i + \gamma_j + \rho_k + \alpha_t + e_{ijkt},$$

in which μ is the fixed overall mean effect; $\beta_i$ is the fixed $RFI_{REG}$, $RFI_{NRC}$, or G:F effect; $\gamma_j$ is the fixed pen type effect; $\rho_k$ is the covariate effect of initial age; $\alpha t$ is the random effect of sire; and $e_{ijkt}$ is the random residual error associated with $y_{ijkt}$.

Variables related to HR and EHP did not show normal distribution and, for this reason, generalized mixed models (PROC GLIMMIX in SAS) were used. Following recommendations of Gbur (2012), in accordance with characteristic data, γ distribution was assumed for those variables. The effects of $RFI_{REG}$, $RFI_{NRC}$, or G:F and pen type (sheltered and unsheltered) were considered a fixed effect, initial age was considered a covariate, and time of day (morning or afternoon) when oxygen consumption was measured was considered a random effect.

$$y_{ijkt} = \mu + \beta_i + \gamma_j + \rho_k + \eta_t + e_{ijtk},$$

in which μ is the fixed overall mean effect; $\beta_i$ is the fixed $RFI_{REG}$, $RFI_{NRC}$, or G:F effect; $\gamma_j$ is the fixed pen type effect; $\rho_k$ is the covariate effect of initial age; $\eta_t$ is the random effect of day of the period when the measurement was made; and $e_{ijkt}$ is the random residual error associated with $y_{ijkt}$. Gamma distribution was assumed and critical probability level of 5% was adopted for type I error in all tests realized.

## RESULTS AND DISCUSSION

### *Performance, DMI, and Efficiency Indices*

Average daily gain, DMI, and DMI as percent of BW (Table 2) were similar to those reported in the literature for *Bos taurus* and *B. indicus*. Nkrumah et al. (2007), working with 464 *B. taurus* crosses, obtained values of 1.46 kg/d for ADG and 10.45 kg/d for DMI, whereas Lancaster et al. (2009a) detected values of 1.40 kg/d for ADG and 8.45 kg/d for DMI in Angus cattle. Zorzi et al. (2013), working with 59 Nellore steers, detected DMI of 7.13 kg/d and 1.67% BW.

Although the $RFI_{REG}$ mean was very close to zero, the $RFI_{NRC}$ mean was 0.70 kg/d (Table 2). A positive $RFI_{NRC}$ mean indicates that the equation to predict DMI by the NRC underestimated DMI. A $RFI_{NRC}$ mean different from zero was also reported by Fan et al. (1995), wherein the averages obtained were –1.30 ± 0.10, –0.76 ± 0.10, and 0.11 ± 0.10 ME Mcal/d for a 3-yr test. Hennessy and Arthur (2004) reported a negative $RFI_{NRC}$ mean, indicating that the expected consumption was overestimated in relation to the NRC equation.

**Table 2.** Mean, SD, and range of performance traits of Nellore steers during the feed efficiency evaluation period

| Trait | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Initial age, d | 614.2 | 25.84 | 568 | 649 |
| Final age, d | 697.2 | 25.84 | 651 | 732 |
| Initial BW, kg | 280.6 | 22.46 | 241 | 313 |
| Final BW, kg | 421.0 | 27.47 | 361 | 464 |
| ADG, kg/d | 1.72 | 0.159 | 1.48 | 2.06 |
| DMI, kg/d | 9.07 | 0.701 | 7.70 | 10.3 |
| DMI, % BW | 2.59 | 0.210 | 2.22 | 3.02 |
| TDN intake,[1] kg/d | 6.01 | 0.529 | 4.89 | 6.91 |
| $RFI_{REG}$[2] | 0.00 | 0.634 | –1.26 | 0.84 |
| $RFI_{NRC}$[3] | 0.70 | 0.645 | –0.46 | 1.72 |
| G:F[4] | 0.19 | 0.022 | 0.15 | 0.23 |

[1]TDN intake according to Weiss et al. (1992).

