INTRODUCTION

Climate studies have indicated a warming trend over the last 20 yr of the global surface temperature (IPCC, 2014). Concomitant with this increase in temperature, drought is also expected to increase in frequency, severity, duration, and persistence in the Northern Hemisphere and especially in the interior regions of the United States (Soulé, 1992; Meehl and Tebaldi, 2004; Burke and Brown, 2008; IPCC, 2014). The expression of warming in the spring is also predicted to accelerate in the western United States (Westerling et al., 2006). If these forecasts hold, cattle

Drought effect on weaning weight and efficiency relative to cow size in semiarid rangeland

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ABSTRACT: Cow size has been suggested to be an important consideration for selecting cattle to match their production environment. Over the last several decades, the trend in genetic selection for maximum growth has led to gradual increases in beef cow size. An unrelated trend during this same period in the western United States has been an increase in temperature, drought frequency, and drought severity. Due to the potential influence of the increasing cow size trend on nutritional maintenance costs and production, we assessed the effect of cow size on weaning weight and efficiency in relation to drought on a semiarid high-elevation ranch in Wyoming. This study addresses a lack of empirical studies on the interaction between cow size and drought. We measured calf weaning weights of 80 Angus × Gelbvieh cows from 2011 to 2014 and assessed how drought affected weaning weights, efficiency (considered as calf weight relative to cow weight), intake requirements, and potential herd sizes relative to cow size. We stratified cows into 5 weight classes (453, 498, 544, 589, and 634 kg) as a proxy for cow size and adjusted weaning weights to a 210-d calf sex adjusted value. Cow size was a significant factor every year, with different cow sizes having advantages or disadvantages different years relative to weaning weight. However, efficiency for the smallest cows (453 kg) was always greater than efficiency for largest cows (634 kg; $P < 0.001$). Efficiency for the smallest cows was greater in the driest year (0.41 ± 0.02) than efficiency of the largest cows in the wettest years (0.37 ± 0.01). The change in efficiency ($\Delta E$) between wet and dry years was 0.18 for the smallest cow size and 0.02 for the largest cow size, and $\Delta E$ decreased as cow size increased. This is an indication of the ability of smaller cows to lower maintenance requirements in response to changes in the production environment but with optimal upside potential when conditions are favorable. These results indicate large cows (589 to 634 kg) do not maximize genetic potential in this production environment when conditions are optimum or provide any advantage over small or moderate size cows (453 to 544 kg) across the drought gradient.

Key words: climate, cow–calf, high elevation, precipitation, production, Wyoming


INTRODUCTION

Climate studies have indicated a warming trend over the last 20 yr of the global surface temperature (IPCC, 2014). Concomitant with this increase in temperature, drought is also expected to increase in frequency, severity, duration, and persistence in the Northern Hemisphere and especially in the interior regions of the United States (Soulé, 1992; Meehl and Tebaldi, 2004; Burke and Brown, 2008; IPCC, 2014). The expression of warming in the spring is also predicted to accelerate in the western United States (Westerling et al., 2006). If these forecasts hold, cattle
producers will need to consider potential adaptive decisions to drought conditions, which could include matching animals to their environment (Adams et al., 1996).

Cow size has been suggested to be an important trait for selecting animals to match their environment, primarily in regards to matching animal demand with forage supply (Doye and Lalman, 2011). Ultimately, this decision can optimize genetic growth potential relative to nutritional maintenance requirements provided by rangeland and pasture forage (Adams et al., 1996). Recent trends in the North American beef industry have seen an increase in cow size due to selection for growth traits, primarily through the enhanced selection of terminal bulls with higher EPD for growth characteristics (Johnson et al., 2010). As a result of increased cow size, the amount of forage required per cow for maintenance has increased beyond the baseline animal unit (AU) value; currently, an AU is calculated as the amount of air-dried forage biomass required to nutritionally maintain a 500-kg nonlactating cow (Allen et al., 2011). A more classic definition that is commonly applied to public grazing allotments is a 1,000-pound (454-kg) cow with a calf (Scarnecchia, 1985).

Given the expected changes in precipitation patterns, the negative effects of drought on cattle production, and the lack of suitable studies addressing the influence of cow size in semiarid rangeland scenarios, we studied the effect of cow size on weaning weight in relation to drought. Our objectives were to 1) quantify the effect of drought on weaning weight regardless of cow size, 2) compare how cow size influenced the weaning weights of calves relative to precipitation variability, and 3) determine how efficiency was influenced by cow size and drought.

