2014

Beef heifer growth and reproductive performance following two levels of pasture allowance during the fall grazing period1

B. L. Bailey

T. C. Griggs

E. B. Rayburn

K. M. Krause

Beef heifer growth and reproductive performance following two levels of pasture allowance during the fall grazing period[1]

B. L. Bailey,* T. C. Griggs,† E. B. Rayburn,‡ and K. M. Krause*[2]

*Division of Animal and Nutritional Sciences, West Virginia University, Morgantown 26506; †Division of Plant and Soil Sciences, West Virginia University, Morgantown 26506; and ‡West Virginia University Extension Service, Morgantown 26506

ABSTRACT: The objective of this study was to compare heifer growth and reproductive performance following 2 levels of stockpiled fall forage allowance of orchardgrass (30.5%) and tall fescue (14.1%). Spring-born heifers (n = 203 and BW = 246 ± 28.9 kg) of primarily Angus background were allocated to 2 grazing treatments during the fall period (November 12 to December 17 in yr 1, November 7 to January 4 in yr 2, and November 7 to January 14 in yr 3) each replicated 3 times per year for 3 yr. Treatments consisted of daily pasture DM allowance of 3.5% of BW (LO) or daily pasture DM allowance of 7.0% of BW (HI) under strip-grazing management. Throughout the winter feeding period, mixed grass–legume haylage and soybean hulls were fed. Heifers were grazed as 1 group under continuous stocking after the winter period. Heifers in the LO group gained less than heifers in the HI group during the fall grazing period (0.12 vs. 0.40 kg/d; P < 0.0001). For each 1 10 g increase in NDF/kg fall pasture (DM basis), fall ADG decreased 0.14 kg (P = 0.01). During winter feeding, ADG was 0.30 and 0.39 kg/d for LO vs. HI heifers, respectively (P = 0.0008). During the spring grazing period (April 16 to May 24 in yr 1, April 22 to May 26 in yr 2, and April 5 to May 16 in yr 3), LO heifers had numerically greater ADG than HI heifers (1.38 vs. 1.30 kg/d; P = 0.64). Hip height (122.7 vs. 121.4 cm; P = 0.0055), BCS (5.8 vs. 5.6; P = 0.0057), and BW (356 vs. 335 kg; P < 0.0001) at the end of spring grazing was greater for HI than LO heifers. Heifers in the LO group compensated with greater summer ADG than heifers in the HI group (0.74 vs. 0.66 kg/d; P = 0.03). Total ADG from treatment initiation (November) through pregnancy diagnosis (August) was greater for HI than LO heifers (0.61 vs. 0.55 kg/d; P < 0.001) as was BW at pregnancy diagnosis (415 vs. 402 kg; P = 0.0055). Percentage of heifers reaching puberty by the time of AI was 34% for both groups (P = 0.93). Percentage of heifers becoming pregnant to AI tended (P = 0.13) to be greater for HI (44%) than for LO heifers (32%). Fall ADG across treatment groups affected the probability of a heifer becoming pregnant by AI (P = 0.01). Percentage pregnant by natural service (61% for LO vs. 59% for HI; P = 0.80) and final pregnancy rate (74% for LO vs. 77% for HI; P = 0.61) was not different for the 2 groups. These results indicate that altering fall forage allowance may delay the majority of BW gain until late in heifer development without negatively affecting overall pregnancy rates.

Key words: beef heifers, grazing, growth, reproductive performance

J. Anim. Sci. 2014.92:3659–3669
doi:10.2527/jas2013-7121

INTRODUCTION

Forage systems in Appalachia are based on cool-season forages, such as orchardgrass (*Dactylis glomerata*), tall fescue (*Schedonorus phoenix*), white clover (*Trifolium repens*), and red clover (*Trifolium pratense*). These systems have an abundance of forage in the spring and most falls but are not as productive in mid to late summer. Feed resources used in developing replacement females are a major factor influencing cost of production (Freetly et al., 2001; Clark et al., 2005). Due to rising costs of production, interest is increasing in alternative

[1]This study was conducted with funding from USDA/ARS (Economic Pasture-Based Beef Systems for Appalachia, project number 1932-21630-003-00D). The authors thank R. Kiser and staff at the WVU Agricultural and Forestry Experiment Station Reedsville Farm for taking care of the animals and for help with sampling. Scientific Article No. 3213 of the West Virginia Agricultural and Forestry Experiment Station, Morgantown.

