# INTAKE, REPRODUCTIVE, AND GRAZING ACTIVITY CHARACTERISTICS OF RANGE CATTLE ON SEMI-ARID RANGELANDS

by

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As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Colt W. Knight, titled Intake, Reproductive, and Grazing Activity Characteristics of Range Cattle on Semi-arid Rangelands and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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**ABSTRACT:** ***Study One -*** Our objective was to characterize mature range cows based on intake and grazing activity. Starting in the early spring of 2013, 4 experiments were conducted. First, mature range cows (*n* = 137) were fitted with radio frequency identification tags (RFID) and placed in a dry-lot pen equipped with GrowSafe® technology to monitor DMI of alfalfa hay. These data were then used to assign cows a residual feed intake (RFI) value utilizing the National Research Council (NRC) (1996) model to predict intake of beef cattle. Cattle with negative and positive RFI were characterized as low-intake and high-intake, respectively. In addition, the following data were also recorded: weight (kg), age (mo), days pregnant (d), and body condition score (BCS). Second, 30 mature range cattle were selected from the first trial and fitted with pedometers for 7 d to monitor activity with step counts and estimate distance traveled. Third, mature range cows (*n* = 25) selected from the first trial were fitted with global position system (GPS) collars, and placed on pinyon-juniper rangeland from 20 June 2014 to 17 September 2014. Forth, mature range cows (*n* = 28) were fitted with GPS collars, and placed on ponderosa pine rangeland from 17 September 2014 to 15 October 2014. Distance traveled, slope, distance from water, elevation data were collected from both GPS trials. Low-intake and high-intake cows consumed 9.3 and 12.2 kg/d, respectively ($P < 0.0001$). Low-intake cattle became pregnant sooner ($P = 0.002$) than high-intake cattle (average of 16 d sooner). Cattle age (mo) equaled 90 and 98 for low- and high-intake cows, respectively ($P = 0.04$). Weight, predicted DMI, and BCS did not differ between groups (P > 0.06). Step counts for low- and high-intake animals were 5839 and 5383 ± 2089, respectively ($P$ = 0.61), and estimated distance traveled was 4.31 and 5.35 ± 1.66 km $d^{-1}$ for low- and high-intake animals, respectively ($P = 0.77$). Low-intake cows (6.23 km $d^{-1}$) traveled farther ($P$

= 0.005) each day than high-intake cows (5.84 km $d^{-1}$) on pinyon-juniper rangelands, and high-intake cows utilized ($P$ = 0.013) steeper slopes. No differences were detected ($P \geq$ 0.06) for distance traveled, distance from water, and elevation for cows grazing ponderosa pine rangeland). However, low-intake cattle preferred ($P$ = 0.046) steeper slopes on ponderosa pine rangeland than high-intake cattle. These results indicate that low-intake animals may travel farther on some rangelands and rebreed earlier.

***Study Two*** - Commercial grade heifers ($n$ = 173) born and raised on the University of Arizona's V bar V Ranch from 2012 to 2014 were fitted with radio frequency identification tags (RFID) and placed in a drylot equipped with Growsafe® technology (8 bunks) for 60 d in 3 groups based on birth year in order to calculate DMI, residual feed intake (RFI), ADG, G: F, and residual gain (RG). Birth date, birth weight, weaning weight, age at start of trial, initial trial weight, and final trial weights were also recorded. Residual feed intake scores were utilized to place heifers in one of three treatment groups, low-, medium-, and high-intake. Reproductive and calf data were collected on heifers born in 2012. Means for birth date, birth weight, weaning weight, initial weight, final weight, and ADG did not differ among the three treatments. Residual gain for low-, medium-, and high-intake heifers were different ($P$ < 0.05) at 0.07, 0.00, and -0.07 kg $d^{-1}$, respectively. Low-intake cattle had an improved ($P$ < 0.05) GF ratio of 0.19 when compared to the medium- and high-intake heifers with ratios of 0.15 and 0.13 ($P$ > 0.05), respectively. Differences ($P$ < 0.05) in DMI were detected with low-, medium, and high-intake heifers consuming 5.2, 6.2, and 7.5 kg $d^{-1}$, respectively. No differences were detected for pregnancy rate, calving rate, percent bred artificial insemination (AI), percent bull calves, calf birth weight, and calf birth date among treatments ($P$ > 0.05).

***Study Three -*** Commercially available GPS tracking collars for cattle are cost prohibitive to most researchers. This paper will present a low-cost alternative to those collars (Knight GPS tracking collars), and provide detailed instructions on where to source materials and how to fabricate inexpensive GPS tracking collars. In addition, the two types of collars will be compared in a study where Brangus cattle ($n$ = 8) were each fitted with LOTEK® 3300 and Knight GPS tracking collars for 31 d beginning 14 March 2015 at the Chihuahuan Desert Rangeland Research Center (CDRRC) 37 km north of Las Cruces, New Mexico. Location, slope, distance from water, distance traveled and elevation were recorded every 10 min. A record of GPS fix rate was logged. No differences were detected ($P \geq 0.369$) between collar types for location, slope, or distance from water. However, there was a tendency ($P = 0.08$) for Knight collars to report a lower estimate for distance traveled at 6171 m $d^{-1}$ compared to Lotek collars at 7104 m $d^{-1}$. Fix rate was greater ($P \leq 0.001$) for Lotek collars compared to Knight collars at 99.9 and 66.2%, respectively.

***Study Four -*** Previously characterized commercial cows ($n$ = 26) were placed into either high (positive RFI) or low intake (negative RFI) groups. On 14 May 2015, 13 high- and 13 low-intake cows were fitted with modified igotU GT-120® GPS logging collars. Cattle were then placed on rangeland for 120 d. The first 30 d period animals transitioned from desert shrubland to pinyon-juniper. From 31 to 60 d, animals grazed pinyon-juniper rangeland. Next, during days 61 to 90, animals transitioned from pinyon-juniper to ponderosa pine, and the last 30 d were spent in ponderosa pine. Time periods will be referred to as month 1, 2, 3, and 4 for days 0 to 30, 31 to 60, 61 to 90, and 91 to 120, respectively. Location, slope, distance from water, elevation, and time spent close to water were recorded every 10 min. No differences were observed in the utilization of elevation or distance traveled, or distance from water ($P > 0.05$). Low intake animals used a higher maximum slope ($P < 0.05$) during month 3, but slope utilization differences were not detected for other portions of the trial ($P > 0.05$).

***Study Five* -** Hereford sires ( $n = 35$) with 7 or more cow offspring on the University of Arizona V bar V ranch in Rimrock, Arizona were tested at Neogen laboratories in Lincoln, NE for an Igenity Gold genetic profile. Their residual feed intake (RFI), ADG, tenderness, marbling score, milk production, percent choice, yield grade, fat thickness, ribeye area, heifer pregnancy rate, stayability, maternal calving ease, birthweight and docility were estimated. Sires were given a genetic RFI score based on their RFI profile and placed into one of three intake groups, low (< 0.5 SD), medium ( ± 0.5 SD) and high (> 0.5 SD). Performance traits of cow offspring ($n = 839$) from those sires were also compared based on their sire's intake group. No differences ($P > 0.05$) were detected among sire intake groups for ADG, tenderness, marbling score, percent choice, yield grade, fat thickness, ribeye area, heifer pregnancy rate, stayability, maternal calving ease, birthweight and docility. Residual feed intake differed among groups ($P < 0.05$), and high intake cattle had more estimated milk production compared to low intake animals ($P < 0.05$). Cows from low intake sires were born later in the year ($P < 0.05$). High intake cattle had a higher ($P < 0.05$) birthweight and survived longer ($P < 0.05$) in the herd when compared to low and medium intake cows. Genetic RFI and expected milk production were moderately to highly correlated.

CHAPTER ONE

# LITERATURE REVIEW

***Introduction***

One of the largest costs in animal production remains the cost of feed (Arthur and Herd, 2008). Unlike grazing animals, feed input costs are easy to calculate in swine and poultry production, and because of this, those industries have taken steps to significantly improve the feed efficiency of their herds (Luiting, 1991). Calculating the cost of feed for livestock raised in extensive grazing industries, like beef animals, becomes more difficult when determining the value of free standing forage and the logistical costs of delivering feed to the animals (Herd et al., 2003). Even so, feed remains a large cost of a beef herd. For example, Dodsworth estimates that 60-70% (1972) of the energy cost associated with beef production comes from the cow herd, and Ferrell and Jenkins (1982) suggest that simply maintaining the cow herd accounts for up to 70% of that estimate. Therefore, it can be said that approximately 46% of the energy cost of beef production is due to simply maintaining the cow herd. Johnson et al. (2003) reported that cow maintenance has remained virtually unchanged in the last 100 years.

Traditionally, the beef industry has focused on output traits such as: reproduction, body weight, and carcass characteristics to improve production, while input traits have been given less credence. However, one such input trait, feed efficiency, has been studied. Feed efficiency has been expressed in the literature as: feed conversion ratio (FCR), gain to feed ratio (G:F), residual body weight gain (RG) and residual feed intake (RFI). Feed conversion ratio, or units of body weight gain per unit of feed, and the inverse, G:F, are considered to be moderately heritable. Initial work done by Knapp and Nordskog (1946) characterized the heritability of FCR utilizing steer calves (N=177) from 23 different sires and found heritability for FCR of half-sibling and sire-offspring to be 0.54 and 0.48, respectively. Later, Woldehawariat et al. (1978) compiled heritability estimates from 17 separate studies through 1977, and concluded the weighted average for FCR heritability to be 0.47. In a more comprehensive review of the literature from 1946 to 1991, Koots et al. (1994) found that overall heritability of FCR and its inverse, G:F, to be 0.36 and 0.42, respectively. More recently, Arthur et al. (2001c) and Nkrumah et al. (2007) suggested that heritability for FCR is a moderately heritable trait, ranging from 0.29 to 0.41. These data suggest that FCR could be used as selection criteria to improve feed efficiency of the herd (Arthur et al., 2001c). However, selection for FCR and G:F have been associated with an increase in mature cow size, leanness, organ weights, and heat increment while decreasing digestibility, mostly due to increases in intake (Herd and Bishop, 2000).

***Feed Conversion Ratio***

Feed conversion ratio tends to be well correlated with average daily gain (ADG), which means that improvements in FCR yield improvements in ADG. In species such as swine, correlations between FCR and ADG have been reported by Johnson et al. (1999) and Hoque (2007) to range from -0.25 to -0.39. Correlations in cattle, have been shown to be much higher, ranging from -0.52 to -0.87 (Arthur et al., 2001b; Arthur et al., 2001c; Archer et al., 2002; Schenkel et al., 2004 and Nkrumah et al., 2007). Alternatively, FCR has varying reports on correlations to feed intake in the literature. An early review of the literature by Koots (1994) suggests the average correlation to be 0.38, while more recent studies show a range from 0.30 to 0.72 (Arthur et al., 2001b; Arthur et al., 2001c; Archer et al., 2002; Schenkel et al., 2004 and Nkrumah et al., 2007). Carstens and Tedeschi (2006) described the correlation of FCR to feed intake as 0.21 and 0.25 for growing and finishing stages of calves, respectively. Interestingly, Robinson and Oddy (2004) found phenotypic and genetic correlations of FCR to feed intake to be -0.14 and -0.49, respectively.

In addition, correlations between FCR and body weight also vary greatly in the literature, and become difficult to compare because weight measurements differ. One common measurement of weight (kg) used is the metabolic mid weight (MMWT), which is defined as the mid weight of the animal on test, raised to the power of 0.75. Using MMWT, Archer et al. (2002) reported phenotypic and genotypic correlation of 0.01 and -0.12, respectively. Similarly, Schenkel et al. (2004) published phenotypic and genetic correlations of 0.05 and -0.13, respectively. However, these numbers do not remain similar throughout the literature, and phenotypic and genotypic correlation can range from -0.14 to 0.23 and -0.62 to 0.06, respectively (Robinson and Oddy, 2004; Lancaster et al., 2005; Nkrumah et al., 2007).

***Residual Gain***

Residual gain, often reported as a measure of feed efficiency in cattle, is defined as the difference in the expected and actual rate of weight gain for a given amount of feed. Typically, MMWT is used as a measure of body weight. A linear regression equation is used to calculate RG:

$$ADG = \beta_0 + \beta_1 (DFI) + \beta_2 (BW) + RG$$

where

$\beta_0$ = regression intercept, $\beta_1$ = partial regression coefficient, DFI = daily feed intake and $\beta_2$ = partial regression coefficient of ADG on DFI.

In short, cattle exhibiting a positive RG score gain more weight than expected, and those with a negative RG, gain less than expected. Cattle with a positive RG are considered more efficient.

A study conducted by Berry and Crowley (2012) estimated the heritability of RG to be 0.28 ± 0.06 utilizing 2605 bulls. Both Crowley et al. (2010) and Berry and Crowley (2012) describe RG as independent of DFI and BW. In addition, both authors report that RG is highly correlated with FCR both phenotypically and genotypically at -0.71 and -0.89, respectively. Also, Hafla et al. (2013) found that the inverse of FCR, G:F, was also highly correlated to RG at 0.97 in heifers and pregnant animals. Berry and Crowley (2012) published data suggesting that RG is highly correlated to ADG with phenotypic and genotypic correlations of 0.70 and 0.82. Hafla et al. (2012) reported an even higher phenotypic correlation of 0.88.

***Residual Feed Intake***

Residual Feed Intake equals the difference between an animals expected feed intake and actual feed intake. Animals consuming less than expected have a negative RFI score, whereas, animals eating more than expected have a positive RFI score. Scores are commonly reported as how much more/less the animal is expected to eat per day expressed in common unit of weight (lbs or kg). Mature cow RFI can be calculated once an expected intake has been determined. A common method to generate expected feed intake is to utilize the National Research Council (1996) computer model which takes into account the animals diet, weight, body condition score (BCS) reproductive status, age, breed, sex, and environmental conditions. Actual intake is quantified by measuring the amount of feed consumed by the animal in a day. This becomes a labor intensive task because feed and refusals must be weighed to calculate actual intake. Technology, such as Growsafe® systems place individual feed bunks on computerized scales. Animals are fitted with radio frequency identification (RFID) tags so the computer can identify, in real time, the amount of feed an individual animal consumes. These data are then transmitted to a hard drive where they can be retrieved for analysis. Laboratory analysis of the feed for nutrient and water composition are used by the NRC model to calculate expected intake, as well as, determining dry matter composition used to determine the dry matter intake of the animal.

However, young animals have a significant requirement for growth which needs to be accounted for in the model to generate an accurate expected intake. A simple statistical calculation, multiple linear regression, can be utilized to calculate RFI in the growing animal, similar to RG:

$$DFI = \beta_0 + \beta_1 (ADG) + \beta_2 (MMWT) + RFI$$

where

DFI = daily feed intake, $\beta_0$ = regression intercept, $\beta_1$ = partial regression coefficient of feed intake on average daily gain, ADG = average daily gain, $\beta_2$ = partial regression coefficient of feed intake on body weight expressed, MMWT = metabolic mid weight, and RFI = residual feet intake.

Expected feed intake can also be predicted utilizing the feeding standard formulas from the NRC (1984) or Geay and Micol (1988). Arthur et al. (2001c) compared the two methods in Charolais bulls, and found the genotypic and phenotypic correlations to be 0.70 and 0.89, respectively. While the correlation between the methods is high, utilizing the feed standards may result in ADG and body weight not being independent of RFI, $r^2 \approx 0.35$ which were similar to the results published by Fan et al. (1995).

Arthur et al. (2001b) reported that heritability for both male and female British cattle is 0.39± 0.03, while Renand et al. (1998) described the heritabilities for RFI to range from 0.21 to 0.39 for Charolais bulls. Further, Liu et al. (2000) found the heritability for RFI for both beef and dairy bulls to be 0.29. Herd et al. (2003) compiled RFI heritabilities from the literature and found estimates between 0.16 to 0.43 in males and females. Herd et al. (2003) also found that the genotypic correlation of FCR to RFI ranged from 0.66 to 0.85, and that RFI had a negative correlation to mature cow body weight, -0.09 to -0.22 which may indicate that low-RFI mature cows have a slightly higher bodyweight. Crowley et al. (2010) reported phenotypic and genotypic correlations of RFI with RG of -0.40 and -0.46, respectively. Hafla et al. (2013) described a similar phenotypic correlation between the two traits of -0.46.

***Cow Intake***

Cow intake, on average, relates to cow size, physiological state, milk production, and cow age (NRC, Beef Cattle Requirements, 2005 and Herd et al., 2004), but cattle express a large individual variation in intake. Koch et al. (1963) suggested a method to identify individuals that consumed more/less than expected called residual feed intake (RFI), or the difference between expected feed intake and actual feed intake. Carstens and Kerley (2009) stated that RFI is phenotypically independent of production traits used to calculate intake, meaning cattle of various types and production levels can be compared. For example, Arthur et al. (2001) demonstrated that calves from parents selected for RFI differed significantly in feed intake, but were similar in body weight (BW) and production, suggesting that selecting for negative RFI could result in lower feed costs without affecting the level of production. In contrast, feed conversion ratios, such as feed:gain, are positively correlated with growth rate, increased body size, increased leanness, increased organ weights, increased heat increment, and decreased digestibility (Herd and Bishop, 2000).

Herd et al. (2004) concluded that residual feed intake is related to intake, digestion, metabolism, activity, and thermoregulation. They also proposed that approximately 10% of variation in RFI is due to physical activity in growing cattle, which can be measured using pedometers. Additionally, activity in laying hens selected for RFI has been shown to account for 29 to 54% of their total energy expenditures (Luiting et al., 2001). Carstens and Kerley (2009) suggest these studies could merit utilizing feeding behaviors as indicator traits for RFI. Cow intake has been estimated to be as high as 75% or more of a commercial beef cattle herd's total feed consumption (Archer et al, 1999). However, according to Herd and Pitchford (2011) most research is focused on growing animals, steers in particular.

Most studies concentrate resources on determining the feed efficiency of young growing cattle (Arthur and Herd, 2008), even though the largest portion (65-85%) of feed supplies goes to the breeding herd cows, with maintenance requirements making up the bulk (60-65%) of that cost (Montano-Bermudez et al., 1990). The cattle industry has relied heavily on the selection of outputs because of the difficulty and cost in monitoring cattle intake on pasture/rangeland, especially on an individual basis. However, the swine and poultry industries have embraced both genetic and non-genetic means to improve feed utilization, and have made significant progress in lowering the cost of feed in production (Arthur and Herd, 2008). The development of technology, such as GrowSafe®, allows researchers to reliably calculate feed intake without tremendous labor expenses.