**MATERIALS AND METHODS**

**Cattle Production Data**

We tracked calf production of 80 Angus × Gelbvieh cows at the University of Wyoming (UW) Agricultural Experiment Station Beef Unit from 2011 through 2014 in a semiarid high-elevation rangeland production environment. Cows calved at the UW Beef Unit (41°17′10″ N, 105°32′55″ W) 42 km north of Laramie, WY, and then were moved for the summer to the UW McGuire Ranch (41°40′17″ N, 105°32′55″ W) 42 km north of Laramie, WY. The UW Beef Unit comprises 400 ha in the Laramie River plain with sandy, loamy, and saline lowland soils with 0 to 15% slopes. These pastures range in productivity from 300 to 6,700 kg/ha and comprise 80% native rangeland that is dominated by the same upland plant species as the McGuire Ranch (see below) and alkali sacaton [Sporobolus airoides (Torr.) Torr.], basin wildrye [Leymus cinereus (Scribn. and Merr.) A. Löve], and greasewood [Sarcobatus vermiculatus (Hook.) Torr.] and 20% subirrigated hay meadows dominated by smooth brome (Bromus inermis Leyss.). The McGuire Ranch, where cow–calf pairs graze the summer and early fall, comprises 2,226 ha of clay loam and calcareous soils, slopes up to 50% with rocky outcrop complexes, and an elevational range of 2,157 to 2,283 m. The dominant plant species at the McGuire Ranch are western wheatgrass [Pascopyrum smithii (Rydby) A. Löve], needle and thread [Hesperostipa comata (Trin. and Rupr.) Barkworth], and sagebrush ( Artemisia spp.). There are minor areas dominated by nonnative grasses including crested wheatgrass [Agropyron cristatum (L.) Gaertn.] and Russian wildrye [P. smithii (Rydby) A. Löve]. Forage production, based on the dominant soils and ecological sites, ranges from 1,413 kg/ha in favorable years and 1,092 kg/ha in normal years to 651 kg/ha in unfavorable years (Soil Survey Staff, 2014). These categorizations are defined as ‘favorable’ or years with the amount and distribution of precipitation and the temperatures making growing conditions substantially better than average, ‘normal’ or years with growing conditions that are about average, and ‘unfavorable’ or years with growing conditions are well below average, generally because of low available soil moisture. Rangeland condition of the McGuire Ranch based on the quantitative climax method is estimated to be “good.” We used cows that had been in the herd for at least 4 consecutive years. This ensured no first calf heifers or old cows that were culled during the study were assessed because cow age can influence cow production potential (Davis et al., 1994). With the exception of a few cows that experienced the loss of calf, all cows calved and weaned a calf all 4 yr (78 in 2011, 2012, and 2013 and 76 in 2014 for a total of 310 calves assessed in this 4-yr study). Cows were calving primarily in March and April. Weaning dates ranged from September 7 to October 19 depending on the year and drought conditions. Mean stocking rate for the grazing period at the McGuire Ranch over the 4-yr study period was 0.35 (SE 0.3) AU months per hectare and stocking rate was reduced after the 2012 drought from 0.35 to 0.31 AU months per hectare. No supplemental feed was provided from June to October regardless of drought conditions. Artificial insemination was used to have control over sire-influenced growth genetics. For the 9 AI bulls used over the 4-yr study period, mean EPD was 49 (SE 3) and 82 (SE 5) for weaning weight (WW) and yearling weight, respectively, so assumptions about growth potential are not confounded by variable sire influences.

**Weather Data**

For the purposes of our study, we define drought as the period of time when precipitation is less than
Drought and cow size effect on production

Efficiency

Drought and cow size effect on production efficiency

Wilton, 1976; Dinkel and Brown, 1978), as calculated the Standardized Precipitation Index (SPI) for 6 to 9 mo of each year as reported by the National Oceanic and Atmospher Admini sion (NOAA, 2015) in the national drought overview report for Albany County, WY. The SPI has been suggested to be very consistent for detecting drought signals, especially when using multi-month time steps such as 6 to 9 mo and practical indices for operational drought monitoring in arid and semiarid ecosystems (Morid et al., 2006; Dogan et al., 2012).