[2]Corresponding author: marie.krause@mail.wvu.edu

Received September 4, 2013.
Accepted May 28, 2014.

heifer development systems using grazing and minimizing the use of harvested feedstuffs (Larson et al., 2011).

Several decades ago, guidelines were established indicating replacement heifers should achieve 60 to 65% of their expected mature body weight by breeding (Patterson et al., 1992). However, subsequent research has demonstrated that harvested feed input can be reduced without major adverse effects on reproduction. Recent research indicates heifers reaching <55% of mature BW by breeding have similar reproductive ability to heavier counterparts (Funston and Deutscher, 2004; Martin et al., 2008). However, much of this research has been performed in a dry-lot setting and limited or no data exist comparing development systems using standing forage (Larson et al., 2011). Additionally, there are limited data comparing the effects of different levels of stockpiled fall forage allocation of naturalized cool-season forage mixtures on beef heifer growth. Therefore, this study evaluated the effect of allocating 2 different levels (daily pasture DM allowance of 7.0% of BW [**HI**] vs. daily pasture DM allowance of 3.5% of BW [**LO**]) of stockpiled cool-season naturalized pasture during the fall period on beef heifer growth, puberty, and pregnancy rate.

MATERIALS AND METHODS

All procedures and facilities used in this study were approved by the West Virginia University Animal Care and Use Committee (Institutional Animal Care and Use Committee number 09-0818).

Experimental Procedures

A 3-yr study (August 2009 through August 2012) was conducted with 203 beef heifers at the West Virginia University Agricultural and Forestry Experiment Station Reedsville Farm in Reedsville, Preston County, in northern West Virginia (530 m elevation; 39°30′ N, 79°50′ W) to investigate heifer responses to 2 levels of fall forage allocation. For simplicity, the 2009 through 2010 season will be termed yr 1, the 2010 through 2011 season yr 2, and the 2011 through 2012 season yr 3. Heifers were all Angus sired, minimum 50 to 75% Angus, with the remaining being Hereford. Estimated mature BW was 600 kg with a frame score of 5.5 to 6. Heifers were weaned on September 15 of each year at 177 ± 17.1 (mean ± SD) days of age. After weaning, heifers were commingled at the West Virginia University Reedsville Farm (Reedsville, WV) and maintained on mixed cool-season grass pasture containing predominantly orchardgrass, tall fescue, and quackgrass. Age at the start of the study ranged from 180 to 272 d. Heifers were stratified by birth date and body weight and randomly assigned to treatments consisting of LO or HI that were based on assigned land area during the fall grazing period. Herbage mass allowances were set below 6% (DM basis) of BW to restrict intake and above 6% of BW to avoid restriction of intake (Combellas and Hodgson, 1979). Three 5-ha fields were selected as blocks in a randomized complete block design for application of grazing treatments. Each block was divided into 2 paddocks (grazing treatments), such that a total of 6 paddocks (experimental units) were available each year. Heifers were allocated to 2 grazing treatments (n = 10–12/treatment replicate), each replicated 3 times for the fall grazing period. All experimental units had been in long-term hay and pasture production and contained perennial cool-season species including orchardgrass (30%), tall fescue (14%), and quackgrass (12%) at the beginning of the study. The soil types at this location were silt loams with Rayne, Ernest, and Gilpin being most prevalent. These soil types are silt loams, are moderately to well drained, and have 3 to 15% slopes. Soil test results from sampling to a 5 to 8 cm depth over the 3 yr experimental period were pH of 6.2, 25 mg/kg P, and 189 mg/kg K.