[2]$RFI_{REG}$ = residual feed intake obtained by regression of DMI in relation to ADG and midtest metabolic BW.

[3]$RFI_{NRC}$ = residual feed intake calculated by the NRC (1996) equation.

[4]Feed efficiency (ADG/DMI).

The $RFI_{REG}$ and $RFI_{NRC}$ indices ranged from –1.26 to 0.84 and –0.46 to 1.72 kg/d with an amplitude of 2.10 and 2.19 kg/d, respectively, indicating phenotypic variability for this characteristic (Table 2). Smith et al. (2010) reported that the most efficient steers had –0.65 and 0.98 kg/d whereas the least efficient had 0.90 and 0.90 kg/d for $RFI_{REG}$ and $RFI_{NRC}$, respectively. Phenotypic RFI variance in Nellore has also been reported (Gomes et al., 2012; Costa e Silva et al., 2013). Gomes et al. (2012) detected minimum and maximum values of –2.72 and 1.54 kg/d for RFI in Nellore, an increase of 4.26 kg/d consumption among steers, whereas Costa e Silva et al. (2013) detected a difference of 2.0 kg/d.

No significant difference was detected between efficiency groups for initial and final live weight, live weight gain, and metabolic average daily weight when $RFI_{REG}$ and $RFI_{NRC}$ were used (Table 3). This result was expected because RFI is known to be independent of the weight characteristics. Still, Smith et al. (2010) observed that bulls with low $RFI_{NRC}$ had significantly greater weight gain and were consequently heavier at 140 d of the experimental period compared with steers with medium and high $RFI_{NRC}$.

The regression slope between G:F and ADG was positive ($P < 0.001$), meaning that efficient steers had 17.4% greater ADG than inefficient ones (Table 3). Smith et al. (2010) also observed a negative correlation between G:F and ADG ($r = –0.56$, $P < 0.001$) and final BW after 140 d of the test period, indicating that bulls with lower G:F showed faster growth rate and greater final BW compared with bulls with greater G:F values.

Differences between efficient and inefficient groups based on $RFI_{REG}$, $RFI_{NRC}$, and G:F were highly significant for DMI, DMI as percent of BW, and TDN intake (Table 3). Therefore, efficient steers had lower DMI regardless of the method used to calculate efficiency of feed utilization.

Efficient $RFI_{REG}$, $RFI_{NRC}$, and G:F steers consumed 13.9, 11.6, and 10.31% less feed (kg/d), respectively, compared with inefficient ones. The same pattern was observed for TDN intake. Smith et al. (2010) also observed lower DMI in efficient steers regardless of the method used to calculate feed efficiency; however, the authors detected no correlation between total DMI and $RFI_{NRC}$, indicating that phenotypic selection based on $RFI_{NRC}$ could slightly affect DMI. Arthur et al. (2001a) also reported weak phenotypic and genotypic correlations with DMI when RFI was calculated using standard models instead of regression between DMI, ADG, and metabolic BW.

Arthur et al. (2001b) observed an annual decrease of 0.240 kg/d in DMI in the low-RFI selection line steers compared with those selected for high RFI. Several studies confirmed a positive relationship between RFI, $RFI_{NRC}$, and G:F and DMI in different breeds (Arthur et al., 2001a,b; Castro Bulle et al., 2007; Lancaster et al., 2009a,b; Smith et al., 2010; Ahola et al., 2011; Lucila Sobrinho et al., 2011; Gomes et al., 2012; Santana et al., 2012; Welch et al., 2012; Zorzi et al., 2013). Smith et al. (2010) detected a difference of 13.9% (9.72 vs. 8.36 kg/d) in DMI between low- and high-$RFI_{NRC}$ Angus steers, and Zorzi et al. (2013) reported a difference of 10% between low- and high-RFI Nellore steers.