Statistical Analysis

Based on a May 2013 cow weight, we stratified the 80 cows into 5 weight classes based on commonly used 100-pound or 45.4 kg increments in production agriculture (453 \( n = 9 \) cow), 498 \( n = 22 \) cows), 544 \( n = 29 \) cows], 589 \( n = 10 \) cows], and 634 kg \( n = 10 \) cows). Because we were stratifying cows by weight as a metric of size, using only cows at a given degree of maturity and body composition under uniform nutritional conditions truly reflected weight as a composite character of size (Fitzhugh and Taylor, 1971; Cartwright, 1979). Due to the differences in birth dates, birth weights, and weaning dates, we adjusted WW to a uniform 210-d weight:

\[
210\text{-d adjusted WW} = \frac{(WW - BiW)/(WD - BD)}{210},
\]

in which BiW = birth weight and BiW was subtracted from WW to determine total kg of gain; WD = weaning date and BD = birth date and BD was subtracted from WD to determine days between birth and weaning; and total kg of gain was divided by days between birth and weaning to determine daily gain and daily gain was multiplied by 210 to determine an adjusted WW for uniform comparison of cow production. We then accounted for calf sex with an adjustment factor that adjusted heifer calf weights relative to average bull calf weights within each cow size and year group (Lancaster and Arthington, 2014). The use of an adjusted WW makes the assumption that weight gain is linearly associated with time, an assumption that can only be overcome by weighing animals at regular intervals between birth and weaning. To quantify a measure of cow efficiency, we used the concept of maximum total product value per female relative to the dam’s body size (Dickerson, 1970; Morris and Wilton, 1976; Dinkel and Brown, 1978), as calculated by efficiency = 210-d adjusted WW:cow weight

This metric of cow efficiency can be interpreted as the percent of cow BW weaned. Finally, we calculated the change in efficiency (\( \Delta E \)) between the driest and wettest year for each cow size class as follows:

\[
\Delta E = \frac{E_{\text{wet}} - E_{\text{dry}}}{E_{\text{wet}}} \times 100
\]

Drought studies on range cattle performance at the system level can be very difficult to duplicate (i.e., mimicking drought) or replicate at the system scale. By assessing the influence of cow size on productivity within a single common pasture, we reduced variation from multiple pastures that could confound the results (Adams et al., 2000). When determining effects within a single year, the individual cows within each group are considered the replication (\( n \) ranges from 9 to 29) and we considered the cow size groups as the experimental unit and individual cows within these groups as the sampling unit (Adams et al., 2000; Iason and Elston, 2002). When determining effects across years, we consider year as the replicate (\( n = 4; \) Adams et al., 2000). In production systems research such as our study, replication of systems in space may be logistically difficult and the use of time (years) as a proxy in place of spatial replication can be particularly useful (Adams et al., 1989, 1994; Hart et al., 1991). Our approach to assessing groups of cows as the experimental unit within a common pasture across years has been conducted in other studies on breeds, sire traits, cow age, and milk production (Adams et al., 1986; Anderson and Urquhart, 1986; Colburn et al., 1997; Lathrop et al., 1988; Winder et al., 1996) and any social facilitation is assumed to not influence rumen capacity, DMI, and physical capability that influence production or sample independence (Rook, 1999; Iason and Elston, 2002; Phillips, 2002). Furthermore, phenotypic assessments of grazing distribution have used a similar design where subgroups within a single group grazed together in a common pasture (cow breed and cow age; Bailey et al., 2001).

We conducted a 2-way ANOVA using a general linear model with the 210-d calf sex adjusted WW as the response variable (SAS Inst. Inc., Cary NC). First, we compared annual mean WW regardless of cow size to determine if WW were lower in drier years than wetter years. Then, we tested for a significant effect of cow size within each year. We calculated a \( P \)-value to compare means at \( \alpha = 0.05 \) (SysStat, 2012). To determine that residual distribution and homoscedasticity assumptions were met for the statistical methods applied, we used the Shapiro–Wilk test for normality and a constant variance test. To understand changes and trends in efficiency, we compared mean efficiency for cow size relative to the driest year (2012) and the wettest year (2014) using ANOVA at \( \alpha = 0.05 \). We then used linear least squares regression to determine the slope of efficiency change during dry and wet years
relative to cow size and compared the difference in efficiency using $\Delta E$ for each cow size class between dry and wet years. We calculated the coefficient of determination ($r^2$) as a measure of how well cow size explains changes in efficiency trends in relation to drought severity and assessed the proportion of total variation explained by the cow size model.

We then calculated AU equivalents (AUE) based on metabolic requirements to determine daily forage intake by cow size class (Allen et al., 2011): AUE = (live animal weight kg)$^{0.75}$/500 kg$^{0.75}$.