Stockpiling of pastures began in mid to late August of each year (August 15 in yr 1, August 20 in yr 2, and August 21 in yr 3). Urea (46% N) was broadcast applied to pastures on August 18 through September 1 in yr 1, August 17 through August 24 in yr 2, and August 24 through August 30 in yr 3 at 81 to 123, 85 to 110, and 82 to 92 kg N/ha, respectively (means of 96, 97, and 87 kg N/ha, respectively, for 2009, 2010, and 2011). Nitrogen application rates and dates were consistent among treatments within each block but varied among blocks in relation to herbage legume proportions, dates of rainfall events that constrained equipment operations on slopes, and impacts of irregular terrain on spreader calibration. Where legumes made up equal to or above 20% of herbage DM in a block, N was applied at a lower rate and where they made up above 20% of herbage DM, N was applied at a higher rate. The maximum and mean N application rates decreased over years as herbage legume proportions increased in all blocks. Pastures were allowed to regrow without use for the remainder of the growing season, which ended on October 18, October 30, and October 28, in yr 1, 2, and 3, respectively, at the date of the first frost. Fall grazing treatments began in early November and continued until snow conditions prevented grazing or pastures had been fully consumed. Fall grazing treatments began on November 12, November 7, and November 7 in yr 1, 2, and 3, respectively. Herbage allowances were assigned by delineating appropriate paddock areas with portable electric fencing. Each treatment group was given a new strip area every 3 to 5 d (fences were moved twice weekly) in a strip-grazing pattern without back fencing, allowing animals to return to a permanent watering point. Strip areas provided LO or HI.

Table 1. Regression equations relating clipped forage samples herbage mass with rising plate meter readings for the fall, spring, and summer periods

Period and year	*n*	Equation[1]	*P*-value of *y*-intercept[2]	*P*-value of slope	Root MSE[3]	r^2	R^2
Fall yr 1	96	$y = 128x + 1,410$	<0.01	<0.001	1,450	0.27	–
Fall yr 2	59	$y = 228x$	(0.44)	<0.001	1,107	0.92	–
Fall yr 3	36	$y = 195x$	(0.07)	<0.001	1,875	0.89	–
Spring yr 1	127	$y = 183x – 1.4x^2$	(0.45)	<0.001	1,120		0.89
Spring yr 2	55	$y = 129x$	(0.60)	<0.001	920	0.93	–
Spring yr 3	10	$y = 275x$	(0.23)	<0.001	1,627	0.86	–
Summer yr 2	59	$y = 256x – 2.4x^2$	(0.19)	<0.001	1,710		0.94
Summer yr 3	58	$y = 360x – 6.1x^2$	(0.38)	<0.001	1,031		0.90

[1]*y* = herbage mass (kg DM/ha). *x* = rising plate meter height units.

[2]Significance level of *y*-intercept in original model; () indicates *y*-intercept was dropped. If intercept term was non-significant ($P > 0.05$), regression was forced through origin.

[3]MSE = mean squared error.

Heifers on both treatments were given free-choice access to trace-mineralized salt (Morton ioFIXT T-M; Morton Salt Inc., Chicago, IL) containing 93 to 98% salt, 3,500 mg/kg zinc, 2,800 mg/kg manganese, 1,750 mg/kg iron, 350 to 450 mg/kg copper, 70 mg/kg iodine, and 70 mg/kg cobalt.

At the end of the fall grazing period, the winter feeding period began and round bale mixed-grass/legume haylage was fed on the same pastures (5.9 kg $DM·heifer^{-1}·d^{-1}$ in yr 1, 5.4 kg $DM·heifer^{-1}·d^{-1}$ in yr 2, and 5.6 kg $DM·heifer^{-1}·d^{-1}$ in yr 3). During this same period, soybean hulls were also fed (1.7 kg $DM·heifer^{-1}·d^{-1}$ in yr 1, 1.5 kg $DM·heifer^{-1}·d^{-1}$ in yr 2, and 1.8 kg $DM·heifer^{-1}·d^{-1}$ in yr 3). Initially only haylage was fed, but soybean hulls were added when ADG was negative for both treatment groups. The start date for soybean hull feeding was January 20, February 7, and February 2 in yr 1, 2, and 3, respectively.

In early to mid April, haylage and soybean hull feeding ended and fences between herbage allowance treatments were removed and pastures were continuously stocked through late May (spring grazing period). The spring grazing period began on April 16, April 22, and April 5 and ended on May 24, May 26, and May 16 in yr 1, 2, and 3, respectively. Heifers from all 3 blocks were then combined into 1 group that rotated among pastures until early August (summer grazing period). The summer grazing period ended on August 5 (yr 1), August 15 (yr 2), and August 20 (yr 3).