Efficient steers had lower DMI for maintenance and gain when $RFI_{REG}$ and $RFI_{NRC}$ were used ($P < 0.01$; Table 3). This shows that DMI difference would be more related to a possible change in gain composition or metabolic factors that determine inefficiency in energy use for weight gain over the simple reduction in maintenance requirement.

**Table 3.** Means for efficient and inefficient steers; SEM; linear regression coefficients ($\beta_x$) for residual feed intake obtained by regression of DMI in relation to ADG and midtest metabolic BW ($RFI_{REG}$; $\beta_1$), residual feed intake calculated by the NRC (1996) equation ($RFI_{NRC}$; $\beta_2$), and feed efficiency (G:F; $\beta_3$); and probability level for performance traits of 18 Nellore steers

| | $RFI_{REG}$ | | | | | $RFI_{NRC}$ | | | | | G:F | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait[1] | Efficient | Inefficient | SEM | $\beta_1$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_2$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_3$ | $P > F$ |
| IBW, kg | 281 | 280 | 5.62 | −0.195 | 0.98 | 287 | 274 | 5.44 | −8.951 | 0.36 | 270 | 289 | 5.31 | −11.04 | 0.22 |
| FBW, kg | 423 | 419 | 6.83 | −3.152 | 0.80 | 431 | 412 | 6.54 | −13.00 | 0.27 | 424 | 418 | 6.82 | 4.424 | 0.75 |
| MMBW, kg | 81.3 | 80.8 | 1.04 | −0.322 | 0.86 | 82.5 | 79.7 | 1.00 | −1.937 | 0.28 | 80.4 | 81.5 | 1.04 | −18.99 | 0.71 |
| Hip height, m | 1.42 | 1.44 | 0.01 | 0.012 | 0.58 | 1.43 | 1.43 | 0.01 | 0.001 | 0.96 | 1.43 | 1.43 | 0.01 | −0.089 | 0.88 |
| ADG, kg/d | 1.74 | 1.71 | 0.04 | −0.023 | 0.76 | 1.74 | 1.71 | 0.04 | −0.022 | 0.76 | 1.90 | 1.58 | 0.03 | 5.617 | <0.001 |
| DMI, kg/d | 8.36 | 9.72 | 0.07 | 0.958 | <0.0001 | 8.49 | 9.60 | 0.11 | 0.781 | <0.001 | 8.71 | 9.48 | 0.13 | 0.548 | 0.03 |
| DMI, % BW | 2.37 | 2.79 | 0.03 | 0.296 | <0.0001 | 2.36 | 2.81 | 0.01 | 0.316 | <0.0001 | 2.45 | 2.70 | 0.04 | −4.382 | 0.06 |
| TDN intake,[2] kg/d | 5.45 | 6.52 | 0.05 | 0.754 | <0.0001 | 5.54 | 6.44 | 0.08 | 0.629 | <0.001 | 5.57 | 6.37 | 0.10 | −13.99 | 0.01 |
| ME,[3] Mcal/kg MS | 2.36 | 2.43 | 0.01 | 0.049 | <0.01 | 2.36 | 2.43 | 0.01 | 0.046 | <0.01 | 2.36 | 2.42 | 0.01 | −1.036 | 0.03 |
| NEm,[4] Mcal/kg MS | 2.04 | 1.77 | 0.03 | −0.191 | <0.01 | 1.48 | 1.54 | 0.01 | 0.041 | <0.01 | 2.10 | 1.74 | 0.02 | 6.276 | <0.0001 |
| NEg,[5] Mcal/kg MS | 1.38 | 1.15 | 0.02 | −0.167 | <0.01 | 0.89 | 0.95 | 0.01 | 0.037 | <0.01 | 1.44 | 1.12 | 0.02 | 5.524 | <0.0001 |
| $DMI_m$,[6] kg/d | 3.06 | 3.51 | 0.04 | 0.313 | <0.01 | 3.11 | 3.46 | 0.06 | 0.248 | 0.02 | 2.92 | 3.59 | 0.02 | −11.71 | <0.0001 |
| $DMI_g$,[7] kg/d | 5.29 | 6.21 | 0.07 | 0.651 | <0.001 | 5.37 | 6.14 | 0.09 | 0.537 | <0.01 | 5.59 | 5.92 | 0.12 | −5.881 | 0.32 |