These AUE were then used to calculate the daily forage requirement based on the standard of 8.8 kg of biomass per 1 AU per day and the total forage intake over a 210-d birth-to-weaning period. Based on a 2-way ANOVA using a general linear model to compare WW by cow size across years, we then used mean 4-yr WW by cow size class to determine an input:output ratio using 210-d total forage intake based on metabolic requirements as the input and 4-yr mean WW as the output. Finally, we calculated potential herd sizes assuming herds were homogeneous in cow size based on unfavorable production scenarios using a 25% harvest use efficiency for a 6-mo grazing season. These adjusted herd sizes were then used to calculate total weight of the weaned calf crop using the 4-yr average adjusted WW, the drought year (2012) WW, or the WW in the wettest year (2014).

**Table 1.** Total annual precipitation, difference from the 50-yr mean, and Standardized Precipitation Index as a measure of drought for the McGuire Ranch, Albany County, WY.

<table>
<thead>
<tr>
<th>Measure of drought</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>50-yr mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total precipitation, mm</td>
<td>325</td>
<td>201</td>
<td>372</td>
<td>425</td>
<td>344</td>
</tr>
<tr>
<td>Difference from the 50-yr mean</td>
<td>-19</td>
<td>-143</td>
<td>+28</td>
<td>+81</td>
<td></td>
</tr>
<tr>
<td>Standardized Precipitation Index</td>
<td>0.00</td>
<td>-2.00</td>
<td>+0.65</td>
<td>+1.00</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

**Weaning Weights**

Regardless of cow size, the lightest calf WW were in 2012 at 216 ± 2 kg (Fig. 1). The highest calf WW were in 2013 and 2014 at 250 ± 2 and 256 ± 3 kg, respectively (Fig. 1). Calf WW were intermediate in 2011 at 234 ± 2 kg (Fig. 1). Analysis of variance for a year effect on mean calf WW indicates that WW in 2012 were significantly lower than in 2011 and that WW in both 2011 and 2012 were lower than in 2013 and in 2014 ($P \leq 0.05$; Fig. 1). These significant differences can be explained by the drought and precipitation extremes in the 4-yr study. The year with the lowest WW was 2012, the most severe drought year (~2.00 SPI) and the driest year in the last 50 yr (Table 1; Fig. 2). The years with the highest WW, 2013 and 2014, represent 2 yr of above-average precipitation and the least-severe drought conditions (+0.65 and +1.00 SPI; Table 1). Furthermore, 2014 was the wettest year during the 4-yr study and one of the wettest years on record (Table 1). In addition, 2013 was a wetter than average year, but 2011 was below average and had a neutral SPI value (0.00; Table 1; Fig. 2).

**Influence of Cow Size**

Cow size did influence WW each year ($P \leq 0.05$), but the effect was variable depending on precipitation conditions (Fig. 1). In 2012, the driest and most severe drought year (Table 1; Fig. 2), as cow size increased, WW increased and the largest cows weaned the heaviest calves ($P \leq 0.05$). The opposite trend was evident in 2014, the wettest year and least severe drought year (Table 1; Fig. 2), because as cow size increased, WW decreased and the smallest cows weaned the heaviest calves ($P \leq 0.05$). In 2011, an average precipitation year, intermediate sized cows weaned the heaviest calves, but in 2013, a slightly wetter than average year, cows at the extremes (smaller or larger) weaned heavier calves than intermediate sized cows ($P \leq 0.05$; Table 1; Fig. 1 and 2). However, ANOVA of mean adjusted WW by cow...
Drought and cow size effect on production

Size class using year as the replicate \((n = 4)\) indicates no statistical difference \((P = 0.99)\).

The range between \(WW\) at precipitation extremes demonstrates how cow size and \(WW\) interact across the drought gradient. The smallest cows (453 kg) displayed the greatest change across the drought gradient with a \(192 \pm 7\) kg \(WW\) in the driest year, a \(276 \pm 5\) kg \(WW\) in the wettest year, and a range between extremes of 84 kg (Fig. 3). Intermediate size cows (544 kg) displayed an intermediate change across the drought gradient with a \(219 \pm 3\) kg \(WW\) in the driest year, a \(257 \pm 3\) WW in the wettest year, and a range between extremes of 38 kg. The largest cows (634 kg) displayed the least change across the drought gradient with a \(229 \pm 5\) kg \(WW\) in the driest year, a \(240 \pm 8\) kg \(WW\) in the wettest year, and a range between extremes of 11 kg (Fig. 3). As cow size increases, the line demonstrating this relationship begins to tip to a horizontal position at the largest cow size (Fig. 3). Therefore, as precipitation conditions change, the optimal sized cow for maximum \(WW\) changes also.