The availability of technology in recent times has generated an interest in studying feed efficiency in the breeding cow herd. Historically, feed efficiency was measured in growing animals in a feedlot setting. Common selection criteria for animals entering the feedlot are Feed:Gain ratio (F:G) and/or Residual Gain (RG). Both are positively correlated to feed conversion ratio (FCR), but FCR comes at a cost to the cow herd. As FCR increases, growth rate and body size also increase. As body size increases, so does feed intake. This in turn creates larger organ weights, increased heat increment, increased leanness, and decreased digestibility (Lamb et al., 2013 and Herd and Bishop 2000). On the other hand, selection for RFI does not affect rate of gain or animal size, and can actually improve the F:G ratio. Richardson et al. (2001) showed that steers selected for low RFI (after one generation) had an improved FCR. In the same study, heifers and bulls selected for low RFI (after one generation) had lower intake while production traits did not differ significantly.

Australian research conducted by Arthur et al. (2001) bred divergent lines of RFI cattle. First, cows were placed into either low- or high-RFI groups based on their postweaning RFI scores. Low- and high-RFI females were bred to three to six of the lowest- and highest-RFI bulls. This selection process began in 1993 and ended in 1998. Low-RFI lines consumed 1.247 kg/d less than high-RFI lines. This selection resulted in a 14% cost savings in feed for low-RFI cattle and an increase in post-weaning feed efficiency with little effect on growth. Richardson et al. (1998) utilized the first generation steers from the divergent lines described by Arthur et al. (2001), and reported data from Angus and crossbred steers. Angus steers showed no difference between those that were selected from low- and high-RFI parents in body weight at the beginning of the test (used to calculate RFI), ADG during the duration of the test, or the final body weight as the end of the test. Steers from low-RFI parents had a significantly lower DMI (9.2 kg $d^{-1}$ vs. 9.8 kg $d^{-1}$), lower FCR (7.0 vs 7.6) and lower RFI scores (-0.20 vs 0.17 kg $d^{-1}$). Prior to slaughter, ultrasound was used to determine that steers from low-intake parents had a significantly less subcutaneous fat at the 12/13$^{th}$ rib and rump (Angus: rib 7.1 vs 8.3 mm, rump 8.3 vs. 10.2; crossbred: rib 10.1 vs 12.2, rump 13.3 vs. 14.3). In addition, differences were seen in the area of longissimus dorsii muscle for low- and high-intake selected steers (Angus: 48.5 vs 51.4, crossbred 48.5 vs. 51.4). The authors conclusion states that low-intake steers grew as fast, or faster, and ate less per unit of gain while producing carcasses of acceptable fat finish with no compromises in meat yield, therefore, creating a more profitable animal in the feedlot. Herd et al. (2003) utilized market steers from three years (1997, 1998, and 1999) of aforementioned study for slaughter. Steers from parents selected for low-RFI had consumed less per unit of live weight gain than steers selected from high-RFI parents and exhibited no adverse effects on growth. Similarly, steers placed on rye-grass/tall fescue pasture from these divergent lines showed no difference in intake, but steers from low-RFI parents grew a little faster. Alkane profiles from the pasture and fecal samples indicate a trend that steers from low-RFI parents selected ($p < 0.1$) a higher percentage of rye-grass than the steers with high-RFI parents (Herd et al., 2002).

In 2007, Basarb et al. published the results of a study conducted over 10 production cycles for 222 calves and their mothers. Cows were placed into one of three groups based on their calves' RFI scores, low (RFI < 0.5 SD), medium (RFI ± SD) or high (RFI > 0.5 SD). Calves from low, medium, and high mothers showed no differences in their pregnancy rate, calving rate, calving interval, weaning rate, mature body weight, calf birth weight, pre-weaning ADG or 200-d weight. However, calves from high RFI mothers demonstrated an increased rate of twinning and increased calf death loss compared to low RFI and medium RFI animals. Cows with low RFI progeny ate less during their second trimester, contained 2.5 mm extra back fat thickness, and calved about 6 d later in the year compared to cows with medium and high RFI progeny.

A study conducted by Shaffer et al. (2011) revealed a negative linear relationship between RFI and age at puberty in British breed heifers (n = 137) while pregnancy and conception rates remained equal between the two groups. Authors put forth a hypothesis that the delay in onset of puberty seen by negative RFI heifers could be due to the difference in body fat and metabolic rate. They felt strongly that RFI selection should be combined with reproductive traits to circumvent negative impacts in production. Basarb et al. (2011) suggested that RFI needs to be adjusted for body fatness and feeding behavior or selecting for negative RFI could result in a loss in reproductive rates because negative RFI heifers tend to mature later.

Hafla et al. (2013) tested heifers for RFI, postweaning. They retained the 12 highest RFI and 12 lowest RFI animals for breeding, and carried them for two calving seasons. These animals were tested again during their 1$^{st}$ or 2$^{nd}$ pregnancy. While the authors noted that heifers with a low RFI consumed 17% less forage, they did not detect any differences in calving date, body weight, body weight gain or body composition. First-calf heifers with negative RFI had a lower first-parity calf birthweight, but this difference did not carry over to the second calving. During the retesting, authors noted that heifer postweaning RFI was only moderately correlated to pregnant cow RFI at 0.42. On an interesting note, they were able to demonstrate that low and high RFI cattle had a similar feeding frequency, but low RFI animals spent 26% less time feeding.

### *Utilizing RFI for Bull Selection*

The beef industry has expressed a concern that selecting bulls based on RFI could have a negative impact on bull reproductive performance and fertility (Wang et al., 2012). In mice, selecting for feed efficiency traits has been shown to have a negative impact on reproductive performance and fertility Nielson et al., 1997 and Rauw et al., 2000). Similarly, swine and poultry suffer as well (Estany et al., 2002 and Hagger, 1994). Brien et al. (1984) and Kerr and Cameron (1995) even reported a reduced litter size in mice and swine when selecting for feed efficiency. However, little has been published on direct impacts to beef cattle of RFI on male reproductive performance and fertility (Wang et al., 2012). Most commonly, scrotal circumference (SC) is utilized as an important variable in selecting bulls as it is highly correlated with testes weight, sperm output, semen quality traits, and age of puberty in heifer progeny (Almquist et al., 1976; Brinks et al., 1978;Gregory et al., 1991). Studies conducted by Arthur et al. (2001a) and Schenkel et al. (2004) reported no correlation between RFI and SC or other breeding soundness traits.

In an effort to confront that sentiment, Wang et al. (2012) evaluated 412 RFI-tested bulls. Bulls with a negative RFI score were placed into one group (-RFI), while animals with a positive RFI score (were placed in another). Approximately 23% of the bulls were culled for performance, type, temperament or other reasons. Remaining animals were then subjected to a breeding soundness examination, of which 32, 20, and 36 were culled based on feet and leg, scrotal circumference, and semen quality issues, respectively. However, a concern amongst producers is that negative RFI animals will have less energy, and therefore be less active in multisire mating groups on pasture creating a reduction in reproductive performance and fertility (Wang et al., 2012). Authors were unable to detect any differences in culling reasons due to BSE: feet and legs, scrotal circumference, or semen quality (p = 0.13, 0.52, and 0.48, respectively) or rate of culling between groups (p = 1.0). While semen morphology remained constant (p = 0.71) between the negative and positive RFI sires, authors reported a trend suggesting that negative RFI had a higher rate ( p = 0.07) of culling for sperm motility than high RFI with respective values of 10.2 and 4.4%. Over all, no differences were detected in culling rates based on performance, type and temperament or failed BSE (p = 0.77 and 1.0, respectively). While the authors saw no associations with most reproductive traits, sperm motility tended to suffer in negative RFI bulls, suggesting that bulls selected for negative RFI may have a higher chance of failing a BSE for sperm motility reasons. However, authors did report a decreased number of progeny per bull for positive RFI bulls. Wang et al. (2013) reported no differences in sperm viability (%), sperm mobility (%), or sperm progressive motility (%) when bulls ($n$ =110) were divided into two equal low- and high- RFI groups. However, comparing the 10 lowest and highest RFI bulls, high-RFI bulls had increased sperm viability (%), sperm mobility (%), and sperm progressive motility (%).

***Grazing Behavior***

Rangelands are sensitive to overgrazing, and severe habitat degradation is possible when poor management practices create a lack of productivity, biodiversity and sustainability of the rangelands (Huber et al., 1995). Managers need to make decisions in an effort to preserve rangelands in order to continue grazing. Information on the spatial and temporal distribution of livestock across landscapes are critical to rangeland management (Morgan, 2010). Efforts to improve livestock distribution on rangelands have been noted in the literature as early as 1922 by Fleming, and continued with noted authors such as

Williams (1954) and Savory (1988). Historically, managers have sought to improve grazing distribution by utilizing the rangeland more uniformly in an effort to prevent over/under utilization. This becomes a difficult task when terrain and vegetation types vary greatly on Western rangelands (Coughner, 1991). Distribution greatly effects stocking rate, and as early as 1950, Phinney reported that even when proper stocking rates are calculated, poor grazing distribution can yield damage to sensitive areas and alter vegetation composition in areas where cattle gather.

To further complicate the issue, water availability, topography, and physical barriers throughout rangelands, and weather impact the distribution as well, but is further confounded by the supply of vegetation its relative quality (Duncan and Gordon, 1999 and Bailey and Provenza 2008). Tough terrain is often avoided by cattle, and they tend to spend most of their time on flatter areas like valley bottoms, fields, and ridgetops (Mueggler, 1965). Gillen et al. (1984) further suggested that most cattle actively avoid grazing areas with slopes greater than 20%. Holecheck (1988) recommended that stocking rates need to be reduced when available forage is on steeper slopes. Animals can be enticed to improve their grazing distribution through the placement of water (Valentine, 1947 and Matin and Ward 1970), shade (Mcilvain and Shoop, 1971), salt and supplemental feeds (Bailey and Welling, 1999). Also, distribution can be manipulated through fencing, herding, grazing systems and fire. However, fencing should be considered second to altering or adding water sources to achieve a more uniform grazing distribution. (Williams, 1954). Williams (1954) also stated that the proper spacing of water sources can help prevent overgrazing and minimize erosion. Economic analysis by Holechek (1992) revealed installing water sources at greater than 4 km apart is not economically beneficial to arid rangelands when considering livestock grazing and distribution.

Improvements to rangeland resources such as fences and water sources may be unfeasible due to cost and management constrains. However, cattle tend to have a well-defined home range, and they will continually travel the same areas while conducting their day-to-day business (Bart, 1943). A study by Howery et al. (1996) revealed that 78% of cattle tested demonstrated a high affinity for their home ranges. For examples, cattle with home ranges in the uplands primarily grazed uplands, whereas, cattle with home ranges in riparian areas preferred to graze in riparian areas. Launchbaugh and Howery (2005) hypothesized that cattle have certain behavioral dispositions, physiological systems and physical characteristics that influence their foraging, drinking, resting, and ruminating behavior from birth. Therefore, it should be possible to select animals based on their grazing behavior to influence grazing distribution without expending capitol on expensive infrastructure such as fences and water sources. However, Arnold (1981) noted that environmental influences can have a strong influence on an animal's behavior over time. Bennett et al.(1985) reported that dominant animals can prevent more subordinate ones from utilizing preferred sites, and maintain control over feeding areas, shade, mineral, supplemental feed, and shelter.

Another considerable factor in grazing behavior and distribution is age (Neville, 1971). Younger cattle have a tendency to travel farther and broader than older animals, as observed by (Dunn et al., 1988 and Howery et al., 1996). In Oregan, Bryant (1982) reported that mature cows with calves were more apt to utilize steeper slopes (> 35%) and seek out and use more plant communities than yearling animals. Morrison (2002) observed that first calf heifers spent more time around riparian areas when compared to mature cows. Walburger et al. (2009) reported similar findings in Oregon where young cattle (2 to 3 yr) spent more time close to water than older cattle (> 8 yr). In 2006, Bailey et al. (2006) described older cows (> 4 yr) as using steeper slopes and areas further from water than cows 3 to 4 yr. The authors were also able to characterize cattle based on their affinity for steeper slopes and bottomlands as hill climbers and bottom dwellers, respectively.

The grazing behavior of range cattle is often overlooked by researchers because of cost, both the cost of labor to monitor livestock in person and the cost of expensive technology, such as global positioning satellite (GPS) collars, to monitor animals remotely. Anderson (2010) described at least 68 factors that have been used to characterize grazing distribution in livestock, which include: slope utilization, elevation utilization, distance from water, and distance traveled. In 2004, Bailey et al. described a method to calculate the above factors utilizing GPS tracking collars, digital elevation models of the pasture/range, and geographic information systems such as ArcGIS® (v. 10.2.2, Esri). Commercial GPS tracking collars, such as Lotek® GPS 3300 collars (Lotek Engineering Inc., Newmarket, Ontario), have the ability to monitor location at variable and programmable intervals, ambient temperature, and record the position of the animals head through the use of internal accelerometers. However, such collars are often unaffordable to researchers because the investment per collar can range upwards of $2000, limiting their use.

Initially, GPS was developed in 1973 as a both a navigational tool and a means to precisely locate objects by the department of defense (Herring, 1996). Wildlife biologists were the first to adapt the technology to map animal locations and movements. However, these data would be considered crude, inaccurate, and imprecise by today's standards (Sampson and Delgiudice, 2006). Early adopters of this technology were faced with large spatial resolutions, and GPS coordinates were considered accurate as long as they were within 5 km (Kenward, 1987). Due to this, early research was focused on broad spatial scales, and the tracking of movement was coarse, at best. Tracking animals in smaller spaces such as pastures posed were severely limited (Keating et al., 1991). However, this poor spatial resolution was not due to technology limitations, but selective availability error signal, a purposeful degradation of the GPS signal by the Department of Defense who cited national security concerns (D'Eon et al., 2002). Efforts were made to circumvent this intentional error, and differential correction was created. Differential correction used fixed, ground-based references to determine the difference between the known locations and the GPS signal (Hurn, 1993). By the year 2000, this program was terminated by the department of defense. Coupled with an improvement of GPS technology, civilian and commercial application have become more reliable and affordable (Morgan, 2012). D'Eon et al. (2002) reports that GPS locations are within 31 m 95% of the time, and modern equipment often achieves positions within 5 m of the true position (Wing et al., 2005). In 1997, Rutter et al. reported than GPS collars worn by medium and large framed animals do not effect behavior.

Even with the improved accuracy of modern GPS collars, error is a common concern. Frair et al. (2004) describes loss of data due to failed location attempts and inaccurate spatial location reporting as inherent to utilizing GPS. When combined, these types of errors can create an inflated estimate of measures of animal movement and habitat selection (Pepin et al., 2004). Signal to the GPS can be compromised from atmospheric conditions, satellite geometry, satellite clock error, satellite orbit error and bouncing signals (Hurn, 1993). In addition, the location of the GPS receiver antenna in relation to the sky can impact the fix rate of the GPS (D'Eon and Delparte, 2005). This includes blockages by man-made structures and natural occurrences such as mountains, foliage, and valleys. In 1998, Johnson et al. reported that missing data has more profound effect on estimates than inaccurate locations. While GPS has been increasingly utilized by livestock researchers, there are not standard protocols for GPS utilization, especially in regards to correcting for errors or incorporating GIS software to analyze GPS data.

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APPENDIX ONE

## Intake and grazing activity of mature range cows on Arizona rangelands[1]

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**ABSTRACT:** Our objective was to characterize mature range cows based on intake and grazing activity. Starting in the early spring of 2013, 4 experiments were conducted. First, mature range cows (*n* = 137) were fitted with radio frequency identification tags (RFID) and placed in a dry-lot pen equipped with GrowSafe® technology to monitor DMI of alfalfa hay. These data were then used to assign cows a residual feed intake (RFI) value utilizing the National Research Council (NRC) (1996) model to predict intake of beef cattle. Cattle with negative and positive RFI were characterized as low-intake and high-intake, respectively. In addition, the following data were also recorded: weight (kg), age (mo), days pregnant (d), and body condition score (BCS). Second, 30 mature range cattle were selected from the first trial and fitted with pedometers for 7 d to monitor activity with step counts and estimate distance traveled. Third, mature range cows (*n* = 25) selected from the first trial were fitted with global position system (GPS) collars, and placed on pinyon-juniper rangeland from 20 June 2014 to 17 September 2014. Forth, mature range cows (*n* = 28) were fitted with GPS collars, and placed on ponderosa pine rangeland from 17 September 2014 to 15 October 2014. Distance traveled, slope, distance from water, elevation data were collected from both GPS trials. Low-intake and high-intake cows consumed 9.3 and 12.2 kg/d, respectively ($P < 0.0001$). Low-intake cattle became pregnant sooner ($P = 0.002$) than high-intake cattle (average of 16 d sooner). Cattle age (mo) equaled 90 and 98 for low- and high-intake cows, respectively ($P = 0.04$). Weight, predicted DMI, and BCS did not differ between groups (P > 0.06). Step counts for low- and high-intake animals were 5839 and 5383 ± 2089, respectively ($P = 0.61$), and estimated distance traveled was 4.31 and 5.35 ± 1.66 km $d^{-1}$ for low- and high-intake animals, respectively ($P = 0.77$). Low-intake cows (6.23 km $d^{-1}$) traveled farther ($P = 0.005$) each day than high-

intake cows (5.84 km $d^{-1}$) on pinyon-juniper rangelands, and high-intake cows utilized ($P$ = 0.013) steeper slopes. No differences were detected ($P \geq 0.06$) for distance traveled, distance from water, and elevation for cows grazing ponderosa pine rangeland). However, low-intake cattle preferred ($P$ = 0.046) steeper slopes on ponderosa pine rangeland than high-intake cattle. These results indicate that low-intake animals may travel farther on some rangelands and rebreed earlier.