Forage Mass Determinations

Forage mass of each experimental unit was determined at the end of each growing season (October 26, 2009, October 29, 2010, and October 21, 2011) and every 11 to 19 d thereafter, depending on environmental conditions, during the fall, spring, and summer period except during the summer of yr 1 when no data were collected. Forage mass was determined from each experimental unit by taking at least 100 rising plate meter readings in the upcoming strip and 12 calibrations were clipped each sampling period. An Ellinbank-type rising plate meter with 0.32 by 0.32 m square aluminum plate was used (Earle and McGowan, 1979). It was obtained from the University of Missouri Research Reactor Center (Columbia, MO). The rising plate meter readings were calibrated by clipping forage within square quadrats (0.1 m^2) to nearly soil surface (approximately 1 cm) using forged grass shears. The clipped samples were dried at 60°C for ≥48 h and weighed. Regression was used to develop herbage mass equations relating the clipped forage samples with the rising plate meter readings. For each period and year, a herbage mass prediction model was selected using the following model: $y = a + bx + cx^2$, in which *y* is herbage mass (kg DM/ha) and *x* is rising plate meter height units. Coefficients that were not significant ($P > 0.05$) were dropped from the model. Regression equations are shown in Table 1.

Botanical Composition of Pastures

Botanical composition of pastures was determined in late October each year using the dry-weight-rank method (Mannetje and Haydock, 1963). Measurements were obtained within a 0.1 m^2 quadrat and 55 data points were assessed for each experimental unit.

Forage Nutritive Composition

To determine the nutritive value of the pastures, whole plant forage samples were taken every 2 wk during the fall, spring, and summer periods. Samples were also taken of the haylage and soybean hulls throughout the winter feeding period. Forage samples were analyzed in duplicate. Partial DM was determined by oven drying at 60°C for 48 h. Dried samples were ground through a 1-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Analytical lab DM of the forages was determined by oven drying at 100°C for 24 h (AOAC International, 1995). Ash content was determined by combustion at 550°C overnight, using the procedure described by the AOAC International (1995). Neutral detergent fiber and ADF content were determined using an Ankom 200 Fiber Analyzer (Ankom Technology Corp., Macedon, NY). Heat-stable α-amylase and sodium sulfite treatments (Mertens, 2002) were used to obtain NDF. Ether extraction of the forages and soybean hulls was performed according to the AOAC International (1995) using a Soxtec Foss Tecator (Foss Analytical, Hillerød, Denmark). Crude protein content was analyzed according to the AOAC International (1995) using an automated Tecator digestion system (Tecator Inc., Herndon, VA).

In vitro true dry matter digestibility (**IVTDMD**) of haylage samples was determined by Cumberland Valley Analytical Services (Hagerstown, MD) using the procedures of Goering and Van Soest (1970). Near-infrared reflectance spectroscopy (**NIRS**) was used to determine IVTDMD of pasture samples. Pasture samples for analysis of nutritive value via NIRS were oven dried for 48 h at 60°C and ground to pass a 1-mm screen of a cutting mill (Wiley Laboratory Mill, model 4; Thomas Scientific, Swedesboro, NJ). Each ground sample was riffle-split into subsamples that were 1) retained without additional grinding and 2) reground to pass a 1-mm screen of a cyclone mill (Cyclotec 1093 Sample Mill; FOSS North America, Eden Prairie, MN). Cyclone-ground subsamples packed in powder cells were used for collection of near-infrared reflectance (**NIR**) spectra on a SpectraStar 2400 RTW scanning monochromator (Unity Scientific, Brookfield, CT). Spectral data were recorded as the reciprocal log of reflectance (log 1/R) at 1-nm increments over a range of 1,250 to 2,350 nm.

Chemometrics software (Ucal, version 2.0.0.31 for Windows; Unity Scientific, Brookfield, CT) was used to select a calibration subset of 98 to 121 (depending on constituent) samples representing the distribution of spectral and chemical properties of the whole sample population, following procedures of Shenk and Westerhaus (1991). The same software was used to develop prediction equations relating reference wet chemical compositional values to NIR spectra in the calibration set, as described later.