**Efficiency**

In the wettest year (2014), the efficiency ratio for the smallest cow size (453 kg) was significantly greater than all other cow sizes (Table 2). In 2012 (the driest year) and 2013 (a year with slightly above average rainfall), the smallest 2 cow sizes had higher efficiency ratios than all other cow sizes, and in 2011 (a year with slightly below average rainfall), the efficiency ratio for the 3 smallest cows was significantly greater than the largest 2 cow sizes. Regardless of year or precipitation amount, the 2 smallest cow sizes always had significantly higher efficiency ratios than the 2 largest cow sizes (Table 2). Furthermore, only the smallest size cow reached an efficiency of 0.50 or weaned 50% of her BW (Table 2).

During the drought year of 2012, the slope of the line explaining the efficiency trend influenced by body size was –0.0002 (Fig. 4). In other words, we can expect a reduction of 0.002 of calf weight relative to cow BW for every 10-kg increase in dam size. During the wet year of 2014, the slope was 2 times greater at –0.0005, indicating an efficiency reduction of 0.005 of calf weight relative to cow BW for every 10-kg increase in dam size. The SE of the slopes and 95% confidence intervals suggest these 2 slopes are different (Fig. 4).

**Efficiency Changes and Trends**

When comparing the \(\Delta E\) between drought and wet years for each of the 5 cow size classes, \(\Delta E\) for the smallest cow size was 0.18 (0.58 in 2014 versus 0.41 in 2012) and \(\Delta E\) for the largest cow size was 0.02 (0.37 in 2014 versus 0.35 in 2012; Fig. 4). The advantage of smaller cows over larger cows is demonstrated by their almost...
3-fold increase in efficiency in response to wetter years. Furthermore, efficiency for small cows was greater in the driest year than efficiency of the largest cows in the wettest years (0.41 in 2012 for smallest cows versus 0.37 in 2014 for the largest cows). As cow size increased, ΔE decreased in a predictable fashion (Fig. 4).

**Daily Forage Intake (Input): Calf Weaning Weight (Output) Ratio**

As cow size increases, AUE based on metabolic requirements also increase. The smallest cows have an AUE of 0.96 and the largest cows have an AUE of 1.23 in our study (Table 3). This influences the input required for maintenance based on daily forage intake. The smallest cows require 8.5 kg per cow per day and the largest cows require 10.8 kg per cow per day (Table 3). Over the course of a 210-d birth-to-weaning period, this results in an additional 483 kg of dry forage for the largest cows compared with the smallest cows. When comparing WW across precipitation extremes, using year as the replication (n = 4), there is no difference in WW relative to cow size but there was a difference in efficiency (Table 2 and 3). Because cow size cannot realistically be adjusted from year to year depending on weather, comparing WW across years with forage intake requirements can determine the input relative to the output. In our study, the smallest cows (453 kg) required 7.6 kg of forage for each kilogram of calf weaned, intermediate size cows (544 kg) required 8.4 kg of forage for each kilogram of calf weaned, and the largest cows (634 kg) required 9.5 kg of forage for each kilogram of calf weaned (Table 3).

**Herd Size Implications**

Because different size cows have different advantages or disadvantages and production systems rely on the bottom line of calf weight sold, it is important to consider the tradeoff in total herd size across years and in the worst drought scenarios. Based on “Natural Resources Conservation Service forage production conditions for unfavorable years and a 25% harvest use efficiency, we determined the number of cows that could be grazed in a 6 mo summer to early fall period for a homogeneous herd in cow size composition (Table 4). If the herd comprised all small cows (453 kg), it should consist of 237 cow; if the herd comprised all intermediate size cows (544 kg), it should consist of 208 cow; and if the herd comprised all large cows (634 kg), it should consist of 186 cow (Table 4). This is a 51 cow difference in total number of cows between the cow size extremes. Based on the 4-yr average WW for each cow size and probable cow numbers in each hypothetical herd, the smallest cow size would yield a total calf crop weight of 55,502 kg and the largest cow size would yield a total calf crop weight of 44,502 kg for a difference of 11,000 kg between the cow size extremes (Table 4). Based on the drought year WW for each cow size, the smallest cow size would yield a total calf crop weight of 45,463 kg and the largest cow size would yield a total calf crop weight of 42,676 kg, with small cows having a 2,787 kg advantage compared with the largest cows in the worst conditions even when they wean lighter calves if herd size were adjusted (Table 4). Based on the wettest year (2014) WW for each cow size, the smallest cow size would yield a total calf crop weight of 42,676 kg, with small cows having a 2,787 kg advantage compared with the largest cows in the worst conditions even when they wean lighter calves if herd size were adjusted (Table 4). Based on the wettest year (2014) WW for each cow size, the smallest cow size would yield a total calf crop weight of 42,676 kg, with small cows having a 2,787 kg advantage compared with the largest cows in the worst conditions even when they wean lighter calves if herd size were adjusted (Table 4).