**INTRODUCTION**

Cow intake, on average, relates to cow size, physiological state, milk production, and cow age (NRC, Beef Cattle Requirements, 2005), but cattle express large individual variation in intake. Koch et al. (1963) suggested a method to identify individuals that consumed more/less than expected called residual feed intake (RFI), or the difference between expected feed intake and actual feed intake. Carstens and Kerley (2009) state that RFI is phenotypically independent of production traits used to calculate intake, meaning cattle of various types and production levels can be compared. For example, Arthur et al. (2001) demonstrated that calves from parents selected for RFI differed significantly in feed intake, but were similar in body weight (BW) and production, suggesting that selecting for negative RFI could result in lower feed costs without affecting the level of production. In contrast, feed conversion ratios, such as feed:gain, are positively correlated with growth rate, increased body size, increased leaness, increased organ weights, increased heat increment, and decreased digestibility (Herd and Bishop, 2000). Herd et al. (2004) concluded that relative feed intake is related to intake, digestion, metabolism, activity, and thermoregulation. They also proposed that approximately 9% of variation in RFI is due to physical activity in growing cattle, which can be measured using pedometers. Additionally, activity in laying hens selected for RFI has been shown to account for 29 to 54% of their total energy expenditures (Luiting et al., 2001). Carstens and Kerley (2009) suggest these studies could merit utilizing feeding behaviors as indicator traits for RFI.

Archer et al. (1999) estimated cow intake to be as high as 75% or more of a commercial beef cattle herd's total feed consumption. However, according to Herd and Pitchford (2011) most research is focused on growing animals, steers in particular. The objective of this study was to compare weights, BCS, breeding dates and grazing behavior of low- and high-intake cows.

## MATERIALS AND METHODS

### *Animal Care and Use:*

Experimental protocols were approved for all animals by the University of Arizona Institutional Animal Care and Use Committee.

Beginning in the spring of 2013, 137 multiparous-mature cows (≥ 60 mo) born and raised on the University of Arizona's V Bar V ranch in Rimrock, AZ were fitted with RFID and placed in a drylot equipped with Growsafe® technology. Cattle were fed alfalfa hay and intake data were recorded for at least 10 d. Hay samples were analyzed at Servi-tech Laboratories in Dodge City, KS for forage quality. In addition, weight (kg), age (mo), days pregnant (d), and BCS data were recorded. The NRC (1996) model was then used to calculate RFI values for cows. Cattle with negative and positive RFI were characterized as low-intake and high-intake, respectively. Days pregnant was determined by palpation.

After RFI data were collected, cows were returned to their normal rangeland conditions. In summer 2013, all ranch cows were gathered, and synchronized for artificial insemination (AI) utilizing Eazi-Breed CIDRs® (Zoetis). While animals were worked through the chute, 15 high- and 15 low-intake cattle were fitted with Omron HJ-113® pedometers (Omron Healthcare, Inc. Vernon Hills, Il.). Pedometers were attached to the cows behind the front left shoulder utilizing Heatwatch II® estrus detection pouches (Cow Chips, LLC. Manalapan, NJ). These pedometers have the capability to store daily data for 7 consecutive days, as well as, estimate distance traveled when individual stride length is programmed into the unit. Cows were then released back on a rangeland pasture for 7 d. Attaching pedometers to animals during CIDR synchronization helps eliminate increased variation in step counts due to estrous behavior. Days animals were driven to and from the chute were not used to estimate distance traveled (km/d). Data from 24 of the 30 pedometers equipped were recovered. Six pedometers failed due to loss or pedometer malfunction.

On 20 June 2014, low-intake ($n$ = 14) and high-intake ($n$ = 12) cows were fitted with LOTEK® 3300 GPS collars for 89 d on pinyon-juniper rangeland. Cow location, slope, distance to water, and elevation were recorded every 10 min. Utilized slope of pinyon-juniper rangeland ranged from 0.1 to 22.9% rise. Average slope utilized by animals was 5.0%. Utilized elevation ranged from 1757 to 2208 m above sea level, with average elevation utilization being 1936 m above sea level. Pinyon-juniper range accounts for approximately one-third of the ranch's 28,733 hectares.

On 17 September 2014, an additional 14 high- and 14 low-intake cows were fitted with modified igotU GT-120® GPS logging collars. Cattle were then placed on ponderosa pine rangeland for 28 d. Location, slope, distance from water, and elevation were recorded every 10 min. Data were recovered from 25 of the 28 GPS collars due to loss and damage. Average slope utilized by cattle on the ponderosa pine rangeland was 3.8%, and ranged from 0.0 to 11.7 %. Average elevation utilized by animals on the study for ponderosa pine was 2102 m above sea level, with a range of 2067 to 2170 m above sea level.

A list of high and low intake cows was generated based on which animals had been tested for RFI and were available at regularly scheduled working periods. With the ranch being so large, gathering all cattle was not always possible, therefore, cattle were assigned a collar based on the order they came through the chute. As animals with RFI scores came through the chute, they were given a GPS collar until approximately half the collars were fitted to low-intake cattle, and half the collars were fitted to high-intake cattle.

Latitude and longitude coordinates were converted to the Universal Tranverse Mercator coordinate system to facilitate calculation of distance traveled. Elevation, slope, and distance from water data were calculated utilizing spatial analyst tools in the mapping program ArcGIS® (v. 10.2.2, Esri).

***Statistical Analysis***

Production, RFI, and pedometer data were analyzed as a completely random design with RFI (low or high) as a fixed effect using the GLM procedure of SAS (v. 9.4, SAS Inst. Inc., Cary, NY). Cow served as the experimental unit. All tracking data were summarized daily for each cow, which provided the average distance traveled per day and daily elevation use, slope use and distance cows were from water. GPS tracking data were analyzed using the repeated measures procedures of PROC MIXED (SAS Version 9.4, Cary, NC). Intake (low or high) was used as a fixed effect, and Julian day was used as a covariate. Linear, quadratic and cubic responses to Julian day were evaluated. The subject was the cow, and the autoregressive order 1 structure was used to model the covariance of repeated records (Littell et al., 2006). We also evaluated the interactions of intake with the linear, quadratic and cubic functions of Julian day. The interactions of intake with Julian day were not significant ($P > 0.05$) for any of the dependent variables, and for brevity these results are not presented.

## RESULTS AND DISCUSSION

Of the 137 mature cows tested for intake, 37% were characterized as low-intake with the remaining 63% characterized as high-intake. No differences in predicted DMI intake were detected ($P = 0.86$) between low-intake and high-intake cows. However, actual DMI for high-intake cows (12.2 kg/d) was greater ($P < 0.001$) and differed from low-intake cows (9.32 kg/d). High- and low-intake cattle had mean RFI scores of +1.66 and -1.23, kg $d^{-1}$, respectively ($P < 0.001$). No differences in cow weight were detected between groups ($P = 0.21$). Low- and high-intake cattle weighed 494 and 506 kg, respectively. Also, no differences in BCS were detected ($P = 0.06$) between low- (5.2 BCS) and high-intake cattle (5.4 BCS). In addition, low-intake cows (218 days pregnant) became pregnant sooner ($P = 0.0002$) than high-intake cows, (201 days pregnant), indicating that low-intake cattle rebred 16 d earlier than high-intake cattle. The average age of high-intake cattle was 98 mo while low-intake cattle were 90 mo ($P = 0.041$). However, the correlation between cow age (mo) and RFI was low ($r = 0.076$). Carstens and Kerley (2009) and Herd and Arthur (2008) both state that RFI is phenotypically independent of production characteristics used to calculate RFI, and this study is consistent with their assessment.

### *Physical Activity Measured with Pedometer*

No differences in physical activity as measured with pedometers were detected ($P = 0.61$) between low- and high-intake animals (5839 and 5383 steps/d, respectively). Estimated distance traveled for low- and high-intake cows were 5.35 and 4.31 km/d, respectively (*P* = 0.72). Connor et al. (2013) divided dairy cattle into low-, medium- and high-intake groups, and measured activity with an electronic pedometer, and reported similar findings that low-RFI cattle had a numerically higher (*P* >0.05) pedometer reading than medium- and low-RFI animals. However, the reported regression coefficient (-0.02) of pedometer readings on RFI indicate no relationships between the two (*P* = 0.92). Herd and Arthur (2008) suggest that 9% of the variation seen in RFI can be explained by physical activity.

***Physical Activity Measured with GPS***

Physical activity measured with GPS on pinyon-juniper rangeland is presented in Table 1. Differences in distance from water (*P* = 0.24) and elevation (*P* = 0.13) were not detected. Low-intake traveled 0.50 km further per day than high-intake cattle (*P* = 0.005), and high-intake cattle utilized (*P* = 0.013) steeper slopes. While little research has been done to quantify breed differences as they relate to grazing behavior, a study by Herbel and Nelson (1966) found the bos *indicus* influenced Santa Gertrudis cattle traveled further each day than Hereford cattle (bos *taurus*) during spring and summer months, averaging 12.6 km/d and 7.9 km/d, respectively. Funston et al., (1991) describes *Bos indicus* influence cattle as more tolerant to ambient temperature, and many have attributed their heat tolerance to their increased grazing behavior in warmer mo when compared to *Bos taurus* cattle. A similar comparison could be made between low- and high-intake cattle. Cattle with negative-RFI scores consume less feed and therefore have a lower heat increment allowing them more freedom to roam throughout the hotter moths compared to positive-RFI cattle.

Physical activity measured with GPS on ponderosa pine rangeland is presented in Table 1. Low-intake cattle utilized (*P* = 0.046) steeper slopes than high-intake cattle.

Differences in distance from water ($P$ = 0.41) and distance traveled ($P$ = 0.8432) were not detected. Elevation differences between cattle approached significance ($P$ = 0.057), showing a trend that low-intake cattle utilized slightly higher elevations. However, 5 m is well within normal resolution of modern GPS technology.

The pinyon-juniper rangelands located on the V Bar V have more varied and challenging topography than the ponderosa pine rangelands. Also, the pinyon-juniper rangelands had less available forage. Average elevation for low- and high-intake cattle was not expected to differ for cattle placed on ponderosa pine rangeland because pasture elevation did not differ drastically. Distance traveled only differed significantly for the rougher pinyon-juniper country suggesting that low-intake animals may be searching for higher quality forage to meet their nutritional demands instead of consuming higher quantities of lower quality forage, as opposed to the ponderosa pine rangelands were higher quality forage was more available. Slope data differed between low- and high-intake cattle, however, high-intake utilized steeper slopes on pinyon-pine rangelands while low-intake cattle utilized steeper slopes on ponderosa pine rangelands. These differences could be due to differences in forage quality, type, and location between the two differing types of rangelands. The authors hypothesize that low-intake cattle could be searching out higher quality forage to meet their nutritional needs which may have been located on different slopes. Alternatively, cattle may have formed groups and coincidently utilized differing slopes throughout the rangeland. Authors intend to conduct future studies including forage data to determine if low-intake cattle are selecting higher quality forage, and if so, are they merely selecting more nutritious parts of the plant or selecting a different diet altogether.

## IMPLICATIONS

Western rangelands with challenging topography and limited forage availability could benefit from cattle that are willing to utilize higher elevations and travel further to seek out forage. Coupled with reviews of the literature by Archer et al. (1999) and Pitchford (2004) that report cattle intake has low to moderate heritability, selecting replacement heifers from low-intake cows could help improve herd efficiency by improving grazing distribution, forage utilization, and help inform managers to create expected stocking rates. Future studies are recommended to investigate range cow intake and grazing behavior.

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**Table 1.** Physical activity measured with GPS on pinyon-juniper and ponderosa pine rangeland

| | Low-RFI | High-RFI |
|---|---|---|
| *Pinyon-juniper rangeland* | | |
| Distance traveled, m | $634^{A}$ | $584^{B}$ |
| Distance from Water, m | $685^{C}$ | $715^{C}$ |
| Elevation, m | $1904^{D}$ | $1877^{D}$ |
| Slope* | $4.19^{E}$ | $4.82^{F}$ |
| *Ponderosa pine rangeland* | | |
| Distance traveled, m | $600^{A}$ | $596^{A}$ |
| Distance from Water, m | $668^{B}$ | $654^{B}$ |
| Elevation, m | $2105^{C}$ | $2100^{C}$ |
| Slope* | $3.98^{D}$ | $3.63^{E}$ |

**Slope is measured in percent-rise*
*Means with different superscripts are considered significantly different ($P \leq 0.05$)*
*RFI = residual feed intake*

APENDIX TWO

## Residual feed intake of heifers raised on semi-arid Arizona Rangelands

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Authors note – Ashley D. Wright assisted with intake and feed efficiency calculations for this chapter.

**ABSTRACT:** Commercial grade heifers (*n* = 173) born and raised on the University of Arizona's V bar V Ranch from 2012 to 2014 were fitted with radio frequency identification tags (RFID) and placed in a drylot equipped with Growsafe® technology (8 bunks) for 60 d in 3 groups based on birth year in order to calculate DMI, residual feed intake (RFI), ADG, G:F, and residual gain (RG). Birth date, birth weight, weaning weight, age at start of trial, initial trial weight, and final trial weights were also recorded. Residual feed intake scores were utilized to place heifers in one of three treatment groups, low-, medium-, and high-intake. Reproductive and calf data were collected on heifers born in 2012. Means for birth date, birth weight, weaning weight, initial weight, final weight, and ADG did not differ among the three treatments. Residual gain for low-, medium-, and high-intake heifers were different ($P < 0.05$) at 0.07, 0.00, and -0.07 kg $d^{-1}$, respectively. Low-intake cattle had an improved ($P < 0.05$) GF ratio of 0.19 when compared to the medium- and high-intake heifers with ratios of 0.15 and 0.13 ($P > 0.05$), respectively. Differences ($P < 0.05$) in DMI were detected with low-, medium, and high-intake heifers consuming 5.2, 6.2, and 7.5 kg $d^{-1}$, respectively. No differences were detected for pregnancy rate, calving rate, percent bred artificial insemination (AI), percent bull calves, calf birth weight, and calf birth date among treatments ($P > 0.05$).

**INTRODUCTION**

Residual feed intake (RFI) is genetically independent of body size and growth rate, and is described as moderately heritable ($h^2 = 0.255 \pm 0.008$) by meta-analysis reported by Mercandante et al. (2014). Often, cattle are selected for terminal characteristics of feedlot animals, or outputs, and little has been done to select for inputs. Common selection criteria for animals entering the feedlot are Feed:Gain ratio (F:G) and/or Residual Gain (RG). Both are positively correlated to feed conversion ratio (FCR), but FCR comes at a cost to the cow herd. As FCR increases, so does growth rate and body size. As body size increases, so does feed intake. This creates larger organ weights, increased heat increment, increased leanness, and decreased digestibility (Lamb et al., 2013 and Herd and Bishop 2000). On the other hand, selection for RFI does not affect rate of gain or animal size, and can actually improve the F:G ratio. The cattle industry is currently behind most other livestock with a F:G ratio of about 7:1, compared to 3:1, 2:1, and 1:1 for swine, chicken, and fish, respectively. Considering that cow intake has been estimated to be as high as 75% or more of a commercial beef cattle herd's total feed consumption (Archer et al, 1999), decreasing the amount of feed consumed by the cow herd would reduce costs and make beef more competitive in the livestock industry.

Selecting for RFI has shown few negative effects. For example, Paul Arthur describes cattle selected for RFI exhibiting more lean tissue, and a study by Donoghue et al. (2011) showed that low RFI cows calved about 5 days later than high RFI cows. However, a study by Arthur et al (2001) demonstrated a 14% savings in feed cost by selecting cattle in a herd with low RFI scores compared to ones selected for high RFI scores. In addition, Arthur indicated selecting for RFI had minimal to no effect on growth. Richardson et al (2001) demonstrated that steers selected for low RFI (after one generation) had an improved FCR. In the same study, heifers and bulls selected for low RFI (after one generation) had lower intake while production traits did not differ significantly. In addition, Richardson and Herd (2004) presented evidence that low RFI cattle are less susceptible to stress than high RFI cattle. In 2010, Montaholi et al, documented that low RFI cattle have greater energy efficiency measured by snout and cheek temperature. The purpose of this study was to compare birth date, birth weight, weaning weight, age at start of trial, initial weight, final weight, dry matter intake, RFI, ADG, G:F, and RG for low-, medium-, and high-take heifers.

## MATERIALS & METHODS

### ***Animal Care and Use:***

Experimental protocols were approved for all animals by the University of Arizona Institutional Animal Care and Use Committee.

Commercial grade heifers (*n* = 173) born and raised on the University of Arizona's V bar V Ranch during 2012, 2013, and 2014 were fitted with radio frequency identification tags (RFID) and placed in a drylot equipped with Growsafe® technology (8 bunks) for 60 d in 3 separate groups: group 1 to 24 December 2012 through 18 February 2013, group 2 to 12 March 2013 through 22 May 2013, and group 3 to 10 November 2014 to 17 January 2015. Animals were weighed on first day prior to entering the drylot, and last two days, which were averaged to yield a final weight. Cattle were fed a forage diet of mixed alfalfa hay (TDN 56.4 to 59.3%) and given ad libitum access to water and mineral block supplement. Growsafe® data were monitored by a technician, and data compromised due to weather or other events were not used in the final calculations. In order to calculate dry matter intake, RFI, ADG, G:F, and RG, birth date, birth weight, weaning weight, age at start of trial, initial trial weight, and final trial weights were recorded. Residual feed intake scores were utilized to place heifers in one of three treatment groups, low-, medium-, and high-intake based on one-half standard deviation from the mean.

Residual feed intake was calculated utilizing a linear regression model:

daily DMI = $\beta 0 + \beta 1(ADG) + \beta 2(WT) + RFI$,

where daily DMI equals average DMI per day, $\beta 0$ is the regression intercept, $\beta 1$ is the partial regression coefficient of daily DMI on ADG, $\beta 2$ is the partial regression coefficient of daily DMI on WT, and the regressors used were ADG and average trial Weight, onto daily DMI (Wright, 2014). Residual feed intake was calculated independently for group 1, 2, and 3 using the PROC REG of SAS (SAS Inst. Inc., Cary, NC).

Residual gain was calculated using the linear regression:

ADG = $\beta 0 + \beta 1$(daily DMI) + $\beta 2(WT) + RG$,

where $\beta 0$ is the regression intercept, $\beta 1$ is the partial regression coefficient of ADG on daily DMI, $\beta 2$ is the partial regression coefficient of ADG on WT, and the regressors used were average daily DMI and average trial weight, both on ADG (Wright, 2014). Group RG was calculated independently utilizing PROC REG of SAS (SAS Inst. Inc., Cary, NC).

Reproduction data, such as percent calving, percent AI, BW of calves, and calving date, were recorded for first and second calf heifers remaining in the breeding herd. Heifers were characterized as: low-intake, medium-intake, or high-intake, based on their RFI score. Animals within one standard deviation of the herd average were considered medium-intake, whereas, those above and below, were characterized as high- and low-intake, respectively.