[1]IBW = initial BW; FBW = final BW; MMBW = midtest metabolic BW; $DMI_m$ = DMI for maintenance; $DMI_g$ = DMI for gain.

[2]According to Weiss et al. (1992).

[3]Estimated per kilogram DM intake.

[4]According to Zinn and Shen (1998).

[5]According to Zinn and Shen (1998).

[6]Estimated per NEm requirement/diet NEm.

[7]Estimated per difference between DMI and $DMI_m$.

**Table 4.** Means for efficient and inefficient steers; SEM; linear regression coefficients ($\beta_x$) for residual feed intake obtained by regression of DMI in relation to ADG and midtest metabolic BW ($RFI_{REG}$; $\beta_1$), residual feed intake calculated by the NRC (1996) equation ($RFI_{NRC}$; $\beta_2$), and feed efficiency (G:F; $\beta_3$); and probability level for LM and back fat thickness traits of 18 Nellore steers

| Trait | $RFI_{REG}$ | | | | | $RFI_{NRC}$ | | | | | G:F | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Efficient | Inefficient | SEM | $\beta_1$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_2$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_3$ | $P > F$ |
| LM area,[1] $cm^2$ | | | | | | | | | | | | | | | |
| Initial | 46.9 | 41.1 | 1.07 | −4.044 | 0.05 | 47.6 | 40.5 | 0.95 | −4.908 | <0.01 | 42.9 | 44.8 | 1.23 | −33.33 | 0.58 |
| Final | 56.9 | 52.0 | 1.35 | −3.430 | 0.18 | 57.9 | 51.1 | 1.25 | −4.733 | 0.05 | 54.7 | 54.1 | 1.44 | 10.09 | 0.89 |
| Deposition | 9.99 | 10.6 | 1.29 | 0.451 | 0.84 | 10.3 | 10.4 | 1.28 | 0.055 | 0.98 | 11.8 | 9.09 | 1.26 | 46.31 | 0.46 |
| Back fat thickness,[1] mm | | | | | | | | | | | | | | | |
| Initial | 2.36 | 2.72 | 0.19 | 0.254 | 0.48 | 2.47 | 2.62 | 0.20 | 0.101 | 0.77 | 1.96 | 3.02 | 0.17 | −18.44 | 0.04 |
| Final | 5.15 | 6.04 | 0.21 | 0.622 | 0.13 | 5.27 | 5.93 | 0.22 | 0.455 | 0.25 | 5.11 | 6.02 | 0.22 | −15.83 | 0.16 |
| Deposition | 2.79 | 3.30 | 0.23 | 0.365 | 0.38 | 2.79 | 3.30 | 0.23 | 0.354 | 0.38 | 3.13 | 2.99 | 0.23 | 2.502 | 0.82 |

[1]Measured by ultrasound between the 12th and 13th ribs.

There were no differences between the G:F animal groups in DMI for gain, although DMI for the maintenance of G:F-efficient steers was 18.7% lower ($P < 0.0001$), showing that the observed difference in DMI can be partially explained by a greater dilution of maintenance. Furthermore, although efficient steers showed the same DMI for gain as inefficient steers ($P > 0.05$), ADG was 17.4% greater (Table 3).