**DISCUSSION**

If the objective of cattle production efficiency is the maximum total product value per female relative to the dam’s body size (Dickerson, 1970), our results indicate that 453 to 498 kg offer an advantage to high-elevation semiarid range cattle operations in Wyoming. This approach to measuring efficiency was suggested to be more important in cattle than other meat animals because of the comparatively low reproduction rate and/or the high cow-herd cost per meat animal marketed because income is derived only from growth of suckling
calves. Therefore, comparing calf WW with cow size is a robust measure because it allows for the selection of growth efficiency relative to lower per-cow nutritional costs per unit of product. However, our comparison should not be considered an indication of feed efficiency but a measure of efficiency relative to the feed requirements of the cow (Dinkel and Brown, 1978). This approach to quantifying the efficiency of range cattle has economic implications because it is a ratio of output relative to input (Morris and Wilton, 1976).

A long-term study indicated that optimal size for Angus cows for 5 maternal performance characters (years in the herd, number of calves, total calf weight, average calf weight at weaning, and calf weight per year in the herd) ranged from 465 to 493 kg (1,026–1,088 pounds; Stewart and Martin, 1983). Our results reflect this cow size as optimum relative to the fluctuation between dry and wet years. However, the potential benefit of a somewhat moderate sized to larger size cow during extreme drought also has application. We hypothesize that a trend between WW and cow size became evident during the drought because structurally larger cows have larger rumen capacities. Furthermore, DMI per cow increases 0.0185 kg for each liter increase in rumen capacity under low-quality forage conditions, but no such relationship exists under high-quality forage conditions (Nutt et al., 1980). In Nutt et al. (1980) the physical, energy, and environmental factors governing performance in limiting forage intake became apparent at about 55% DM digestibility. There is also evidence that cattle and sheep with large rumen capacities may consume their forage more rapidly than animals with smaller rumen capacities (Purser and Moir, 1966; Nutt et al., 1980). However, even in drought years, when greater rumen capacity of larger cows conferred an advantage to the adjusted WW, the efficiency of smaller cows was still greatest.

The results reported herein are supported by studies in Montana under similar northern rangeland production conditions that suggested cows of moderate size and milk production were more economically profitable than larger and heavier milking cows (Davis et al., 1994). It is important for producers to consider that given finite grazing resources, larger cow size should affect herd size. However, given the gradual trends in increasing cow sizes, this may not be recognized or addressed (Doye and Lalman, 2011). For example, the Doye and Lalman (2011) economic model comparing moderate (498 kg) cows and large (634 kg) cows under range conditions in the U.S. Great Plains determined that moderate cows resulted in a larger herd size (100 cows versus 76 cows). Due to the higher nutritional maintenance costs of US$89 for large cows, moderate cows resulted in greater returns above total operating on native rangeland (Doye and Lalman, 2011). A deterministic modeling approach compared small (430 kg), medium (500 kg), and large (600 kg) cows with assumed herd sizes of 956, 782, and 614 cows, respectively, and also reported that smaller cows had greater net income (Long et al., 1975). In our production scenario, if cow herd size was adjusted based on cow size, intermediate cows yielded more total WW during drought years whereas small cows yielded more total WW in normal and favorable years.

Our results, however, suggest that 2 assumptions in models may not apply to limited rangeland production environments such as the semiarid high-elevation conditions at the McGuire Ranch. First, WW may not be higher for larger cows most years. In Long et al. (1975), it was assumed that 430-kg cows weaned 241-kg calves, 500-kg cows weaned 280-kg calves, and 600-kg cows weaned 335-kg calves. If that trend between cow size and calf weight were not true in the model assumptions, then net income would be proportionally even higher. Second, DMI rate and efficiency is likely different for cows of different sizes, especially under low forage quality conditions such as drought years (Holloway and Butts, 1984; Doye and Lalman, 2011). Although we did not directly measure rumen capacity, based on published studies and the correlation with our results during the drought year, we hypothesize this assumption applies (Purser and Moir, 1966; Nutt et al., 1980).

The escalation of drought associated with variable weather patterns will be a limiting influence for grazing livestock and dependent human livelihoods due to reduction in livestock performance and production due to heat stress, limited water availability, and reduced...
herbaceous biomass required by ruminants (Wall and Smit, 2005; Brown-Brandl et al., 2006; Godber and Wall, 2014; Thornton and Gerber, 2010). Coincidentally, and partially correlated with the trend of selection for greater growth and larger cows, has been the selection for greater milk production potential (Cartwright, 1979; Brown et al., 2005). The gradual trends over several decades of increasing cow size and milk production potential has been suggested to affect cow–calf production operations because these genetic traits influence the amount of forage biomass and energy requirements and efficiency of use by cows.