Calibration subsamples that had been ground only through a 1-mm screen of a shear mill were analyzed by the University of Wisconsin Soil and Forage Analysis Laboratory, Marshfield, WI, according to reference wet chemical procedures as follows: amylase-treated neutral detergent fiber as described in the AOAC International (Horwitz and Latimer, 2010) methods 984.13 and 2002.04 (and Mertens, 2002), respectively, and IVTDMD by incubating samples in buffered rumen fluid for 48 h followed by refluxing of indigestible residues in neutral detergent solution (Goering and Van Soest, 1970; Peters, 2013). For 48-h incubation times, values of IVTDMD are approximately 12 g/100 g higher (Van Soest, 1994) than those of in vitro apparent digestibility for the same samples analyzed by the traditional 2-stage procedure of Tilley and Terry (1963). Digestible NDF (**dNDF**; as a proportion of DM) and NDF digestibility (**NDFD**; as a proportion of NDF) were calculated from NDF and IVTDMD concentrations.

Prediction equations relating reference wet chemical analytical values to NIR spectra were developed with modified partial least squares regression. Spectral data were first transformed to the first derivative of raw (log 1/R) data; calculations were over every 8 (1-nm) data points with a running smooth of 8 (1-nm) data points. Statistical processing during equation development included 2 outlier elimination passes, 5 cross-validation groups, and use of standard normal variate with detrending for reduction of spectral variation due to light scattering caused by differences in particle size distribution and orientation among samples.

Standard errors of cross-validation for NIRS prediction equations were 37 (3.72%), 36 (3.57%), 37 (3.72%), and 60 (6.03%) g/kg for NDF, IVTDMD, dNDF, and NDFD, respectively. Proportions of variation in NDF, IVTDMD, dNDF, and NDFD concentrations in calibration samples accounted for by NIRS predicted values were 0.81, 0.87, 0.55, and 0.79, respectively. The TDN content of the pasture and haylage samples was calculated using the NRC (2001) summative equation.

Animal Measurements

Data were collected from approximately November 2 to August 20 in each of 3 yr (2009 to 2012) on 203 spring-born weanling beef heifers (n = 72, 64, and 67 in yr 1, 2, and 3, respectively). Heifers were evaluated for growth (measured as weight gain, hip height, and BCS). Individual BW was recorded on treatment initiation and at 2-wk intervals for the remainder of the trial period (261 d in yr 1, 272 d in yr 2, and 274 d in yr 3). Hip height measurements were collected and BCS (scale 1 to 9, in which 1 = extremely thin and 9 = obese; Wagner et al., 1988) were assigned to each animal at trial initiation and at approximately 28-d intervals through May by the same evaluator. Mature BW of heifers was estimated according to equations described in Fox et al. (1988).

Averaged over the 3 yr, stocking rate (heifers/ha) for the entire pasture area including unoccupied paddocks during the fall grazing period was 6.0 for the LO treatment and 3.2 for the HI treatment. Stocking density (kg BW/ha) for only the paddock area being grazed at the beginning of the fall grazing period was 25,358 ± 3,338 and 13,229 ± 1,726 (mean ± SD) for LO and HI treatments, respectively. Heifers grazed an average of 54 d during the fall grazing period, 38 d during the spring grazing period, and 75 d during the summer grazing period and were fed haylage for 101 d and soy hulls for 70 d during the winter feeding period.

Determination of Puberty

Circulating concentration of progesterone was used as an indicator of pubertal status; heifers with progesterone concentrations of >1 ng/mL at the end of the developmental period were considered to be pubertal (Berardinelli et al., 1979). Blood samples were obtained once per month up until 4 wk before breeding when they were taken once per week. Samples were collected into 10-mL EDTA vacutainer tubes via jugular venipuncture and cooled immediately on ice. Samples were refrigerated overnight at 4°C, after which plasma was harvested by centrifugation (3,000 × *g* at 4°C for 20 min) and stored at –80°C. Plasma concentrations of progesterone for each heifer were determined in duplicate using direct solid-phase RIA (Coat-a-Count Progesterone; Siemens Medical Solutions Diagnostics, Dallas, TX) without extraction, as described by Melvin et al. (1999). Intra- and interassay CV were 5.3 and 9.2%, respectively, for yr 1 (n = 8 assays); 3.5 and 8.7%, respectively, for yr 2 (n = 9 assays); and 6.3 and 5.5%, respectively, for yr 3 (n = 10 assays). Sensitivity for minimum detection was 0.02 ng/mL.