### *Statistical Analysis*

Data were analyzed as a completely random design with RFI (low, medium or high) as a fixed effect using the GLM procedure of SAS (v. 9.4, SAS Inst. Inc., Cary, NY). Cow served as the experimental unit. Means were separated using Tukey-Kramer test.

## RESULTS AND DISCUSSION

Of the 173 heifers characterized for intake using RFI scores, 26% were considered low-intake, 43% were considered medium-intake, and 31 % were considered high-intake. High-, medium- and low-intake means by group for birth date, birth weight, weaning weight, age at start of trial, initial weight, final weight, dry matter intake, RFI, ADG, G:F, and RG are presented in Table 2, however, no treatment by group interactions were detected. As a whole, birth date, birth weight, weaning weight, initial weight, final weight, and ADG did not differ among the three intake characterizations. Differences in age of start date in d were detected ($P > 0.05$), however correlation with RFI was extremely low ( Figure 1). Dry matter intake differed among groups ($P < 0.05$), with low-intake animals consuming less and high-intake animals consuming the most as shown by the RFI scores (Table 3). Also, located in the table, RG was highest in low-intake heifers, followed by medium-intake heifers with high-intake heifers having the smallest RG ($P < 0.05$). In addition, low-intake heifers had a higher ($P < 0.05$) G:F than both medium- and high-intake heifers. In addition, range heifers characterized for RFI and RG were placed in low-gain (< 0.5 SD), medium-gain (± 0.5 SD) and high-gain (> 0.5 SD) groups and compared (Table 3a). Of the 173 heifers, 29, 46 and 25 % were characterized as low-, med- and high-gain animals. No differences ($P < 0.05$) in birth weight, initial weight on trial, final weight on trial, and DMI were detected among groups. High-gain heifers were born 13 d later ($P <$

0.05) in the year compared low- and medium-gain animals. Low-gain heifers were 22 kg heavier at weaning than high-gain heifers ($P < 0.05$). Residual feed intake was lower ($P < 0.05$) for high-gain heifers compared to low- and medium-gain animals. However, correlation between RG and RFI was low to moderate ($r = 0.17$). As expected, high-gain heifers had a larger ADG than both medium- and low gain animals, and medium-gain heifers had a larger ADG than low-gain animals ($P < 0.05$). Residual gain was only moderately correlated to ADG ($r = 0.40$).

The following reproductive data were collected on 113 of the heifers remaining in the breeding herd: pregnancy rate, calving rate, percent bred AI, percent bull calves, calf birth weight, and calf birth date. Weaning and yearling weights for heifer calves are not presented because calves were utilized for various early weaning studies or data were not available. No differences were detected among low-, medium-, and high-intake heifers (Table 4).

As expected, low-intake cattle ate less than medium- and high-intake animals which could be beneficial to animals on challenging rangelands where stocking rates are low and forage is often limited. In addition, a study by Knight et al. (2015) indicated that lower intake range cattle may travel further to seek out better quality forage and utilize a wider range of elevation than higher intake range cattle, as well as, rebreed earlier in the season. Selecting for low-intake animals for the breeding herd has the potential to improve forage utilization, grazing distribution, and stocking rates. The expense of collecting intake data to calculate RFI is high, and could be cost prohibitive. Therefore, selecting bulls based on feed intake for replacement heifers would have the greatest economic advantage. Archer et al (2004) established that it would be profitable for the Australian beef cattle industry to incorporate RFI on 10-20% of sires for seedstock producers. The results of this study do not indicate any negative effects of utilizing low-intake heifers. Low-intake animals demonstrated a better RG and GF and retained a lower DMI while ADG remained similar. Arthur et al. (2002) states that RFI should be phenotypically independent of ADG and weight when those traits are used in the calculation for RFI. A study by Hafla et al. ( 2013) characterized two consecutive years of heifers for RFI, and the 12 highest and lowest RFI heifers were kept for breeding. They reported that no differences in calving date, body weight, body weight gain, and body composition (measured via ultrasound) were detected. However, low RFI heifers consumed 17% less forage ($P < 0.01$). The study also noted that calves born to low RFI heifers had a lower birthweight compared to higher RFI heifers, but this trait was not present during their second calving. Results by (Hafla et al., 2013) report strong correlation between phenotypic RG and G:F, ($r = 0.97$). Phenotypic RG correlation to G:F was low-moderate ($r = 0.25$) among the 3 groups of heifers tested in this study.

No differences were detected in pregnancy rate, calving rate, calf birth date, calf birth weight, or percent born by AI, or calf sex for low-, medium- and high-intake heifers which is consistent with the literature. Basarab et al. (2007) found no differences among intake classifications in respect to pregnancy rate, calving rate, weaning rate, cow body weight, calf birth weight, pre-weaning ADG, 200-d weight, or calving interval over 10 production cycles ($n = 222$). However, Shaffer et al. (2011) described a negative linear relationship with age at puberty and RFI. Utilizing British heifers ($n = 137$), they found that positive RFI heifers reached puberty 13 d earlier than negative RFI heifers, but pregnancy and conception rates remained the same. Basarb et al. (2011) reported that heifers selected for low RFI had lower reproductive rates and suggest that low RFI heifers have a decreased percentage of body fat compared to high RFI heifers, which could contribute to a slightly delayed onset of puberty and therefore decreasing reproductive rates. Shaffer et al. (2011) proposes that since a wide variation in the onset of puberty occurs in low and RFI heifers, low RFI and early onset of puberty could be used as selection criteria with little impact on herd fertility.

**CONCLUSIONS**

Utilizing low RFI as a selection criteria for replacement heifers has the potential to reduce costs through reduced feed consumption. On a range situation, low intake animals have the potential to improve grazing distribution, and forage utilization by informing land managers allowing them to make better decisions determining stocking rates. Low RFI heifers could suffer lower reproductive rates due to later onset of puberty caused by slower growth and fat deposition. However, selecting for heifers that are both low RFI and have an earlier onset of puberty can prevent losses in conception rates while reducing herd intake and improving RG and GF of calves.

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**Table 2.** Residual feed intake characteristics of range heifers by group

| | Low-intake | Medium-intake | High-intake |
|---|---|---|---|
| **Group 1** | | | |
| No. of heifers | 14 | 32 | 16 |
| Birth date* | 115 | 112 | 110 |
| Birth weight, kg | 32 | 33 | 32 |
| Weaning weight, kg | 169 | 181 | 175 |
| Age at start, d | 244 | 247 | 249 |
| Initial weight, kg | 195 | 207 | 196 |
| Final weight, kg | 230 | 248 | 239 |
| DMI, kg $d^{-1}$ | 4.8[a] | 6.0[b] | 6.7[b] |
| RFI, kg $d^{-1}$ | -0.85[a] | -0.05[b] | 0.86[c] |
| ADG, kg $d^{-1}$ | 0.86 | 0.94 | 0.91 |
| G:F | 0.18[a] | 0.16[b] | 0.14[c] |
| RG, kg $d^{-1}$ | 0.14[a] | 0.01[b] | -0.14[c] |
| **Group 2** | | | |
| No. of heifers | 16 | 15 | 21 |
| Birth date* | 104 | 93 | 97 |
| Birth weight, kg | 33[a] | 32[ab] | 31[b] |
| Weaning weight, kg | 211 | 212 | 205 |
| Age at start, d | 332 | 344 | 340 |
| Initial weight, kg | 260 | 255 | 256 |
| Final weight, kg | 330 | 323 | 329 |
| DMI, kg $d^{-1}$ | 7.2[a] | 8.5[b] | 9.6[c] |
| RFI, kg $d^{-1}$ | -1.38[a] | 0.12[b] | 0.96[c] |
| ADG, kg $d^{-1}$ | 0.99 | 0.96 | 1.02 |
| G:F | 0.13[a] | 0.11[b] | 0.11[b] |
| RG, kg $d^{-1}$ | 0.04 | -0.02 | -0.03 |
| **Group3** | | | |
| No. of heifers | 15 | 28 | 16 |
| Birth date* | 112 | 103 | 102 |
| Birth weight, kg | 33 | 32 | 32 |
| Weaning weight, kg | 173[ab] | 183[a] | 164[b] |
| Age at start, d | 197 | 226 | 210 |
| Initial weight, kg | 186[ab] | 199[a] | 175[b] |
| Final weight, kg | 197[ab] | 226[b] | 210[ab] |
| DMI, kg $d^{-1}$ | 3.4[a] | 5.3[b] | 5.4[b] |
| RFI, kg $d^{-1}$ | -1.12[a] | 0.09[b] | 0.94[c] |
| ADG, kg $d^{-1}$ | 0.72 | 0.82 | 0.78 |
| G:F | 0.27[a] | 0.16[b] | 0.14[b] |
| RG, kg $d^{-1}$ | 0.04 | 0.00 | -0.04 |

**Birthdate is reported in Julian day*

*Means with different superscripts are considered significantly different ($P \leq 0.05$)*

**Table 3.** Residual feed intake characteristics of range heifers

| | Low-intake | Medium-intake | High-intake |
|---|---|---|---|
| **Total** | | | |
| No. of heifers | 45 | 75 | 53 |
| Birth date* | 110 | 105 | 102 |
| Birth weight, kg | 33 | 32 | 32 |
| Weaning weight, kg | 185 | 188 | 183 |
| Initial weight, kg | 215 | 213 | 213 |
| Final weight, kg | 255 | 255 | 266 |
| Age at start, d | $262^{ab}$ | $254^{a}$ | $275^{b}$ |
| DMI, kg $d^{-1}$ | $5.2^{a}$ | $6.2^{b}$ | $7.5^{c}$ |
| RFI, kg $d^{-1}$ | $-1.14^{a}$ | $0.03^{b}$ | $0.92^{c}$ |
| ADG, kg $d^{-1}$ | 0.86 | 0.90 | 0.92 |
| G:F | $0.19^{a}$ | $0.15^{b}$ | $0.13^{b}$ |
| RG, kg $d^{-1}$ | $0.07^{a}$ | $0.00^{b}$ | $-0.07^{c}$ |

**Birthdate is reported in Julian day*
*Means with different superscripts are considered significantly different ($P \leq 0.05$)*

**Table 3a.** Residual gain characteristics of range heifers

| | Low-gain | Medium-gain | High-gain |
|---|---|---|---|
| **Total** | | | |
| No. of heifers | 50 | 79 | 44 |
| Birth date* | $102^{a}$ | $102^{a}$ | $115^{b}$ |
| Birth weight, kg | 31 | 32 | 33 |
| Weaning weight, kg | $196^{a}$ | $186^{ab}$ | $174^{b}$ |
| Initial weight, kg | 215 | 217 | 207 |
| Final weight, kg | 254 | 263 | 254 |
| Age at start, d | 264 | 271 | 246 |
| DMI, kg $d^{-1}$ | 6.1 | 6.6 | 6.2 |
| RFI, kg $d^{-1}$ | $0.26^{a}$ | $0.08^{a}$ | $-0.45^{b}$ |
| ADG, kg $d^{-1}$ | $0.70^{a}$ | $0.90^{b}$ | $1.12^{c}$ |
| G:F | $0.12^{a}$ | $0.15^{b}$ | $0.20^{c}$ |
| RG, kg $d^{-1}$ | $-0.19^{a}$ | $-0.01^{b}$ | $0.22^{c}$ |

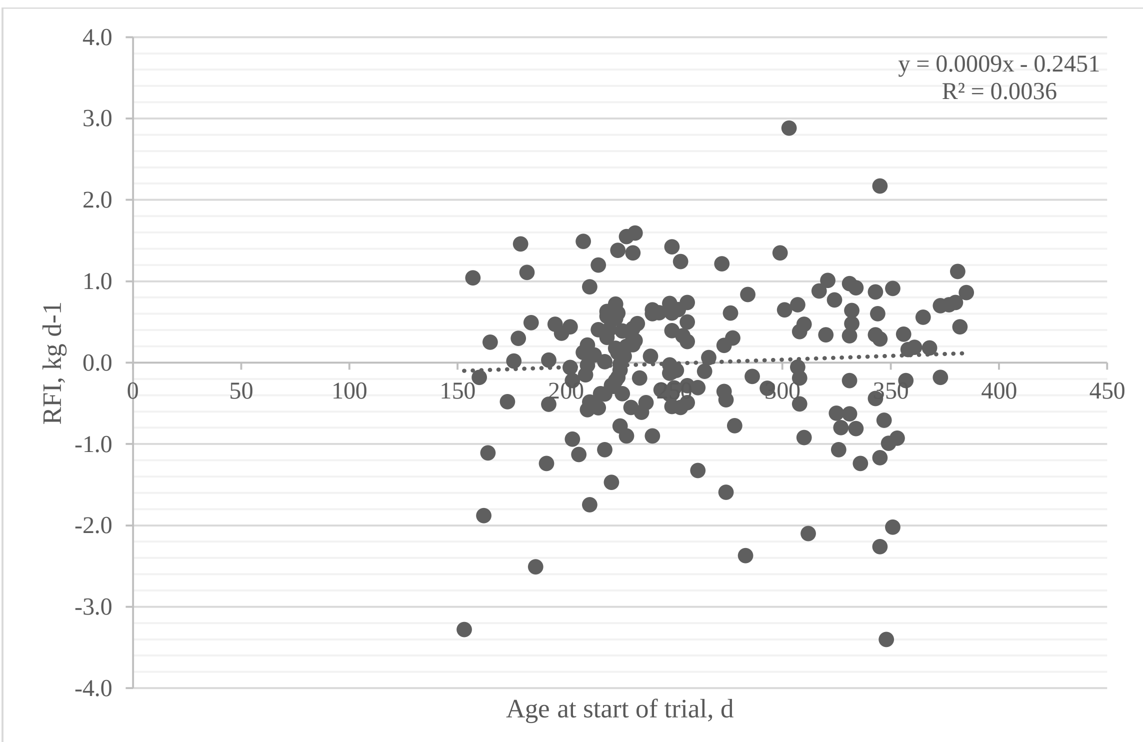
**Birthdate is reported in Julian day*
*Means with different superscripts are considered significantly different ($P \leq 0.05$)*

**Table 4.** Low-, medium-, and high-intake heifer reproductive characteristics for 2014 calving season

| | Low-intake | Medium-intake | High-intake |
|---|---|---|---|
| No. of heifers | 30 | 46 | 37 |
| Pregnant, % | 70 | 76 | 76 |
| Calving, % | 63 | 63 | 65 |
| Bred AI, % | 68 | 76 | 58 |
| Bull calf, % | 47 | 31 | 58 |
| Calf BW, kg* | 33 | 31 | 32 |
| Calf birth date** | 67 | 63 | 65 |

**Calf BW adjusted for sex*
***Birthdate is reported in Julian day*
*Means with different superscripts are considered significantly different ($P \leq 0.05$)*

**Figure 1.** Correlation of age at start of trial to RFI



APPENDIX THREE

# Low-cost GPS tracking collars for use on cattle.

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**ABSTRACT:** Commercially available GPS tracking collars for cattle are cost prohibitive to most researchers. This paper will present a low-cost alternative to those collars (Knight GPS tracking collars), and provide detailed instructions on where to source materials and how to fabricate inexpensive GPS tracking collars. In addition, the two types of collars will be compared in a study where Brangus cattle ($n$ = 8) were each fitted with LOTEK® 3300 and Knight GPS tracking collars for 31 d beginning 14 March 2015 at the Chihuahuan Desert Rangeland Research Center (CDRRC) 37 km north of Las Cruces, New Mexico. Location, slope, distance from water, distance traveled and elevation were recorded every 10 min. A record of GPS fix rate was logged. No differences were detected ($P \geq 0.369$) between collar types for location, slope, or distance from water. However, there was a tendency ($P = 0.08$) for Knight collars to report a lower estimate for distance traveled at 6171 m $d^{-1}$ compared to Lotek collars at 7104 m $d^{-1}$. Fix rate was greater ($P \leq 0.001$) for Lotek collars compared to Knight collars at 99.9 and 66.2%, respectively.

## INTRODUCTION

Global Positioning Satellite (GPS) technology has successfully been utilized by researchers to monitor both grazing distribution and activity. Important response variables, such as, distance traveled can be calculated from positioning data acquired from the GPS, and other sought after data, such as: elevation use, slope use, and distance from water or other key factors can be derived from an elevation model of the area (U.S. Geological Service) in conjunction with a geographic information system program such as ArcGIS® (v. 10.2.2, Esri). (Bailey et al., 2004) However, commercially available GPS tracking collars are cost prohibitive, with investments that can reach up to around $2000 per animal not including maintenance costs. Considering individual animal variability, researchers may not be able to afford the investment needed to properly utilize GPS technology.

Wildlife scientists have experimented with GPS technology longer than the livestock industry, and their commercially available collars tend to be more expensive because they need to incorporate technology in order to retrieve the collar to collect data. (Matthews et al., 2013) Even with collar costs exceeding thousands of dollars, failure is common due to construction and animal damage. (Gau et al., 2004, Strauss et al., 2008 and Ruykys et al., 2011) To combat the cost of losing equipment and data, efforts were made to repurpose inexpensive GPS technology to track wildlife. (Allan et al., 2013) Authors determined the lowest cost technology to be GPS data loggers commonly used to track travel, sports, pets, and map photos. The least expensive technology available was determined to be the Mobile Action i-gotU GT-120(New Taipei City, Taiwan). Authors removed excess weight from the device, added a larger capacity battery, and successfully fitted it to a collar suitable for tracking small wildlife. The purpose of this paper is provide information on constructing an inexpensive GPS tracking collar for cattle, and compare them to the commercially available LOTEK® 3300 GPS.

## MATERIALS & METHODS

### *Materials List and Cost Estimation*

Please see Table 5.

### *Fabricating Knight GPS tracking collars*

Please see Addendum 1.

***Comparing LOTEK® 3300 and Knight GPS tracking collars***

Experimental protocols were approved for all animals by the University of Arizona Institutional Animal Care and Use Committee.

Brangus cattle (*n* = 8) were each fitted with LOTEK® 3300 and Knight GPS tracking collars for 31 d beginning 14 March 2015 at the Chihuahuan Desert Rangeland Research Center (CDRRC) 37 km north of Las Cruces, New Mexico. Location, slope, distance from water, and elevation were recorded every 10 min. A record of GPS fix rate was logged.