### *Body Gain Composition*

There was no relationship between $RFI_{REG}$ and $RFI_{NRC}$ groups for initial and final BF depth and BF deposition, measured by ultrasound ($P > 0.05$). However, the initial LM area was indirectly proportional to $RFI_{REG}$ and $RFI_{NRC}$ ($P < 0.05$), whereas the final LM area was not related to $RFI_{NRC}$. This relationship may indicate that efficient steers had greater ability to deposit muscle (Table 4). Smith et al. (2010) detected no correlation between $RFI_{NRC}$ and BF depth measured by ultrasound at the end of the trial. However, smaller LM area deposition on high-RFI steers was also reported by Trejo et al. (2010), who observed differences between the LM area (92.88, 87.88, and 89.46 $cm^2$, respectively) in lower-, medium-, and high-RFI steers with similar subcutaneous BF depth (1.32, 1.28, and 1.26 mm, respectively).

Furthermore, G:F was not related to the LM area nor was it related to final and deposited BF depth; however, G:F was observed in lower initial BF depth in efficient steers ($P < 0.05$; Table 4). Smith et al. (2010) detected no correlation between G:F and BF depth at the end of 140 d on feed for efficient and inefficient steers, indicating that selection for low G:F may not affect this characteristic. Nevertheless, some authors observed greater BF depth in inefficient steers in trials using *B. taurus* (Herd and Bishop, 2000; Arthur et al., 2001a; Carstens et al., 2002; Lancaster et al., 2009a) and Nellore (Gomes et al., 2012; Santana et al., 2012).

### *Estimated Heat Production Measured by the Oxygen Pulse Methodology*

During calibration, HR was similar to the average daily mean during the 4-d measurement period, indicating that the steers were not under stress during oxygen collection (Table 5).

During the 4-d evaluation period, HR was 89.8 ± 8.04 bpm and mean $O_2P$ was 227.6 ± 52.5 μL $O_2 \cdot BW^{-0.75} \cdot beat^{-1}$. Brosh et al. (1998b), in a study of 6 Hereford steers weighing 345 ± 10.8 kg, detected an average similar to that of the present study, in which HR was 94 bpm and $O_2P$ was 238 μL $O_2 \cdot BW^{-0.75} \cdot beat^{-1}$ in steers fed 80% concentrate and 20% sorghum si-

**Table 5.** Mean, SD, and range of heart rate, oxygen consumption, and heat production traits of 18 Nellore steers during the feed efficiency evaluation period

| Trait[1] | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| $O_2$ calibration period[2] | | | | |
| Heart rate, bpm | 88.5 | 12.21 | 65.9 | 118.3 |
| $O_2$ consumption, mL/beat | 21.5 | 5.84 | 11.8 | 31.5 |
| $O_2$ volume, $mL \cdot min^{-1} \cdot kg\ PV^{-0.75}$ | 19.8 | 4.07 | 13.5 | 28.9 |
| $O_2P$, $\mu L\ O_2 \cdot beat^{-1} \cdot kg\ PV^{-0.75}$ | 227.6 | 52.49 | 140.2 | 329.5 |
| Trial period[3] | | | | |
| Heart rate, bpm | 89.8 | 8.04 | 78.6 | 106.9 |
| $O_2$ consumption, L/d | 2,739 | 626.7 | 1,606 | 3,809 |
| EHP, Mcal/d | 13.4 | 3.06 | 7.9 | 18.6 |
| EHP, $kcal \cdot d^{-1} \cdot kg\ PV^{-0.75}$ | 142.5 | 27.61 | 83.5 | 194.9 |
| EHP, $kJ \cdot d^{-1} \cdot kg\ PV^{-0.75}$ | 596.2 | 115.6 | 349.7 | 815.7 |
| EHP, Mcal/kg gain | 8.31 | 1.95 | 5.23 | 12.02 |

[1]bpm = beats per minute; $O_2P$ = oxygen pulse; EHP = estimated heat production.

[2]Minimum 15 min.

[3]Minimum 4 d.