The general perception within the research and production community is that increasing cow size and milk potential increases maintenance requirements and potentially reduces economic efficiency (Ferrell and Jenkins, 1984; van Oijen et al., 1993). Unfortunately, these general perceptions are not unanimously supported by the empirical evidence, as research has been inconclusive under semiarid rangeland scenarios. Some studies suggest that smaller cows excel in live weight production and net income in pasture-based beef systems compared with medium and large cows (Long et al., 1975). However, these studies modeled only the influence of cow size or did not consider the influence of forage nutrient deficiencies associated with drought conditions relative to cow size (Long et al., 1975; van Oijen et al., 1993). In contrast, other studies have indicated that larger cows are more efficient than smaller cows, although these studies were feeding trials, model simulations, or scenarios of a high plane of nutrition and not a true reflection of semiarid rangeland production systems (Kress et al., 1969; Cartwright, 1979).

Cow size and milk potential are important from a phenotypical perspective on maintenance and growth requirements and genetic perspective due to effects on progeny growth and maturation rates (Cartwright, 1979). In high production environments, larger cows with greater milk production are able to maximize genetic potential for growth (Holloway and Butts, 1984; Nunez-Dominguez et al., 1993). This correlation of WW with mature cow size has been suggested to result in an increase of 0.04 to 0.13 kg in WW for every 1-kg increase in mature cow weight under optimal conditions (Urlick et al., 1971; Stewart and Martin, 1981; Doye and Lalman, 2011). However, in limited production environments such as the McGuire Ranch in Wyoming, cows with greater maintenance requirements due to body size and milk potential may not reach their genetic potential for growth and may not be as efficient in calf weight relative to dam size (Buttram and Willham, 1989). This lack of production potential optimization is due to the inability to lower maintenance requirements in production environments with reduced forage quality and quantity (Frisch and Vercoe, 1977; Taylor et al., 1986).

Studies that have shown larger cows with greater milk production maximizing genetic potential for growth have come from rainfall zones that greatly exceed the mean at our study location by 3 times or more (Holloway and Butts, 1984; Nunez-Dominguez et al., 1993). Furthermore, evidence suggests that CP and ADF, 2 critical aspects of forage nutritive quality and cow–calf performance relative to production stages, are positively and negatively correlated with precipitation (McCuistion et al., 2014). The dominant plant species in this study have the ability to tolerate drought. For example, western wheatgrass can extract deeper soil water than nonnative species and needle-and-thread has displayed rapid soil moisture depletion abilities, but ultimately less drought-induced leaf modification.

### Table 3. Animal unit equivalents and associated daily forage intake requirements based on mean cow weight for each size class and metabolic requirements. Input relative to output based on 4-yr mean weaning weight (WW). Input:output ratio can be interpreted as kilograms required for each kilogram of calf weaning weight

<table>
<thead>
<tr>
<th>Cow size class</th>
<th>Mean cow weight</th>
<th>AUE(^1) based on metabolic requirements</th>
<th>Daily forage intake, kg</th>
<th>Input: 210-d total forage intake, kg</th>
<th>Output: mean adjusted WW, kg (SE)</th>
<th>Input:output ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>453 kg</td>
<td>476 kg</td>
<td>0.96</td>
<td>8.5</td>
<td>1,785</td>
<td>234.4(^6)</td>
<td>7.6</td>
</tr>
<tr>
<td>498 kg</td>
<td>523 kg</td>
<td>1.03</td>
<td>9.1</td>
<td>1,911</td>
<td>239.6(^6)</td>
<td>8.0</td>
</tr>
<tr>
<td>544 kg</td>
<td>563 kg</td>
<td>1.09</td>
<td>9.6</td>
<td>2,016</td>
<td>240.4(^6)</td>
<td>8.4</td>
</tr>
<tr>
<td>589 kg</td>
<td>614 kg</td>
<td>1.17</td>
<td>10.3</td>
<td>2,163</td>
<td>237.7(^6)</td>
<td>9.1</td>
</tr>
<tr>
<td>634 kg</td>
<td>657 kg</td>
<td>1.23</td>
<td>10.8</td>
<td>2,268</td>
<td>238.3(^6)</td>
<td>9.5</td>
</tr>
</tbody>
</table>

\(^a\)Analysis of variance of mean weaning weights by cow size class using year as the replicate indicates no statistical difference (P = 0.99).