Synchronization and Breeding Protocol

In all years, heifers were synchronized in May by insertion of an intravaginal controlled internal drug-release (**CIDR**) device (Eazi-Breed CIDR; Pfizer Animal Health, New York, NY) for 7 d followed by a prostaglandin injection (Lutalyse; Pfizer Animal Health) at time of CIDR device removal and a 2-mL estradiol injection 40 h after CIDR device removal (May 20 in yr 1, May 19 in yr 2, and May 17 in yr 3). All heifers received timed AI by trained technicians approximately 72 h after CIDR device removal. A cleanup bull was used for 35 d. Turnout dates were June 4 for yr 1, June 3 for yr 2, and June 1 for yr 3. Pregnancy status (either AI or bull) was determined via rectal palpation by trained technicians (who were blind to treatments) in August (August 5 in yr 1, August 15 in yr 2, and August 20 in yr 3).

Statistical Analysis

Paddocks where the treatments (HI and LO) were applied were considered the experimental units for heifer performance and reproductive data. Continuous data were analyzed using PROC MIXED (SAS Inst. Inc., Cary, NC). The statistical model included fall pasture allowance (treatment), period (season), and treatment × period interaction as fixed effects. Year, block within year, and treatment by block within year were included as random variables. Average daily gain over periods (seasons) were analyzed as repeated measurements. The Kenward-Rogers adjustment for degrees of freedom was applied and comparisons were made using Bonferroni adjustment. The model with the best fit according to Akaike's information criterion used a heterogeneous autoregressive covariance structure. The relationships between fall ADG and nutritional composition of the pastures were investigated using PROC MIXED. The model included nutritional variables as a fixed effect and year and block within year as random effects. Binary variables were analyzed using PROC GLIMMIX using the same model as for continuous variables. The relationship between fall ADG and pregnancy outcome by AI was analyzed using the GLIMMIX procedure and a logit-link function. Significant differences were defined as $P \leq 0.05$ and tendencies at $P \leq 0.15$. To determine regression equations for prediction of herbage mass the NCSS 2000 Statistical System was used (Hintze, 1998).

RESULTS AND DISCUSSION

Climatological Data

Precipitation (rainfall and snowfall) and temperatures were recorded on site (Table 2). Average temperature for the 3-yr study was consistent with the 30-yr (1980–2010) average for the area. In yr 1, rainfall was below average during the first part of the accumulation period in August and September followed by above average rainfall in October. During the winter, snow in December was 324 mm above average, which mostly occurred in 1 snowfall event, which ended fall grazing early. In January and February, snowfall amounts were above average: 122 and 2,155 mm, respectively. Rainfall during the spring and summer was generally below average. This trend continued into the fall forage accumulation period of yr 2 with rainfall amounts in July, August, and September below average, which contributed to less herbage mass amounts at the end of the fall stockpiling period in year 2. During the winter of yr 2, snowfall amounts were below average in November, January, and February. Rainfall was above average in March and April, below average in May and June, and above average in July and August and continued through the accumulation period of yr 3. These above average rainfall amounts contributed to more stockpiled forage in yr 3 than yr 1 and 2. However, throughout the majority of the fall grazing period (November and December) rainfall was still above average, which resulted in some trampling and burial of pasture grasses and therefore intake may have been less than expected.