*Fix = When the GPS loggers acquires satellite signal and records position data*

*Fix rate = Actual GPS coordinates recorded / Scheduled GPS coordinates*

Latitude and longitude coordinates were converted to the Universal Transverse Mercator coordinate system using a spreadsheet provided by the University of Wisconsin (http://www.uwgb.edu/dutchs/usefuldata/howuseexcel.htm) to facilitate calculation of distance traveled. Distance traveled can be calculated between any two points using Pythagorean theorem. Elevation, slope, and distance from water data were calculated utilizing spatial analyst tools in the mapping program ArcGIS® (v. 10.2.2, Esri) as described by D. W. Bailey in Sustainable Agriculture Research and Education SW09-054 (http://mysare.sare.org/sare_project/sw09-054/?page=final&view=print).

***Statistical Analysis***

Data were analyzed as a completely random design with collar (Lotek or Knight) as a fixed effect using the GLM procedure of SAS (v. 9.4, SAS Inst. Inc., Cary, NY). Cow served as the experimental unit.

**RESULTS & DISCUSSION**

Distance traveled ($m \cdot d^{-1}$), elevation (m), slope (% rise), distance from water (m), and fix rate (%) are presented in Table 6. Fix rate for Knight Collars were lower ($P < 0.001$) than Lotek 3300 units. Knight collars, equipped with igotU GT-120 GPS loggers were set to record every 10 min and were placed in power saving mode to save battery. Essentially, power saving mode powers down the unit between GPS fixes, and has to restart and reacquire GPS signal if the unit is set at intervals longer than a few minutes. If the unit takes too long to acquire signal, data is not recorded. Frair et al. (2004) commented on that one inherent problem with GPS telemetry is the failure for units to acquire signal and record data. Combined with spatial inaccuracies, distance traveled may be over-estimated. (Pépin et al., 2004) Other conditions leading towards GPS error include: atmospheric conditions, satellite geometry, satellite or receiver clock error, satellite orbit error, and bounced signals (Hurn, 1993), as well as, obstructions to the antenna's line of sight to the sky (D'Eon and Delparte 2005) like: trees, valleys, mountains, buildings, and etc. However, Johnson et al. (1998) suggests that lost data could impact results more than inaccurate data.

A trend ($P = 0.080$) in distance traveled between Lotek and Knight collars were detected, and correlation between collars was only moderate ($r = 0.33$). This trend is most likely due to the lower fix rate of the Knight collars. Knight et al. (2015) was able to utilize Knight collars to show differences among low- and high-intake cattle on semi-arid rangelands in Arizona. Numerically, the estimate of distance traveled was lower for Knight Collars compared to Lotek, and the lower fix rate ($P < 0.001$) could account for that difference.

Average, maximum and minimum elevation utilization, slope utilization, and distance from water indicate no meaningful differences ($P \geq 0.369$). Animals utilized flat ground daily during this trial, so minimum slope utilization was 0 for all collars. Minimum distance from water between Lotek and Knight Collars had a greater magnitude of difference, numerically. This is most likely due to the time at which fixes were taken. Both Lotek and igotU loggers can be programmed to start at a specific time and at regularly scheduled intervals. However, the igotU loggers do not adhere to the schedule as well as Loteks. For example, if Loteks are programmed to take a fix every 10 min at the start of every hour, they will record at 1200, 1210, 1220, 1230, 1240, 1250, 0100 etc. typically, within 1 min. The igotU loggers will waiver from the precise schedule if they need extra time to acquire a satellite fix. For example, if fixes are scheduled like above, but the unit is unable to acquire a fix for 3 minutes, the log may look like this; 1200, 1210, 1223, 1233, 1243, 1253, 0103 etc. This type of scheduling error means that these loggers would not be well suited if the researcher needs to compare where 2 or more animals are in relation to one another at specific times.

In addition, Lotek collars are able to record ambient temperature, have accelerometers that can detect motion both up/down and left/right, and include a Position Dilution of Precision (DOP) for each fix. Accelerometer data, combined with distance traveled information can be used to detect activity associated with grazing and walking. (Ungar et al. 2005; Ganskopp and Bohnert 2006) The DOP measurement is useful as a tool to quickly screen for inaccurate data. However, there is no universal method currently used to filter out inaccurate GPS data points.

## IMPLICATIONS

Do to the lower fix rate of the igotU GT-120 logger, comparing distance traveled data between Knight and Lotek collars could compound error. In order to improve fix rate on the igotU GT-120 devices, power saving mode should not be utilized. The authors' experience thus far with the collars suggests that power saving mode is unnecessary, and the GPS logger's memory will most likely fill before battery power is drained. In addition, shortening the scheduled fix interval will allow the logger to stay in contact with satellites preventing lost data due to failure to acquire fixes. Data between collars associated with distance from water, elevation and slope appear the same and could be compared between collar types. Lotek collars have a more reliable fix rate and fix schedule, as well as, additional features such as the ability to record ambient temperature, motion detection on two axes, and provide a DOP for individual data points. However, the cost of these collars is prohibitive to most researchers, and a more cost-effective tool is needed. Utilizing low-cost GPS tracking collars would allow researchers to detect differences in individual animals for response variables with larger individual variation. Inexpensive collars would also allow more researchers the opportunity to utilize GPS technology which will lead to new ideas and advancements on how to best use the technology.

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**Addendum 1.** Creating low-cost GPS tracking collars for cattle

1. Place heavy latigo leather side on large table (table top will be cut/scratched)
2. Using a long straight edge (1.2-1.8 m (4-6 feet) aluminum rulers available at the hardware store work well), trim the back side of the leather straight using a sharp utility knife (change blades frequently when working with leather).
3. Place the newly cut straight edge of the leather side along the edge of the table. Supporting the leather with one hand, use a draw gauge set to 38.1 mm (1.5 inch) to cut straps the length of the leather.
    a. NOTE - Avoid using the belly portion of the latigo side. It is soft and will not stay stiff over time.
4. Cut straps to 1346 mm (53 inches).
5. Use a 1346 mm (1.5 inches) English point strap end cutter to shape both ends of the strap.
6. Using card stock or manila folder material create templates for the buckle end of the strap and the adjustment hole end of the strap. Punch holes in appropriate locations.
    a. See Figure 2. Buckle end measurements
    b. See Figure 3. Adjustment hole end
7. Place template on appropriate end of the strap, and use a large black permanent marker to mark all punch locations.
8. Using a quality 3.175mm (0.125 inches) leather hole punch and leather working maul lubricate end of the punch using a block of beeswax and punch holes in buckle end of the strap. Using a quality 25.4 mm (1 inch) oblong punch, lubricate the punch

in a block of beeswax and punch 1in oblong hole in the buckle end of the strap. See Figure 2

   a. NOTE – Use a quality punch that you strike with a hammer (Weaver Leather in Mt. Hope, OH supplies Weaver Master Tools). Plier type punches will take longer to use and most likely break before all collars are made.
   b. NOTE – Not using beeswax will cause the punches to become stuck in the leather. The beeswax will lubricate the tool end and make removing punches much easier.
   c. NOTE – Do not strike leather working tools with a metal hammer, only use rawhide or poly head mallets and mauls.
   d. NOTE – Mauls are rounded to prevent pitting with repeated striking. Mallets have flat faces. Mauls will have an extended service life but mallets will be easier to strike punches. Heavier Mauls and Mallets make hole punching in thick leather easier because the weight of the tool does the work.
   e. NOTE – Thick latigo leather can be bent over easily if it is soaked in water and placed in a bench vice. This makes installing the rivets much easier because the strap sits flush.

9. Starting six inches from the opposite end of the strap from the buckle end, begin punching 6.35 mm (0.25 inch) holes 31.75 mm (1.25 inch) apart. 9 holes total. See Figure 3.

a. NOTE – Punching holes is much easier if you have a solid workbench and a good polymer pad or tree stump to prevent damage to the end of the punch or making the punch dull prematurely
b. NOTE – Punches can be kept sharp by frequently lubricating with beeswax (stabbing the punch into the beeswax block lightly is enough). Also, punches can be kept very sharp by stropping the punch along a piece of leather with automotive rubbing compound or jewelers rouge.

10. Place a 1346 mm (1.5 inches) stainless steel center bar buckle on the buckle end of the strap.
11. Using 15.875mm (0.625 inch) #12 copper rivets and a #12 copper rivet setter, rivet first two position rivets to hold buckle onto strap.
    a. NOTE – To use copper rivets, place rivet through both holes, and place on a solid metal surface such as an anvil or shop vice. Place bur on top of rivet, and drive bur to the leather with a single firm blow from the maul and rivet setter. Once bur is in place, use a set of heavy nipper (like horse shoeing nippers – Authors use 406 mm (16 inches) Channel Lock nippers available from hardware stores) to remove excess rivet shaft (about 15.875mm (0.0625 inch) from the bur). Then use the rounded portion of the rivet setter to peen the rivet head. This will take 2-3 blows from the maul.
12. Place a 1346 mm (1.5 inches) stainless steel keeper between the 2$^{nd}$ and 3$^{rd}$ holes, and install 3$^{rd}$ copper rivet See Figure 4
13. Create a template for GPS pouch. See Figure 5
14. Trace templates onto 8 oz vegetable tanned leather and cut/punch.

a. NOTE – vegetable tanned leather is also referred to as tooling leather, skirting leather, saddle leather or strap sides. It is available in many different forms from many different tanneries. Purchasing a side or 2 double shoulders should be enough to construct 30 collars.

b. Lining up straight edges on the leather hide will allow you to cut the leather with a long straight edge and a sharp utility knife – change blades often.

c. NOTE – Do not cut 90 degree concave corners in leather – It creates a weak point that can tear easily. Instead, use a hole punch in the corners. This also prevents accidently cutting into the pouch with the utility knife. This also makes cutting the straight edges with the utility knife easier. Authors prefer to use a 9.5 mm (0.375 inch) punch to allow a lot of room for the utility knife blade.

15. Approximately 508 mm (20 inches) from the buckle end of the strap, rivet the wide portion of the pouch to the strap using 2 #12 copper rivets using the holes located between the stitch lines on figure 5.

16. Stitch the pouch to the leather strap using a Compound Feed walking foot sewing machine using at least #138 bonded nylon thread. The first 3 and last 3 stitches need to be back stitched, and thread ends melted with a lighter to secure in place.

a. NOTE- Bigger thread like # 207 or #277 would be better, but stitch size is dependent on sewing machine.

b. NOTE – compound feed walking foot sewing machines are expensive (starting ~ $1600), and used machines can be hard to find. This may need to be an outsourced step. Hand sewing is possible using pricking irons and harness needles using a saddle stitch but probably too labor intensive to be practical. Authors use a modified Consew 206RB-1 to stitch collars. Generic copies of JUKI 441 machines would work best for this task (makers Cobra, Cowboy, Techsew, etc.)

17. Place Corner F and Corner A together and stitch the entire edge 4.76 mm (0.1875 inch) or 6.35 mm (0.25 inch) from the edge. Again, backstitching the first and last 3 stitches. Melt the thread ends.
18. Repeat, but place Corners H and C together and stich the length of the edge.
    a. NOTE – Edges will not align perfectly. Once both edges are sewn, place them on the edge of a table and use a sharp utility knife to cut the edge flush.
19. Close the flap using 9.5 mm (0.375 inch) decorative Chicago screws.
    a. NOTE – Place the decorative head of the screw inside the pouch. The decorative head provides grip from the rough surface and make tightening the screw easier.
    b. NOTE – Chicago screws will come loose eventually – Authors use Loc Tite to hold screws together permanently. To remove the GPS Unit, simply cut the Chicago screw with the nippers.
20. Strap is now ready to be used with GPS unit.
    a. If you would like to attach a permanent number to the collar, Authors recommend buying set of number stamps. Soak the leather with water, place on a hard solid surface, and stamp the numbers into the leather using the stamp and maul. Custom makers mark stamps can be purchased to add identifying marks if desired.

MAKING THE GPS UNIT

1. Remove rubber cover from iGotU Gt-120 Gps Unit (GPS).
2. Punch a 3.2 mm (0.125 inch) hole in the back right corner (on the side close to the back) of the rubber cover.
3. Place batter leads through the rubber cover hole just punched (from outside in).
4. Tin the leads of the 3.7volt 5200miliamphour li-ion battery pack.
    a. NOTE -Tinning is melting solder to the ends of the wire. Heat the wire not the solder with the solder iron and touch the solder to the hot wire to melt it into the strands of the wire. Heating the solder will result in cold solder joints that will fail at a later date. Do not blow on hot solder it creates weak/brittle solder joint.
    b. NOTE – Make sure the battery pack has PCB protection (overcharge protection).
5. On the back right corner of the GPS, careful pry the back cover off using an awl. Don’t worry about slightly damaging the side wall at the entry point. This will also serve as a location to file a small notch for the battery leads.
    a. NOTE – This unit is not made to come apart. Care needs to be taken not to damage the portion of the case with the USB plug port.
    b. NOTE – The silicone board located in the GPS unit can be damaged if the board is allowed to pivot up and down. Be careful, and don’t let it rock up and down.

6. Remove battery from back. Apply light pressure to existing battery leads. Touch soldering iron to solder holding battery leads to the unit. Remove one at a time.
7. Solder new battery pack leads onto the unit. If you forget which wire goes where, the Red wire attaches to the positive side, which is marked with a (+).
    a. NOTE – stray solder or solder pooling together can be corrected by scraping it with the awl. If care is taken, no damage will be done.
8. Apply liquid electrical tape to the circuit board. Cutting an appropriate sized hole in cardboard makes a great spraying template. Allow to dry thoroughly.
    a. NOTE – Use liquid tape conservatively. Applying to heavily will allow liquid tape to bleed around the circuit board and block the LED lights. The LED lights are extremely useful in telling whether the unit is on and acquiring signal.
9. Mix two part marine epoxy and apply a small amount to secure battery leads to circuit board. Then apply a small amount to the circuit board.
10. While epoxy is still wet, make a small loop in the battery leads and mash it into the epoxy. Place more epoxy on top of the loop and replace the back cover. Use electrical tape to hold the unit together while it dries. Take care not to cover up the 2 LED lights or USB port. Making the loop on the inside of the unit and epoxying it in place prevents the wires from being pulled out or applying any pressure to the circuit board.
    a. NOTE – Epoxying the board you can easily rock the circuit board and break the connections rendering the unit useless. Take extra care on this step. Once the epoxy has set though, the unit is extremely tough. I suggest buying

3-4 extra GPS units in case you break a few. I have made 32 of these units and broken 3 of them. Also, due to the nature of inexpensive electronics, you may find a malfunctioning unit. Having a few spares on hand is nice.

11. Leave on electrical tape and replace rubber case.
12. Place in a quality 0.95 liter (1 quart) freezer bag. Remove air, zip closed.
13. Place decorative end of Chicago screw on the inside of pouch.
14. Place bagged gps in Batter first and unit button facing down (towards the latigo strap) to prevent anything from accidently poking the top and pushing the button.
15. * I like to put two bands of gorilla tape around the pouch to add a third means of attachment (probably unnecessary).
16. The tail of the strap, once on the animal, is secured using gorilla tape. Also, placing a hole on the tail end of the strap for an outdoor rated cable tie provides extra security.

The iGotU GT-120 will store 65,000 way points, and the above battery pack will last at least 6 months set to take reading every 10 min. Authors have not yet run the units longer than 6 months.

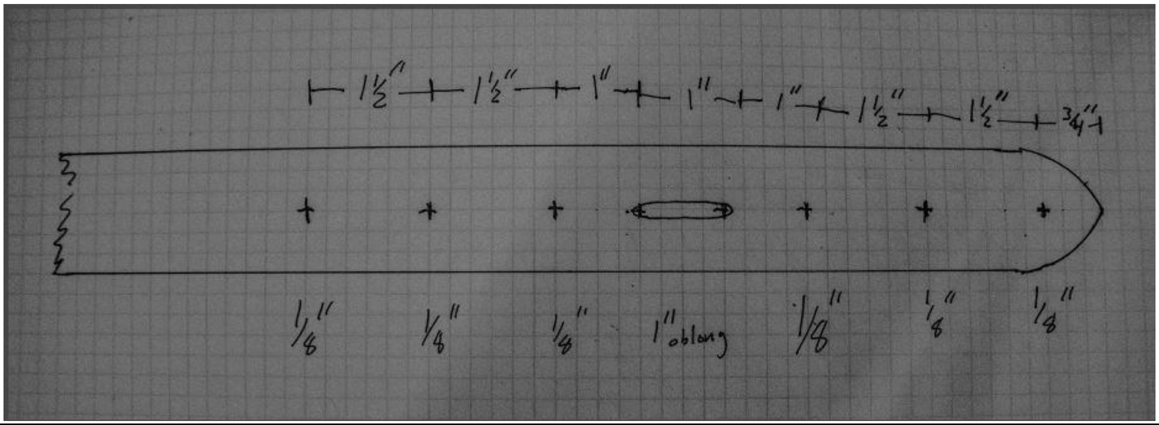
The unit may need to be reset after installing the new battery. Simply connect the unit to a computer with the included USB cable to allow it to reboot.