\(^1\)AUE = animal unit equivalent. Based on the metabolic weight concept of an AUE to a mature cow in the middle trimester and nonlactating at a weight of 500 kg and zero weight gain plane of nutritional maintenance (Allen et al., 2011; AUE = (live animal weight kg)0.75/(500 kg)0.75).

\(^2\)Based on the forage intake unit equivalent of 1 animal unit or 8.8 kg of DM per day (Allen et al., 2011).
Table 4. Tradeoffs related to cow size and weaning weight across years with a conservative stocking rates using unfavorable forage production values based on the average weaning weight across years, average weaning weight during the drought (2012) year, or average weaning weight during the wettest year (2014)

<table>
<thead>
<tr>
<th>Cow size class</th>
<th>Total cows for 6-mo season (difference)</th>
<th>Total weight, kg, based on 4-yr mean weaning weight (difference)</th>
<th>Total weight, kg, based on drought year mean weaning weight (difference)</th>
<th>Total weight, kg, based on wet year mean weaning weight (difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>453 kg</td>
<td>237 (+29)</td>
<td>55,502 (+5,101)</td>
<td>45,463 (–661)</td>
<td>65,353 (+11,472)</td>
</tr>
<tr>
<td>498 kg</td>
<td>221 (+13)</td>
<td>52,993 (+2,592)</td>
<td>47,552 (+1,428)</td>
<td>56,620 (+2,739)</td>
</tr>
<tr>
<td>544 kg</td>
<td>208 (0 base)</td>
<td>50,401 (0 base)</td>
<td>46,124 (0 base)</td>
<td>53,881 (0 base)</td>
</tr>
<tr>
<td>589 kg</td>
<td>196 (–12)</td>
<td>46,448 (–3,953)</td>
<td>42,403 (–3,271)</td>
<td>49,047 (–4,834)</td>
</tr>
<tr>
<td>634 kg</td>
<td>186 (–22)</td>
<td>44,502 (–5,899)</td>
<td>42,676 (–3,448)</td>
<td>44,726 (–9,155)</td>
</tr>
<tr>
<td>Range</td>
<td>51</td>
<td>11,000</td>
<td>5,149</td>
<td>20,627</td>
</tr>
</tbody>
</table>

is expected in C_4 versus these C3 species (Barnes and Harrison, 1982; Frank et al., 1985; Hardy et al., 1995).

Conclusion

The results of this study indicate when conditions are optimal on semiarid high-elevation rangeland, small to moderate size cows are as productive as large cows in terms of calf WW and optimal in relative efficiency. However, under extreme drought conditions, such as those experienced in 2012, moderate to large size cows offer an advantage in calf WW due to potential advantages of balancing optimal rumen capacity and DMI and greater WW than smaller cows. Other advantages of a herd comprising moderate cows versus large cows includes the ability to maintain more cows, the ability to spread fixed costs over more animals, greater returns above operating costs, and lower individual animal maintenance costs for nutrition (Doye and Lalman, 2011). From an economic perspective, when small or moderate cows wean calves of WW similar to large cows, the ratio of total product per female relative to female metabolic size is reduced, leading to greater efficiency in the livestock production system (Dickerson, 1970). Even though small cows weaned smaller calves in the drought year, smaller cows had higher biological efficiency, suggesting that per unit of production, smaller cows are more efficient and WW may not always reflect that advantage. This information could develop regionally specific conceptual models relating cow size to WW and efficiency with thresholds where expected genetic potential is no longer a realized benefit, similar to conceptual models relating returns to stocking rate (Hart et al., 1988). Given the recent trend of increasing cow body size and milk production potential, producers should pay attention to genetic selection for moderate size and low to moderate milk production potential, especially in northern rangeland production environments (Ferrall and Jenkins, 1984; van Oijen et al., 1993; Davis et al., 1994). This caution is especially important if producers select terminal bulls with ideal production EPD (high WW and low birth weight) because these can be correlated with maternal EPD that continue the trend of increasing size (high milk, maternal weight, and maternal height), especially if heifers are to be retained as replacements out of that terminal bull. Finally, given the gradual trend in cow size increase, it has been suggested that producers may not have accounted for increasing maintenance requirements, and we suggest that when matching cow size to the environment, careful attention is paid to cow size in stocking rate calculations (Doye and Lalman, 2011). This study may be considered a case study of a semiarid high-elevation ranch, and because drought is periodic and difficult to replicate and because of the limited number of such studies, we feel that this information is relevant and can guide future experiments on the interaction between cow size and drought on western rangelands.

LITERATURE CITED

Drought and cow size effect on production