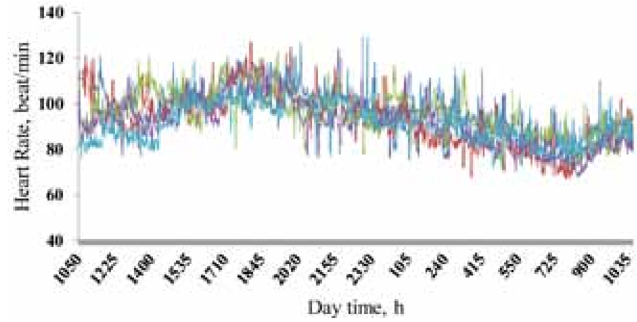


**Figure 1.** Profile of diurnal heart rate of 4 Nellore for 24 h. Each color represents an animal.

lage. In addition, HR in cows ranged from 61 to 88 bpm. Oxygen volume values reported by Brosh (2007) of 20 to 30 $mL \cdot min^{-1} \cdot kgBW^{-0.75}$ were also similar to those observed in the present study.

Daily EHP was 13.4 ± 3,06 Mcal/dia and 596.2 ± 115.6 $kJ \cdot d_{-1} \cdot kg\ BW_{-0.75}$). Brosh et al. (2002) observed EHP as 340 ± 18.4 $kJ \cdot d^{-1} \cdot kg\ BW^{-0.75}$ in a study on the use of HR to estimate heat production in 6 cows in different reproductive stages. Additionally, Brosh et al. (2004) observed an average of 481 ± 53 $kJ \cdot d^{-1} \cdot kg\ BW^{-0.75}$ in pasture-fed nonlactating cows. Heat production differences between studies may be attributed to differences in breed, seasonal, age, metabolism, HR, and ME intake of the steers studied. The steers in the study conducted by Brosh et al. (2002) showed HR of 44.9 ± 1.81 bpm, whereas the average observed in the present study was 89.4 ± 8.27 bpm. Greater EHP can be observed in steers with greater HR and steers fed a ME-rich diet (Brosh et al., 2002).

The nycterohemeral profile of HR was within the normal pattern established for the conditions of the trial, whose peaks were equivalent 2 h after feeding, which happened at 0800 and 1500 h (Fig. 1). Under stable conditions, that is, without stress factors or sudden changes in feed intake, the daily pattern of HR is similar over time throughout the days (Brosh, 2007).

Although daily HR during calibration and the 4-d evaluation period were numerically lower for efficient steers, they were not related to the efficiency of feed utilization indices studied (Table 6). Inefficient steers showed HR 6.9% greater at the calibration time in relation to the rate measured in the 4-d evaluation period, whereas this variation in efficient steers was only 1.5%. This may be attributed to greater response to stress in these steers. Some studies show (Lancaster et al., 2005; Hafla et al., 2013) that steers with high RFI had greater HR compared with steers with low RFI. Factors related to this difference in HR are not clear, but they may be related to increased requirements for maintenance or greater response to stress in inefficient steers. Cortisol blood circulation is negatively related to temperament and calmness in steers, indicating great responsiveness to stress, which may contribute to variation of RFI in Nellore (Gomes et al., 2013). Some studies on sheep (Knott et al., 2008, 2010) and Nellore (Gomes et al., 2013) reported high cortisol levels in plasma of inefficient steers.

Oxygen consumption (mL/beat) was not related to G:F; however, it was lower for efficient $RFI_{REG}$ and $RFI_{NRC}$ steers, and consequently, $O_2$ volume ($mL \cdot min^{-1} \cdot kg^{-0.75}$) and $O_2P$ values were lower in this group of steers (Table 6). A study of 16 heifers classified as high or low RFI indicated that steers with high RFI also presented greater $O_2P$ and $O_2$ consumption in relation to those with low RFI (Paddock, 2010).