**Table 5.** Knight GPS tracking collar materials and cost estimate based on fabrication of 30 collars

| *Quantity* | *Material* | *Cost per unit* |
|---|---|---|
| (2) | 12/13 oz. Latigo leather side | 225.00 |
| (1) | 4' Straight edge | 16.38 |
| (1) | Utility knife | 6.38 |
| (1) | Package utility knife blades | 18.50 |
| (1) | Leather working draw gauge | 36.25 |
| (1) | English point strap end cutter | 73.00 |
| (1) | Card stock/manila folder | 0.00 |
| (1) | 1/8" Hole punch | 35.25 |
| (1) | 1" Oblong hole punch | 86.00 |
| (1) | 1/4" hole punch | 36.00 |
| (1) | Leather working maul/mallet | 95.00 |
| (1) | High density polyethylene cutting board | 8.96 |
| (1) | Bees wax block | 4.98 |
| (30) | Stainless steel center bar buckle 1.5" | 3.50 |
| (1) | 10" Channel Lock nippers | 22.64 |
| (1) | 1 lb #12 0.625" copper rivets and burs | 27.00 |
| (1) | #12 copper rivet setter | 18.80 |
| (30) | 1.5" stainless steel keepers | 0.40 |
| (1) | 8 oz vegtan leather side | 102.00 |
| (1) | 3/8" leather hole punch | 41.50 |
| (34) | Mobile Action iGotU GT-120 GPS data logger | 50.00 |
| (30) | Tenergy Li-Ion 18650 3.7V 5200mAh PCB Protected | 19.99 |
| (1) | Soldering iron with pencil tip | 12.99 |
| (1) | Solder – 0.022 rosin core solder | 7.99 |
| (1) | Awl | 4.38 |
| (4) | Two-part marine grade epoxy | 5.77 |
| (1) | Roll of electrical tape | 1.99 |
| (1) | Small round file | 3.98 |
| (1) | Liquid electrical tape | 7.47 |
| (1) | Loc tite | 6.48 |
| (5) | 1" Gorilla® tape | 2.98 |
| (1) | 3/8" Chicago Screws (100 count box) | 26.25 |
| (1) | Cowboy 3200 sewing machine | 1800.00 |
| **Total** | | **$ 5404.67** |
| **Cost per collar (N = 30)** | | **$ 180.16** |

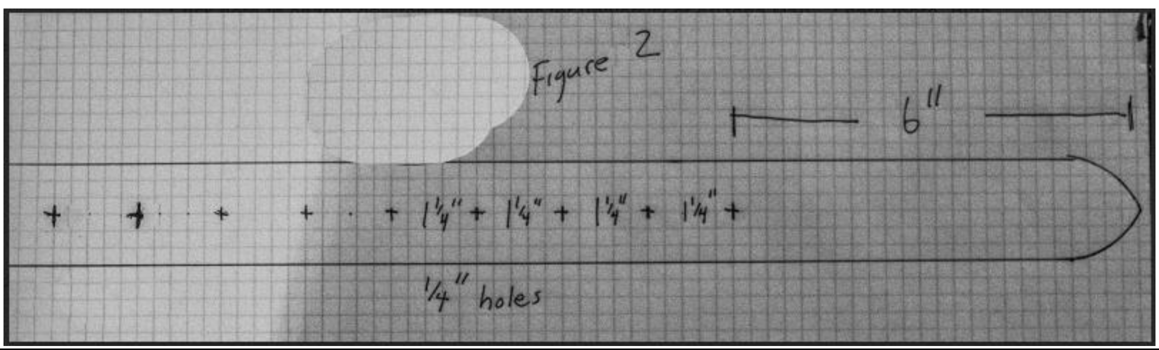
*Cost reflect US dollars. Prices do not reflect quantity or wholesale discounts. Hide House, Napa, California – Resource for leather. Weaver Leather Supply, Mount Hope, Ohio – Leather tools and hardware. Toledo Industrial Sewing Supply, Toledo, Ohio – Sewing machine. Remaining items are commonly available from hardware store or online retailers such as Amazon.com*

**Figure 2.** Buckle end measurements



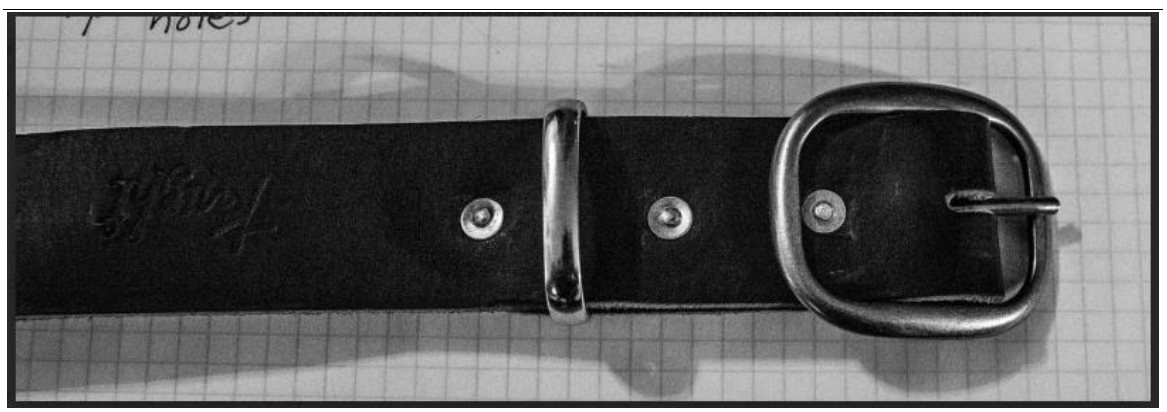

*Resolution of squares equals 0.25 in*

**Figure 3.** Adjustment hole end



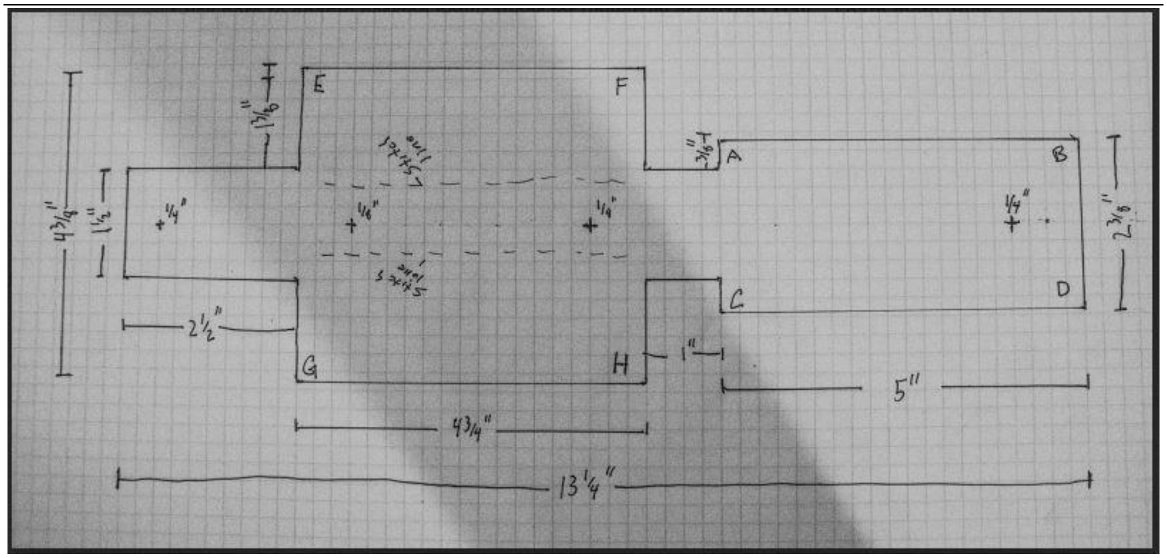

*Resolution of squares equals 0.25 in*

**Figure 4.** Picture of assembled buckle end



*Resolution of squares equals 0.25 in*

**Figure 5.** Blueprint of GPS pouch




*Resolution of squares equals 0.25 in*

**Table 6.** Comparing grazing activity of Brangus cattle using Lotek 3300 and Knight GPS tracking collars

| | Lotek | SD | Knight | SD | *P* |
|---|---|---|---|---|---|
| **Distance traveled, m $d^{-1}$** | 7104 | 1202 | 6171 | 716 | 0.080 |
| **Elevation, m** | | | | | |
| Average | 1319 | 2.2 | 1319 | 0.4 | 0.483 |
| Max | 1323 | 1.8 | 1323 | 2.1 | 0.958 |
| Min | 1309 | 5.6 | 1312 | 6.6 | 0.369 |
| **Distance from water, m** | | | | | |
| Average | 1726 | 105 | 1743 | 114 | 0.752 |
| Max | 2238 | 88 | 2230 | 92 | 0.873 |
| Min | 320 | 223 | 409 | 163 | 0.378 |
| **Slope, % rise** | | | | | |
| Average | 0.86 | 0.09 | 0.83 | 0.10 | 0.449 |
| Max | 7.8 | 0.8 | 7.0 | 0.7 | 0.424 |
| Min | 0.0 | 0.0 | 0.0 | 0.0 | ------- |
| **Fix rate, %** | $99.9^{A}$ | < 0.00 | $66.2^{B}$ | 0.11 | < 0.001 |

*Means with different superscripts are considered significantly different ($P \leq 0.05$)*
*Slope is presented as rise over run*

APPENDIX FOUR

## Intake and grazing activity of mature range cows on Arizona rangelands[2]

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[2] Authors would like to thank Keith G. and Keith O. Cannon, University of Arizona V Bar V Ranch.

**ABSTRACT:** Previously characterized commercial cows ($n$ = 26) were placed into either high (positive RFI) or low intake (negative RFI) groups. On 14 May 2015, 13 high- and 13 low-intake cows were fitted with modified igotU GT-120® GPS logging collars. Cattle were then placed on rangeland for 120 d. The first 30 d period animals transitioned from desert shrubland to pinyon-juniper. From 31 to 60 d, animals grazed pinyon-juniper rangeland. Next, during days 61 to 90, animals transitioned from pinyon-juniper to ponderosa pine, and the last 30 d were spent in ponderosa pine. Time periods will be referred to as month 1, 2, 3, and 4 for days 0 to 30, 31 to 60, 61 to 90, and 91 to 120, respectively. Location, slope, distance from water, elevation, and time spent close to water were recorded every 10 min. No differences were observed in the utilization of elevation or distance traveled, or distance from water ($P > 0.05$). Low intake animals used a higher maximum slope ($P < 0.05$) during month 3, but slope utilization differences were not detected for other portions of the trial ($P > 0.05$).

## INTRODUCTION

Holechek (1998) stated that semi-arid rangelands, such as those present in the Arizona, are subject to overgrazing which can lead to rangeland degradation over time. Improving the grazing distribution of animals across a rangeland could reduce over grazing, improve stocking rates, and promote better forage utilization. Selecting livestock that are willing to utilize higher elevation, tougher terrain, travel further to select forage, and travel further from water would be beneficial to both western rangelands and ranch managers seeking to utilize land to its potential and optimize cattle production.

One way to improve cattle herd efficiency is reduce energy inputs by selecting for animals with lower than expected feed intake. Cow intake can be 75% or more of a mature beef cattle herd’s total feed consumption (Archer et al, 1999), but most research is targeted towards the growing animals, steers in particular (Herd and Pitchford, 2011). On average, cow size, physiological state, milk production, and cow age relates to cow intake (NRC, Beef Cattle Requirements, 2005), however cattle express a large individual variation in intake. Koch et al. (1963) suggested a method to identify individuals that consumed more/less than expected called residual feed intake (RFI), or the difference between expected feed intake and actual feed intake. Carstens and Kerley (2009) state that RFI is phenotypically independent of production traits used to calculate intake, meaning cattle of various types and production levels can be compared. For example, Arthur et al. (2001) demonstrated that calves from parents selected for RFI differed significantly in feed intake, but were similar in body weight (BW) and production, suggesting that selecting for negative RFI could result in lower feed costs without affecting the level of production. In contrast, feed conversion ratios, such as feed:gain, are positively correlated with growth rate, increased body size, increased leaness, increased organ weights, increased heat increment, and decreased digestibility (Herd and Bishop, 2000). Australian research conducted by Arthur et al. (2001) bred divergent lines of RFI cattle. First, cows were placed into either low- or high-RFI groups based on their postweaning RFI scores. Low- and high-RFI females were bred to three to six of the lowest- and highest-RFI bulls. This selection process began in 1993 and ended in 1998. Low-RFI lines consumed 1.247 kg $d^{-1}$ less than high-RFI lines. This selection resulted in a 14% cost savings in feed for low-RFI cattle and an increase in post-weaning feed efficiency with little effect on growth. The objective of this study was to compare weights, BCS, breeding dates, calving interval and grazing behavior of low- and high-intake cows.

## MATERIALS AND METHODS

### *Animal Care and Use:*

Experimental protocols were approved for all animals by the University of Arizona Institutional Animal Care and Use Committee.

Beginning in the spring of 2013, 137 multiparous-mature cows (≥ 60 mo) born and raised on the University of Arizona's V Bar V ranch in Rimrock, AZ were fitted with RFID and placed in a drylot equipped with Growsafe® technology. Cattle were fed alfalfa hay and intake data were recorded for at least 10 d. Hay samples were analyzed at Servi-tech Laboratories in Dodge City, KS for forage quality. In addition, weight (kg), age (mo), days pregnant (d), body condition score (BCS) and average calving interval (CI) data were recorded. Days pregnant is determined through rectal palpation. The NRC (1996) model was then used to calculate RFI values for cows. Cattle with negative and positive RFI were characterized as low-intake and high-intake, respectively.

The University of Arizona V-Bar-V ranch, located in Rimrock, Arizona is approximately 28,732 ha, and roughly divided into three equal parts of desert shrubland, pinyon-juniper, and ponderosa pine with approximate elevations of 1066, 1524, and 2133 m above sea level, respectively. The university's beef cow herd of ~ 450 cow/calf pairs graze towards higher elevation in through spring, summer and fall from desert shrub in winter, to piñon-juniper in spring/summer, ponderosa pine in summer/fall and then return to lower elevations in late fall/winter each year.

On 14 May 2015, 13 high- and 13 low-intake cows were fitted with modified igotU GT-120® GPS logging collars. Cattle were then placed on rangeland for 120 d. The first 30 d period animals transitioned from desert shrubland to pinyon-juniper (average utilized slope 4.0%). From 31 to 60 d, animals grazed pinyon-juniper rangeland (average utilized slope 2.9%). Next, during days 61 to 90, animals transitioned from pinyon-juniper to ponderosa pine (average utilized slope 5.9%), and the last 30 d were spent in ponderosa pine (average utilized slope 4.3%). Time periods will be referred to as month 1, 2, 3, and for days 0 to 30, 31 to 60, 61 to 90, and 91 to 120, respectively. Location, slope, distance from water, elevation, and time spent close to water were recorded every 10 min. Data were recovered from 19 of the 26 GPS collars due to loss and/or error.

A list of high and low intake cows was generated based on which animals had been tested for RFI and were available at regularly scheduled working periods. With the ranch being so large, gathering all cattle was not possible, therefore, cattle were assigned a collar based on the order they came through the chute. As animals with RFI scores came through the chute, they were given a GPS collar until approximately half the collars were fitted to low-intake cattle, and half the collars were fitted to high-intake cattle.

Latitude and longitude coordinates were converted to the Universal Transverse Mercator coordinate system to facilitate calculation of distance traveled. Elevation, slope, and distance from water data were calculated utilizing spatial analyst tools in the mapping program ArcGIS® (v. 10.2.2, Esri).

On 4 June, 8 June, 9 July, 17 July, 29 July, and 8 August 2015 forage production and species composition were recorded. Forage production data were taken in the form of clipped samples taken from random locations in the area of animal grazing from a 40 x 40 cm frame. Clipped samples were dried in a 100° C drying oven, and weights were recorded on a dry matter basis, and data were extrapolated to a kg per hectare forage production.

Species composition data were taken along random transects with 25 points per transect utilizing the dry weight rank technique (Mannetje and Haydock, 2006).

***Statistical Analysis***

Data were analyzed as a completely random design with RFI (low or high) as a fixed effect using the GLM procedure of SAS (v. 9.4, SAS Inst. Inc., Cary, NY). Cow served as the experimental unit.

**RESULTS & DISCUSSION**

Of the 137 mature cows tested for intake, 37% were characterized as low-intake with the remaining 63% characterized as high-intake. No differences in predicted DMI intake were detected ($P$ = 0.86) between low-intake and high-intake cows. However, actual DMI for high-intake cows (12.2 kg/d) was greater ($P$ < 0.001) and differed from low-intake cows (9.32 kg/d). High- and low-intake cattle had mean RFI scores of +1.66 and -1.23, respectively ($P$ < 0.001). No differences in cow weight were detected between groups ($P$ = 0.21). Low- and high-intake cattle weighed 494 and 506 kg, respectively. Also, no differences in BCS were detected ($P$ = 0.06) between low- (5.2 BCS) and high-take cattle (5.4 BCS). In addition, low-intake cows (218 days pregnant) became pregnant sooner ($P$ = 0.0002) than high-intake cows, (201 days pregnant), indicating that low-intake cattle rebred 16d earlier than high-intake cattle. The average age of high-intake cattle was 98 mo while low-intake cattle were 90 mo ($P$ = 0.041). However, the correlation between cow age (mo) and RFI was low ($r$ = 0.076). Calving interval for low- and high-intake animals did not differ ($P$ = 0.977) at 418 and 419 d, respectively, suggesting that low- and high-intake animals maintain this difference year after year. Cattle on the V-bar-V ranch are first bred via artificial insemination and later placed on pasture with clean up bulls. Low-intake cattle may have a higher percentage of conception through artificial insemination year after year. This could explain why low-intake animals have an earlier conception date. Also, conceptus size of low-intake cattle at the time of rectal palpation may differ from high-intake cows contributing to misidentification of the conceptus age leading technicians to believe that low-intake animals have an earlier conception date. In addition, low-intake cattle may retain their body condition better and simply rebreed earlier in the season compared to high-intake cattle.

No differences ($P \geq 0.370$) were detected for distance traveled (m $d^{-1}$) between low- and high-intake cattle across months or as a whole (Figure 6). However, numerically, low-intake cattle traveled further three out of four months. Similar to distance traveled, no differences ($P \geq 0.150$) were detected in elevation utilization, but numerically, low-intake cattle utilized higher elevation for three out of four months, and as a whole (Figure 7). Like distance traveled and elevation, no statistical differences were seen between low- and high-intake animals for average slope utilization, but again, numerically, low-intake cattle utilized tougher terrain for three out of four months, and as a whole (Figure 8). Numerically, high-intake cattle traveled the furthest from water for all 4 months and as a whole, but no statistical differences ($P \geq 0.057$) were seen. However, total distance traveled from water approached ($P = 0.057$) significance (Figure 9). Maximum elevation utilization between treatments was similar ($P \geq 0.170$) across months and as a whole. (Figure 10). No differences ($P \geq 0.123$) were detected in maximum slope utilization between low- and high-intake animals, with exception of month 3 where low-intake cattle utilized ($P < 0.05$) rougher terrain than high-intake cattle with slopes of 19.4 and 17.8, respectively (Figure 11). Again, no differences ($P \geq 0.300$) were detected in maximum distance traveled from water, but high-intake cattle had higher numerical values three out of the four months, and when taken as a whole (Figure 12). Figure 13 represents the average amount of time per day low- and high-intake cattle spent within 200 m of established water sources. While no differences ($P \geq 0.219$) in time spent near water were detected, it is important to note that during months 3 and 4, rainfall created flowing streams and springs which were available to cattle.

Similar studies conducted by Knight et al. (2015) utilized low- and high-intake animals from the same herd in pinyon-juniper and ponderosa pine rangelands with similar numerical trends in distance traveled, elevation utilization, and slope utilization suggesting that individual animal variation is high for these traits between low- and high-intake cows, and more numbers will be needed to successfully study the interaction between intake and grazing behavior. Low-intake cattle maybe seeking out higher quality forage to meet their nutritional requirements. Higher elevations may contain higher concentrations of higher quality cool season forages, and they may have a lower percentage of cell wall due to lower predation. The use of inexpensive GPS tracking collars, such as the Knight GPS tracking collar which uses modified Mobile Action (New Taipei City, Taiwan) igotu GT-120 GPS data loggers could allow researchers an opportunities to study grazing behavior on larger sample sizes.

No differences ($P > 0.05$) in forage production (kg/ha) were detected among collection dates or months 1 to 4 (Table 7). In addition, species composition data are presented in table 8.

**CONCLUSIONS**

These data do not indicate any negative effects to utilizing low-intake as a selection criteria for cow herds on semi-arid rangelands. Low-intake animals may rebreed earlier in the season and consume less forage while maintaining their body condition and reproductive rates. In rougher terrain, and during times when forage quality and availability is low, low-intake cattle appear to utilize tougher terrain, higher elevation, and travel further to seek out higher quality forage. Authors recommend future studies with a larger sample size to further the understanding of the interaction between intake and grazing behavior.

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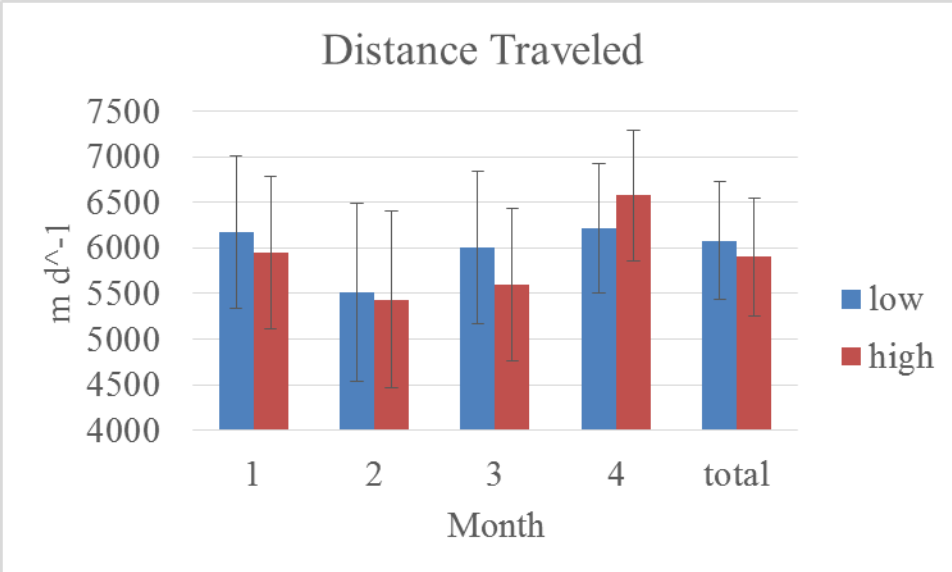
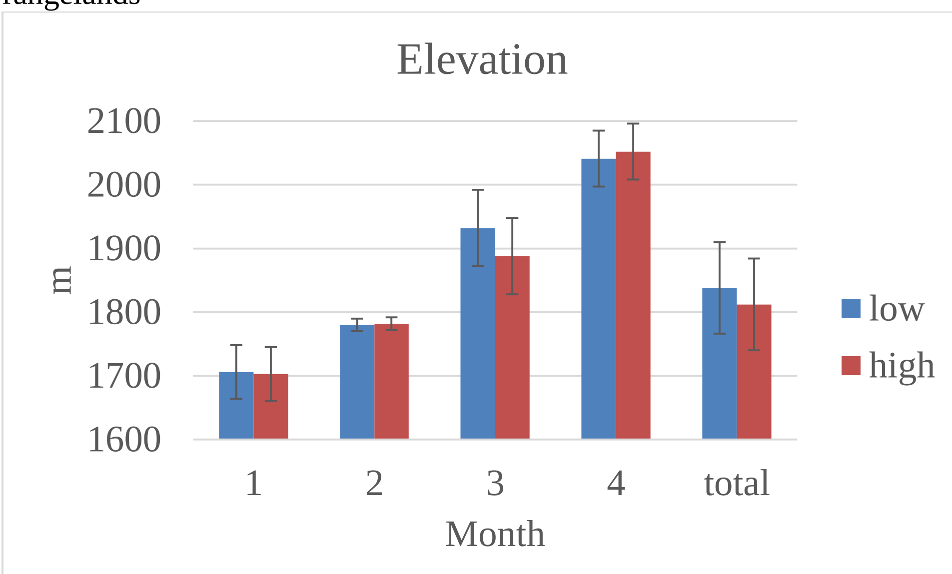
**Figure 6.** Average distance traveled per day by low- and high-intake cattle on semi-arid Arizona rangelands



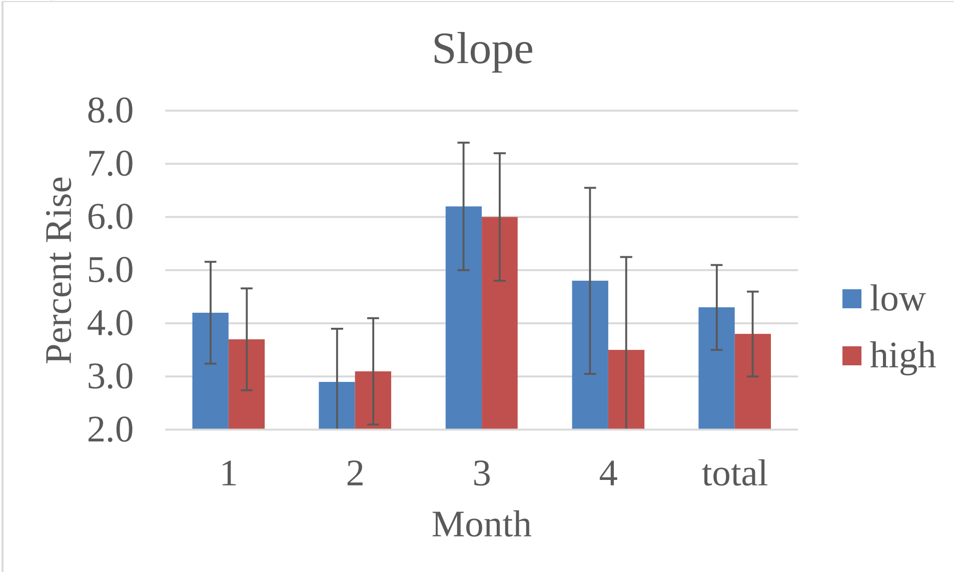

*Error bars represent standard error of the mean*

**Figure 7.** Average elevation utilization by low- and high-intake cattle on semi-arid Arizona rangelands



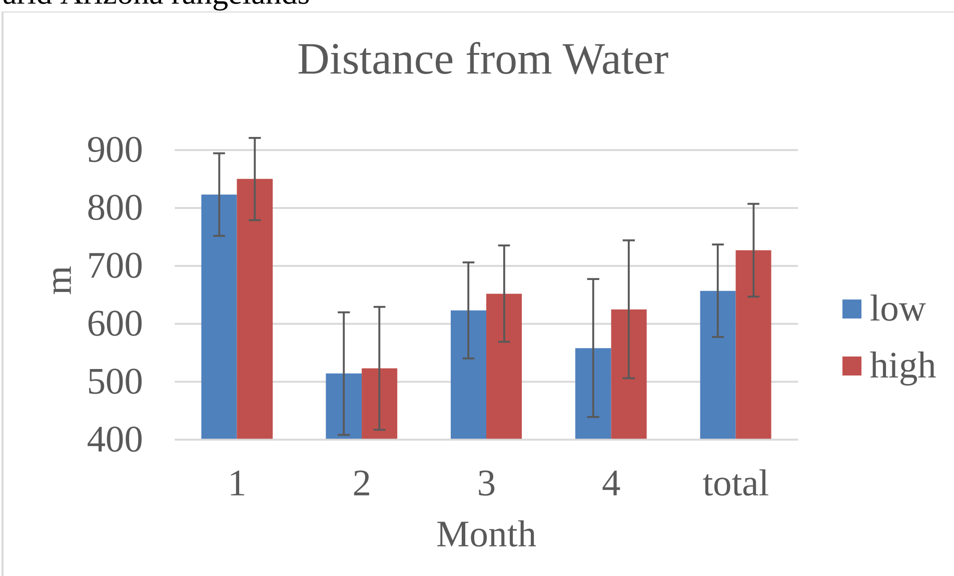

*Error bars represent standard error of the mean*

**Figure 8.** Average slope utilization by low- and high-intake cattle on semi-arid Arizona rangelands



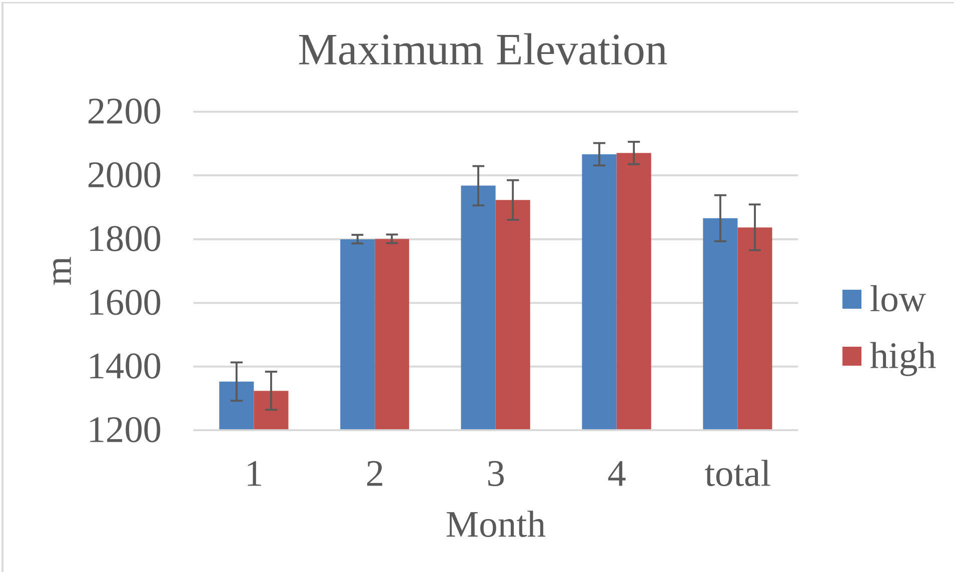

*Error bars represent standard error of the mean*

**Figure 9.** Average distance traveled from water for low- and high-intake cattle on semi-arid Arizona rangelands



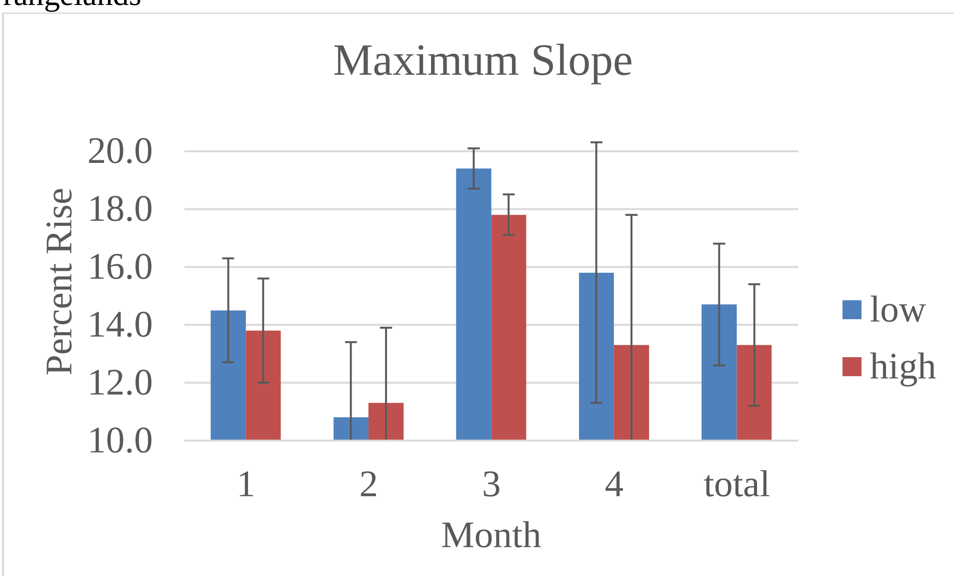

*Error bars represent standard error of the mean*

**Figure 10.** Maximum elevation use for low- and high-intake cattle on semi-arid Arizona rangelands



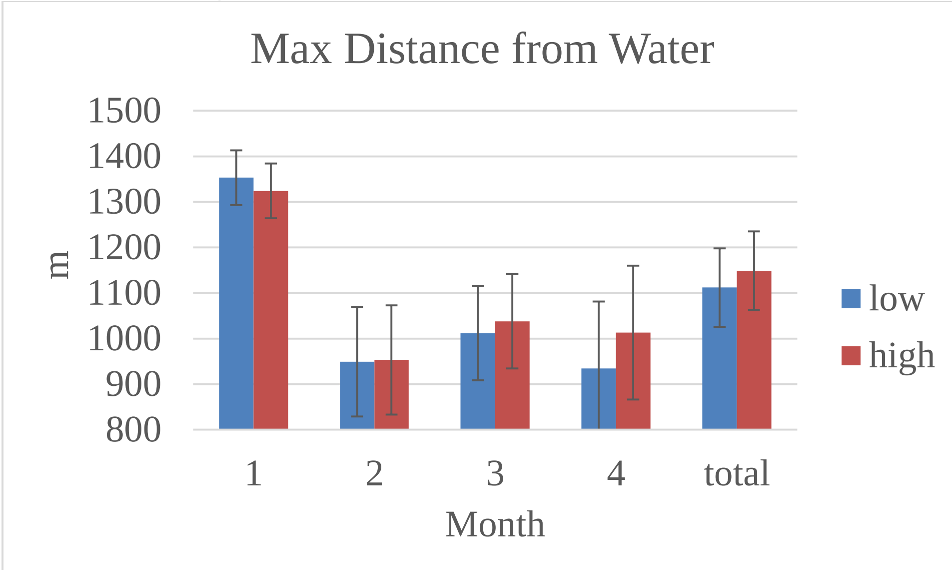

*Error bars represent standard error of the mean*

**Figure 11.** Maximum slope use for low- and high-intake cattle on semi-arid Arizona rangelands



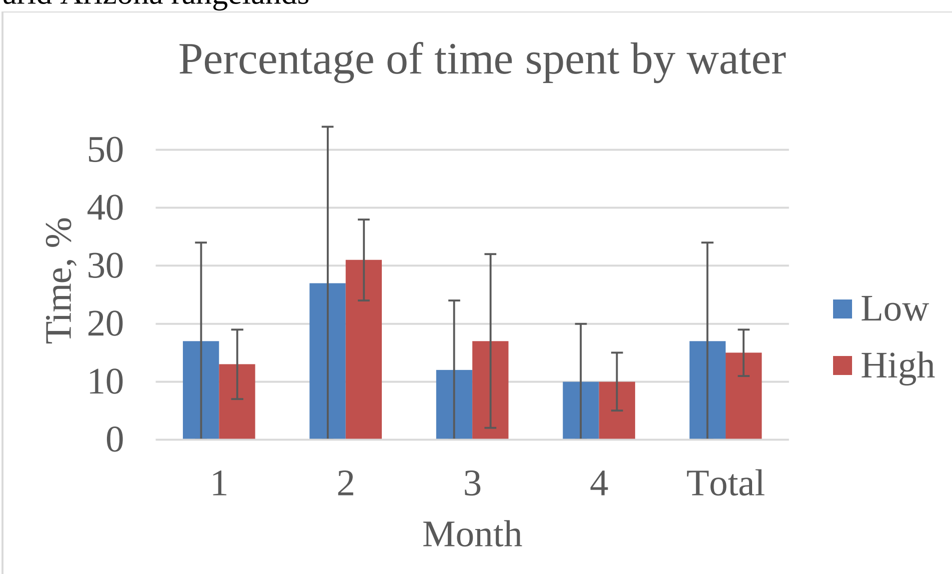

*Error bars represent standard error of the mean*

**Figure 12.** Maximum distance traveled from water for low- and high-intake cattle on semi-arid Arizona rangelands




*Error bars represent standard error of the mean*

**Figure 13.** Percentage of time spent close to water for low- and high-intake cattle on semi-arid Arizona rangelands




*Error bars represent standard deviation of the mean*

**Table 7.** Forage production of the University of Arizona V-bar-V ranch in Rimrock, Arizona

| | Elevation, m* | Month | *n* | kg/ha | SE |
|---|---|---|---|---|---|
| Date | | | | | |
| 6/4/2015 | 4424 | 1 | 14 | 1359 | 248 |
| 6/8/2045 | 4524 | 1 | 11 | 905 | 246 |
| 6/15/2015 | 4590 | 2 | 12 | 1151 | 199 |
| 7/9/2015 | 4736 | 2 | 7 | 877 | 188 |
| 7/17/2015 | 4711 | 3 | 10 | 1394 | 397 |
| 7/29/2015 | 5079 | 3 | 4 | 685 | 447 |
| 8/12/2015 | 5154 | 4 | 4 | 717 | 292 |

Means with dissimilar superscripts within columns are significantly different ($P < 0.05$)
n=number, kg/ha=kilograms of dry matter forage production per hectare, SE = standard error
*Average elevation reported in m above sea level

**Table 8.** Top 5 forage species by clipping date on the University of Arizona V-bar-V ranch located in Rimrock, Arizona

| Date | Species | Composition, % |
|---|---|---|
| **6/3/2015** | | |
| | Sideoats grama, *Bouteloua curtipendula* | 28.8 |
| | Blue grama, *Bouteloua gracilis* | *16.5* |
| | Western wheat grass, *Pascopyrum smithii* | 14.0 |
| | Long leaf false goldeneye, *Heliomeris longifolia* | 6.1 |
| | Hairy grama, *Bouteloua hirsuta* | 5.6 |
| **6/15/2015** | | |
| | Sideoats grama, *Bouteloua curtipendula* | 37.0 |
| | Western wheat grass, *Pascopyrum smithii* | 23.0 |
| | Blue grama, *Bouteloua gracilis* | 7.0 |
| | Long leaf false goldeneye, *Heliomeris longifolia* | 6.0 |
| | Squirrel tail, *Elymus elymoides* | 5.0 |
| **7/1/2015** | | |
| | Western wheat grass, *Agropyron smithii* | 71.0 |
| | Blue grama, *Bouteloua gracilis* | 11.0 |
| | Indian rushpea, *Hoffmannseggia glaucia* | 5.0 |
| | False goldeneye, *Heliomeris* | 4.0 |
| | Annual forb(s) | 3.0 |
| **7/17/2015** | | |
| | Blue grama,*Bouteloua gracilis* | *45.0* |
| | Sideoats grama, *Bouteloua curtipendula* | 18.0 |
| | Sulphur flower buckwheat, *Eriogonum umbellatum* | 4.0 |
| | Fleabane, *Erigeron asteae* | 4.0 |
| | Wild rye, *Elymus elymoides* | 3.0 |
| **7/28/2015** | | |
| | Blue grama, *Bouteloua gracilis* | 52.0 |
| | Sideoats grama, *Bouteloua curtipendula* | 18.0 |
| | Fleabane, *Erigeron asteae* | 7.0 |
| | Wild rye, *Elymus elymoides* | 3.0 |
| | Fairy duster, *Calliandra eriophylla* | 3.0 |
| **8/12/2015** | | |
| | Blue grama, *Bouteloua gracilis* | *48.0* |
| | Long leaf false goldeneye, *Heliomeris longifolia* | 13.0 |
| | Stick pea, *Calliandra benth.* | 7.0 |
| | Wild rye, *Elymus elymoides* | 7.0 |
| | Purple threeawn, *Aristida purpurea* | 5.0 |

Data were determine using the dry weight rank procedure (Mannetje and Haydock, 2006).