Because $O_2P$ is an individual characteristic, for some authors (Brosh et al. (1998a,b, 2004), it may change during the day if the steers are under intense physical activity or stress. In the present study, steers did not undergo any heavy physical exercise or stress, because they were kept in individual pens throughout the trial. This indicates that the use of a constant value of $O_2P$ to calculate heat can properly represent daily heat production.

There was no significant effect of $RFI_{REG}$, $RFI_{NRC}$, and G:F on EHP (Table 6). Paddock (2010), using the $O_2P$ methodology, observed that EHP was 17.4% greater in steers with high RFI compared with those with low RFI. However, Aharoni et al. (2003) observed that EHP increased proportionally with RFI in lactating cows. Furthermore, Aharoni et al. (2006) studied EHP to characterize use efficiency of protein and NE in Holstein or Holstein × Montbeliarde and observed that crossed steers had lower HR but that this was not reflected in differences in $O_2P$ and heat production.

**Table 6.** Means for efficient and inefficient steers; SEM; linear regression coefficients ($\beta_x$) for residual feed intake obtained by regression of DMI in relation to ADG and midtest metabolic BW ($RFI_{REG}$; $\beta_1$), residual feed intake calculated by the NRC (1996) equation ($RFI_{NRC}$; $\beta_2$), and feed efficiency (G:F; $\beta_3$); and probability level for heart rate, oxygen consumption, and heat production traits of 18 Nellore steers

| | $RFI_{REG}$ | | | | | $RFI_{NRC}$ | | | | | G:F | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait[1] | Efficient | Inefficient | SEM | $\beta_1$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_2$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_3$ | $P > F$ |
| $O_2$ calibration period[2] | | | | | | | | | | | | | | | |
| HR, bpm | 83.3 | 89.7 | 3.42 | 0.052 | 0.41 | 81.5 | 91.2 | 3.50 | 0.079 | 0.23 | 86.6 | 92.3 | 1.34 | –0.058 | 0.16 |
| $O_2C$, mL/beat | 19.1 | 23.8 | 2.19 | 0.155 | <0.01 | 19.1 | 24.2 | 2.32 | 0.165 | <0.01 | 21.6 | 21.0 | 1.88 | –0.020 | 0.81 |
| $VO_2$, $mL \cdot min^{-1} \cdot kg\ BW^{-0.75}$ | 16.2 | 21.8 | 1.59 | 0.211 | 0.04 | 15.3 | 23.1 | 1.75 | 0.286 | <0.01 | 19.8 | 19.1 | 1.18 | –0.025 | 0.79 |
| $O_2P$, $\mu L\ O_2 \cdot beat^{-1} \cdot kg\ BW^{-0.75}$ | 202 | 245 | 18.9 | 0.137 | 0.05 | 200 | 252 | 19.9 | 0.161 | <0.01 | 228 | 220 | 16.9 | 0.027 | 0.43 |
| Trial period[3] | | | | | | | | | | | | | | | |
| HR, bpm | 89.2 | 90.3 | 1.44 | 0.784 | 0.77 | 89.5 | 90.1 | 1.44 | 0.409 | 0.87 | 87.5 | 92.4 | 1.32 | –3.561 | 0.43 |
| $O_2C$, L/d | 2,445 | 3,014 | 255 | 0.147 | 0.08 | 2,513 | 2,964 | 255 | 0.115 | 0.19 | 2,673 | 2,765 | 230 | –0.025 | 0.71 |
| EHP, Mcal/d | 12.0 | 14.7 | 1.25 | 0.147 | 0.08 | 12.3 | 14.5 | 1.25 | 0.115 | 0.19 | 13.1 | 13.5 | 1.12 | –0.025 | 0.71 |
| EHP, $kcal \cdot d^{-1} \cdot kg\ BW^{-0.75}$ | 126 | 154 | 11.2 | 0.137 | 0.08 | 128 | 154 | 11.4 | 0.128 | 0.10 | 138 | 143 | 10.3 | –0.025 | 0.78 |
| EHP, $kJ \cdot d^{-1} \cdot kg\ BW^{-0.75}$ | 529 | 643 | 46.7 | 0.137 | 0.08 | 536 | 643 | 47.6 | 0.128 | 0.10 | 577 | 597 | 43.0 | –0.025 | 0.78 |
| EHP, Mcal/kg gain | 7.71 | 8.69 | 0.64 | 0.084 | 0.40 | 7.95 | 8.49 | 0.63 | 0.046 | 0.65 | 7.39 | 9.06 | 0.64 | –0.147 | 0.14 |

[1]HR = heart rate; bpm = beats per minute; $O_2C$ = $O_2$ consumption; $VO_2$ = $O_2$ volume; BW= Body weight; $O_2P$ = oxygen pulse; EHP = estimated heat production.

[2]Minimum 15 min.

[3]Minimum 4 d.

**Table 7.** Means for efficient and inefficient steers; SEM; linear regression coefficients ($\beta_x$) for residual feed intake obtained by regression of DMI in relation to ADG and midtest metabolic BW ($RFI_{REG}$; $\beta_1$), residual feed intake calculated by the NRC (1996) equation ($RFI_{NRC}$; $\beta_2$), and feed efficiency (G:F; $\beta_3$); and probability level for blood traits of 18 Nellore steers

| | $RFI_{REG}$ | | | | | $RFI_{NRC}$ | | | | | G:F | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait[1] | Efficient | Inefficient | SEM | $\beta_1$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_2$ | $P > F$ | Efficient | Inefficient | SEM | $\beta_3$ | $P > F$ |
| Hct, % | 40.0 | 43.4 | 1.20 | 2.425 | 0.28 | 40.5 | 43.0 | 1.22 | 1.744 | 0.42 | 36.8 | 45.7 | 0.924 | –5.639 | <0.01 |
| Hb, g/dL | 13.3 | 15.1 | 0.49 | 1.287 | 0.17 | 13.3 | 15.0 | 0.49 | 1.175 | 0.19 | 12.6 | 15.5 | 0.443 | –1.882 | 0.03 |

[1]Hct = hematocrit; Hb = hemoglobin.

### Blood Parameters

There was no significant relationship between $RFI_{REG}$, $RFI_{NRC}$, and blood parameters; however, G:F-efficient steers had lower hematocrit percentage and lower hemoglobin concentration ($P < 0.05$; Table 7). Richardson et al. (1996), in search of possible physiological indicators for feed efficiency, also studied blood constituents of Angus heifers and bulls with high and low efficiency. These authors observed that the most efficient steers had a greater number of red blood cells. On the other hand, the proportion of hemoglobin and hematocrit in those cells was lower compared with inefficient steers. Richardson et al. (2000) also observed a lower concentration of hemoglobin (11.7 ± 0.15 vs. 12.3 ± 0.13 g/dL, respectively; $P < 0.01$) and hematocrit (31.4 ± 0.50 vs. 33.3 ± 0.42 %, respectively; $P < 0.01$) in Angus bulls with low RFI compared with those with high RFI.

Therefore, the lower hematocrit percentage in the most efficient steers indicates that they may have a greater number of red cells compared with inefficient steers. These differences may be associated with oxygen-carrying capacity.

### Conclusions

Efficient steers had lower DMI regardless of the method used to calculate efficiency of feed utilization.

Although no relationships were detected for G:F, $RFI_{REG}$, and $RFI_{NRC}$ with EHP, classifying the steers based on those indices facilitated the identification of differences in oxygen consumption and $O_2P$, indicating that the $O_2P$ method may be useful to identify efficient steers.

The observed differences in hematocrit and hemoglobin concentrations between efficient and inefficient G:F steers may be associated with oxygen-carrying capacity. Further studies should evaluate theses 2 parameters as alternative markers to estimate biological variation in feed efficiency as well as to understand the physiological basis for this relationship.

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