APPENDIX FIVE

# Performance of cows by sire genetic residual feed intake on semi arid Arizona rangelands

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**ABSTRACT:** Hereford sires ( *n* = 35) with 7 or more cow offspring on the University of Arizona V bar V ranch in Rimrock, Arizona were tested at Neogen laboratories in Lincoln, NE for an Igenity Gold genetic profile. Their residual feed intake (RFI), ADG, tenderness, marbling score, milk production, percent choice, yield grade, fat thickness, ribeye area, heifer pregnancy rate, stayability, maternal calving ease, birthweight and docility were estimated. Sires were given a genetic RFI score based on their RFI profile and placed into one of three intake groups, low (< 0.5 SD), medium ( ± 0.5 SD) and high (> 0.5 SD). Performance traits of cow offspring (*n* = 839) from those sires were also compared based on their sire's intake group. No differences ($P > 0.05$) were detected among sire intake groups for ADG, tenderness, marbling score, percent choice, yield grade, fat thickness, ribeye area, heifer pregnancy rate, stayability, maternal calving ease, birthweight and docility. Residual feed intake differed among groups ($P < 0.05$), and high intake cattle had more estimated milk production compared to low intake animals ($P < 0.05$). Cows from low intake sires were born later in the year (P < 0.05). High intake cattle had a higher ($P < 0.05$) birthweight and survived longer ($P < 0.05$) in the herd when compared to low and medium intake cows. Genetic RFI and expected milk production were moderately to highly correlated.

**INTRODUCTION**

The cost of feed represents about half of the overall cost of production in most livestock species. Determining ways to improve the feed efficiency of the herd would represent a significant cost savings (Kennedy et al., 1993). A common measure of feed efficiency, residual feed intake (RFI), is the measure of the difference between actual and expected feed intake. First proposed by Koch et al.(1963), RFI has only recently began to be studied in earnest since 2000. Unlike other feed efficiency measures (like feed conversion ratio (FCR) and its inverse, gain:feed (G:F)), RFI is phenotypically independent of production traits used to calculate intake, meaning cattle of various types and production levels can be compared. Selecting for RFI is not associated with an increase in mature cow size, leanness, organ weights, or heat increment or a decrease in digestibility (Herd and Bishop, 2000).

In other animal industries where feed consumption is easily accounted for, such as mice, selecting for feed efficiency traits has been shown to have a negative impact on reproductive performance and fertility (Nielson et al., 1997 and Rauw et al., 2000). Swine and poultry suffer similar results when selected for feed efficiency traits (Estany et al., 2002 and Hagger, 1994). Brien et al. (1984) and Kerr and Cameron (1995) even reported a reduced litter size in mice and swine. However, little has been published on direct impacts to beef cattle of RFI on male reproductive performance and fertility, leaving some in the beef cattle industry suspicious of selecting for RFI (Wang et al., 2012).

Most commonly, scrotal circumference (SC) is utilized as an important variable in selecting bulls as it is highly correlated with testes weight, sperm output, semen quality traits, and age of puberty in heifer progeny (Almquist et al., 1976; Brinks et al., 1978;Gregory et al., 1991). Studies conducted by Arthur et al. (2001a) and Schenkel et al. (2004) reported no correlation between RFI and SC or other breeding soundness traits. Wang et al. (2012) recently tested bulls for RFI and recorded their culling rates due to breeding soundness exams and temperament, type, performance or other. Authors found no differences in the rate of culling for positive and negative RFI sires, but did note that sperm motility tended to suffer ($P$ = 0.07) in negative RFI cattle slightly. However, Awada et al. (2013) described a loss in sperm mobility, sperm viability and sperm progressive motility when comparing the 10 lowest and 10 highest RFI bulls (*n* = 110) for negative RFI bulls.

The intent of this study is to compare genetic profiles of sires, especially RFI, and how that relates to the reproductive performance of their cow offspring.

**MATERIALS AND METHODS**

Experimental protocols were approved for all animals by the University of Arizona Institutional Animal Care and Use Committee.

The University of Arizona's V Bar V ranch in Rimrock, AZ is approximately 28300 hectares, and maintains ~ 450 commercial and Hereford cow/calf with reproductive records dating back decades. Purebred Hereford sires (*n* = 40) contributing to the cow herd from 1993 through 2010 were selected based on the criteria that they had at least 7 offspring enter the ranch's cow herd and had DNA samples on record. Samples of their DNA were sent to Neogen laboratories in Lincoln, NE for characterization through their Igenity Gold profile program where RFI, ADG, tenderness, marbling score, percent choice, yield grade, fat thickness, ribeye area, heifer pregnancy rate, stayability, maternal calving ease, milk production, birthweight and docility are estimated. Of the 40 sires, 35 returned results for RFI. A genomic RFI score was calculated based on their Igenity profile RFI ranking, and placed into one of three intake groups, low (< 0.5 SD), medium ( ± 0.5 SD) and high (> 0.5 SD). Sire means were compared among groups for the genetic profiles attained from the Igenity Gold profile and offspring phenotypic traits: avg cow age; avg cow yearling weight (YW); avg cow weaning weight (WW); avg cow birth weight; avg cow calving interval

(CI), average cow postpartum interval (PPI), and the percentage of cows surviving in the herd for at least 5 yr. Actual sire birth weights, WW and YW were recorded.

***Statistical Analysis***

Data were analyzed as a completely random design with RFI (low medium and high) as a fixed effect using the GLM procedure of SAS (v. 9.4, SAS Inst. Inc., Cary, NC). Means were separated using Tukey's multiple comparisons test. Pearson correlation tables were generated using the Corr procedure of SAS.

**RESULTS AND DISCUSSION**

Of the 35 sires characterized for genomic RFI, 13, 16, and 6 were considered to be low, medium, and high intake, respectively. Low, medium and high intake bulls had different RFI scores ($P < 0.05$), with low intake predicted to consume the least and high intake sires predicted to consume the most which is consistent with the literature (Arthur et al., 2007; Herd et al., 2000 and Richardson et al.,2001). No difference were detected among groups for their genetic profile characteristics in birth weight, calving ease, maternal calving ease, survivability, heifer pregnancy rate, docility, ADG, tenderness, marbling, ribeye area or fat thickness. Studies, such as Basarb et al. (2007) who monitored low-, medium- and high-intake cows over ten production cycles reported no differences among groups for birthweight. Since sire profile birthweight does not vary across groups, there would not be an expectance to see a higher level of dystocia associated sire RFI values, especially since sire birth weight profiles were equal. When selecting sires, traits such as birth weight need to be considered if selecting for RFI, as well. However, female offspring of high-intake sires are expected to produce 3 kg more milk than low intake animals ($P > 0.05$; Table 7). No phenotypic differences in sire birthweight, WW, or YW were detected ($P > 0.05$), and results are presented in Table 8. A study conducted by Richardson et al. (1998) placed steers, heifers, and bulls selected from divergent lines of low and high RFI cattle on a feedlot, and followed them through finishing. Heifers and bulls demonstrated no differences in production or growth, but consumed less feed. Similarly, low RFI steers placed on the trial grew as well or quicker than high RFI steers, but were slightly leaner with a smaller ribeye area. However, authors consider their growth, musculature, and composition adequate for feedlot production, and the savings acquired through the consumption of less feed to be profitable. Herd et al. (2003) used 3 separate years of steers from the afore mentioned divergent line selection trials for slaughter, and also concluded that there was no adverse effects to growth and low RFI steers consumed significantly less feed.

The 35 sires tested represent 839 total cow offspring, with 274, 427 and 138 animals in low, medium and high intake groups. Low intake cows were born later in the year than medium and high intake cows by 12 and 14 d, respectively ($P < 0.05$). Basarb et al. (2007) reported similar results, with low RFI progeny calving 6 d later in the calving season, and stated that low RFI cows actually consumed less feed during their second trimester compared to high intake animals. Both low and medium intake cows were lighter ($P < 0.05$) at birth by 2 kg, compared to high intake cows. These results differ from Basarb et al. (2007) who witnessed no difference in birthweight between high and low RFI cows over 10 production cycles. Interestingly, cows characterized as medium intake were 15 and 16 kg heavier at their YW compared to high and low intake cows, respectively ($P < 0.05$). Hafla et al. (2013) were unable to detect any post weaning body weight or body gain difference between heifers sorted into the high and low RFI groups. In terms of life expectancy in the herd, high intake cows survived longer in the herd than low or medium intake animals, and a greater percentage of high intake cows survived until 60 mo of age ($P < 0.05$). If high intake cattle can survive longer in the herd and produce more calves, they could prove more valuable than the energy savings associated with reduced feed intake. The longer a cow is able to stay in the herd and continually produce calves, she becomes more profitable. Producers are able to sell more heifer calves, and they are able to retain cows that are well acclimated to the rangelands they inhabit. Hafla et al. (2013) witnessed low-RFI first parity heifers give birth to lower weight calves, but the difference did not carry over to the second calving. Shaffer et al. (2011) reported a negative linear relationship between RFI and age at puberty in British bred heifers, with low RFI animals taking longer to reach puberty. These factors could influence the culling rate of low and high intake animals, and may help explain why high intake cows survived the longest in the herd (Table 9).

A Pearson correlation coefficient was calculated for the following traits: percent surviving until age 5, genetic RFI, birthdate, calving interval, postpartum interval, birth weight, weaning weight, yearling weight, genetic survivability and milk (Table 10). Genetic RFI had no or low correlation with all traits, except milk which was moderately correlated which is consistent with the literature (Hafla et al., 2013, Shaffer et al. 2012 and Basarb et al., 2007). Birth date, CI, PPI and survivability were all negatively correlated with genetic RFI. Milk production was also demonstrated no to low correlation with all traits except RFI, which was moderate-high correlated. Milk production, however, demonstrated no correlation to PPI or CI. The moderate-high correlation of milk production to genetic RFI may do more to explain why cows with high RFI remained in the herd longer. On range, forage is often limited, and more adequate milk production can be needed to maintain calves until weaning.  If cows are able to wean more calves, then they are more likely to remain in the herd and avoid culling. Interestingly, genetic survivability showed no correlation to cattle surviving at least 60 months in the herd. Genetic survivability was either not correlated or lowly correlated to all traits tested.

**IMPLICATIONS**

Native rangelands in the Western U.S. are often more rugged, arid, and prone to extreme weather variations. Selecting cattle that are well suited for the range is paramount for successful production. Being able to retain cows in the herd longer is not only more profitable on a per cow basis, but retaining cattle that are better adapted to the harsh environments associated with Western rangelands is extremely beneficial to land managers because experienced cattle will be able to utilize the terrain more efficiently than naïve cattle. These data indicate that high intake cattle may survive in the herd longer, and economic studies need to be conducted to determine the cost/benefit to reduced energy needs of low RFI cattle versus the herd longevity of high intake cows. Further study into the reproductive performance on cows selected from high and low intake sires will help reveal if low or high intake animals are better suited to Western rangelands.

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**Table 9.** Genetic profiles of Hereford sires based on residual feed intake

| | RFI | | |
|---|---|---|---|
| | **Low** | **Medium** | **High** |
| Number of sires | 13 | 16 | 6 |
| Birth weight, kg | 1.95 | 2.31 | 2.36 |
| Calving ease, % | 15.5 | 14.2 | 12.4 |
| Maternal calving ease, % | 13.9 | 13.1 | 12.0 |
| Survivability, % | 13.5 | 13.9 | 12.4 |
| Heifer pregnancy rate, % | 7.8 | 8.0 | 8.7 |
| Docility, % | 12.3 | 12.9 | 12.7 |
| Milk, kg | $5.6^{A}$ | $6.6^{AB}$ | $8.6^{B}$ |
| RFI, kg $d^{-1}$ | $-0.01^{A}$ | $0.04^{B}$ | $0.14^{C}$ |
| ADG, kg | 0.05 | 0.05 | 0.05 |
| Tenderness* | -5.84 | -4.57 | -3.30 |
| Marbling** | 64.3 | 68.1 | 76.3 |
| Ribeye area, $cm^2$ | 3.23 | 3.87 | 3.23 |
| Fat thickness, mm | 2.54 | 2.54 | 2.54 |

Means with dissimilar superscripts are statistically significant ($p < 0.05$)
RFI = Residual Feed intake
*Tenderness measured in kg Warner-Bratzler Shear Force
** Marbling measured in USDA Marbling Units

**Table 10.** Phenotypic characteristics of Hereford sires based on genetic residual feed intake

| | RFI | | |
|---|---|---|---|
| | **Low** | **Medium** | **High** |
| Sire birth weight, kg | 33.2 | 30.9 | 36.4 |
| Sire weaning weight, kg | 226.7 | 231.7 | 276.7 |
| Sire yearling weight, kg | 441.6 | 462.2 | 475.1 |

Means with dissimilar superscripts are considered different ($p < 0.05$)
RFI = Residual feed intake

**Table 11.** Cow means based on sire residual feed intake ranking

| | Sire RFI rankings | | |
|---|---|---|---|
| | Low | Medium | High |
| *n* | 274 | 427 | 138 |
| Birthdate, Julian day | $114^{A}$ | $102^{BC}$ | $100^{C}$ |
| *n* | 63 | 69 | 4 |
| Calving Interval, d* | 405 | 399 | 390 |
| *n* | 63 | 69 | 4 |
| Postpartum Interval, d* | 120 | 114 | 105 |
| *n* | 274 | 426 | 111 |
| Birthweight, kg | $32^{A}$ | $32^{A}$ | $34^{B}$ |
| *n* | 273 | 425 | 124 |
| Weaning Weight, kg | 179 | 181 | 183 |
| *n* | 267 | 396 | 102 |
| Yearling Weight, kg | $292^{A}$ | $308^{B}$ | $293^{A}$ |
| *n* | 274 | 425 | 129 |
| Age, mo | $38.5^{A}$ | $38.1^{A}$ | $52.3^{B}$ |
| *n* | 274 | 427 | 138 |
| Survived till 5 years old, % | $17.5^{A}$ | $19.0^{A}$ | $31.2^{B}$ |
| *n* | 283 | 441 | 141 |
| Sire RFI score, kg $d^{-1}$ | $-0.01^{A}$ | $0.03^{B}$ | $0.12^{C}$ |

Means with different superscripts are different, $P < 0.05$
RFI = residual feed intake
*Limited data available

**Table 12.** Pearson correlation for cow offspring based on phenotypic and genetic traits

| Pearson Coefficient Correlations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Survive until age 5** | **Genetic RFI** | **Birthdate** | **Calving interval** | **Postpartum interval** | **Birth weight** | **Weaning weight** | **Yearling weight** | **Surviv-ability** | **Milk** |
| **Survive until age 5** | **1.00** | **0.08** | **-0.18** | **-0.40** | **-0.4** | **-0.08** | **0.09** | **0.08** | **0.00** | **0.07** |
| *P-value* | | *0.02* | *<0.001* | *<0.001* | *<0.001* | *0.02* | *0.01* | *0.03* | *0.95* | *0.08* |
| **Genetic RFI** | | **1.00** | **-0.14** | **-0.18** | **-0.18** | **0.06** | **0.04** | **0.08** | **-0.07** | **0.58** |
| *P-value* | | | | *0.03* | *0.03* | *0.09* | *0.32* | *0.03* | *0.04* | *<0.001* |
| **Birthdate** | | | **1.00** | **0.20** | **0.20** | **0.21** | **-0.27** | **-0.29** | **-0.08** | **-0.05** |
| *P-value* | | | | *0.02* | *0.02* | *<0.001* | *<0.001* | *<0.001* | *0.02* | *0.02* |
| **Calving interval** | | | | **1.00** | **1.00** | **0.20** | **0.05** | **-0.05** | **0.11** | **0.00** |
| *P-value* | | | | | *<0.001* | *0.02* | *0.56* | *0.54* | *0.18* | *1.00* |
| **Postpartum interval** | | | | | **1.00** | **0.2** | **0.05** | **-0.05** | **0.11** | **0.00** |
| *P-value* | | | | | | *0.02* | *0.56* | *0.54* | *0.18* | *1.00* |
| **Birth weight** | | | | | | **1.00** | **0.16** | **0.10** | **-0.13** | **0.11** |
| *P-value* | | | | | | | *<0.001* | *0.01* | *<0.001* | *0.01* |
| **Weaning weight** | | | | | | | **1.00** | **0.46** | **0.08** | **0.11** |
| *P-value* | | | | | | | | *<0.001* | *0.03* | *0.01* |
| **Yearling weight** | | | | | | | | **1.00** | **0.04** | **0.02** |
| *P-value* | | | | | | | | | *0.23* | *0.66* |
| **Surviv-ability** | | | | | | | | | **1.00** | **0.13** |
| *P-value* | | | | | | | | | | *<0.001* |
| **Milk** | | | | | | | | | | **1.00** |