Table 2. Long-term monthly mean rainfall, snowfall, and temperature and departures from the long-term mean in yr 1 through yr 3[1]

Item	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
30-yr mean												
Rain, mm	107	97	90	104	86	153	69	98	103	134	122	129
Snow, mm	–	–	8	96	324	1,021	436	285	66	–	–	–
Avg temperature, °C	20.1	16.3	10.2	4.9	–0.6	–2.7	–1.2	3.3	9.1	14.0	18.7	20.7
Yr 1 departure												
Rain, mm	–14	–19	43	–71	12	–72	–69	–37	–49	–4	54	–66
Snow, mm	–	–	–8	–58	324	122	2,155	–196	–66	–	–	–
Avg temperature, °C	0.5	0.3	–1.4	2.7	–1.6	–2.4	–4.3	0.8	1.5	1.9	2.1	1.1
Yr 2 departure												
Rain, mm	–30	–2	3	9	–42	–144	4	43	125	–51	–21	32
Snow, mm	–	–	–8	–96	508	–94	–258	–221	–28	–	–	–
Avg temperature, °C	1.1	1.3	0.1	0.3	–5.7	–2.9	0.9	0.3	1.9	2.3	0.8	1.9
Yr 3 departure												
Rain, mm	37	123	64	26	82	–68	18	19	–82	3	–34	–37
Snow, mm	–	–	–8	–96	–286	–805	–406	–285	–66	–	–	–
Avg temperature, °C	0.6	0.8	–0.1	2.0	2.7	1.6	1.8	5.7	–1.0	3.5	0.2	2.5

[1]Rainfall, snowfall, and temperature during yr 1 through yr 3 and 30-yr (1980–2010) mean measured on site.

Botanical Composition

Herbage mass averaged across all grazing events of the entire experiment (2009–2012) was composed of 59% grass, 19% legumes, and 22% nonlegume forbs. Predominant species included orchardgrass (30.5%), tall fescue (14.1%), white clover (9.9%), red clover (9.5%), narrowleaf plantain (*Plantago lanceolata*; 9.0%), and quackgrass (*Elymus repens*; 8.5%). Changes in botanical composition of the pastures across the 3 yr of the study will be reported elsewhere (B. L. Bailey, T. C. Griggs, E. B. Rayburn, and K. M. Krause, West Virginia University, unpublished data).

Herbage Mass

Mean herbage mass amounts (kg DM/ha) throughout the fall for all 3 yr was 2,745 ± 445 and 2,696 ± 400 (mean ± SD) for LO and HI, respectively. During the spring and summer periods herbage mass was 1,686 ± 644 and 3,061 ± 864 kg DM/ha, respectively. During the fall grazing period, beginning herbage mass was 3,884 kg DM/ha in yr 1, 2,994 kg DM/ha in yr 2, and 3,872 kg DM/ha in yr 3. Beginning herbage mass in yr 2 was numerically lower than in other years, probably due to below-average rainfall amounts in July, August, and September. This resulted in a shorter grazing period (58 d) compared to yr 3 (68 d). Mean beginning herbage mass in yr 1 was similar to yr 3 (3,884 vs. 3,872 kg DM/ha, respectively); however, above-average snowfall in December yr 1 ended grazing early. This resulted in only 35 d grazing in the fall of yr 1 compared to 68 d grazing in yr 3. Cool-season grasses consistently produce the greatest percentage of their annual yield during the spring when reproductive growth occurs, soil moisture is adequate, and temperatures are near optimum (Denison and Perry, 1990; Moser and Hoveland, 1996). In the current study, however, average herbage mass amounts during spring might have been less than what would normally be expected because heifers had been in the pastures since November and therefore the pastures were never given a rest period.

Forage Quality

Nutritional composition of pastures, haylage, and soybean hulls is described in Table 3. Pastures were consistently higher in quality based on percentages of CP and NDF than the haylage. This is expected because these forages are generally harvested at a later stage of maturity than forages that are grazed. During the fall grazing period, CP averaged 17.3% for LO and 17.1% for HI treatment groups, more than adequate for growing beef heifers (NRC, 2000). Fall means for NDF, IVTDMD, and TDN were 51.3, 78.3, and 66.6%, respectively. There was a larger numerical difference between HI and LO treatments for NDF (50.9 vs. 51.7%, respectively) than for IVTDMD (78.4 vs. 78.1%) and TDN (66.8 vs. 66.5%). As mentioned earlier, whole plant forage samples were collected for forage quality analysis and these values may not represent what was actually consumed by the animals.

Heifer Performance: Growth

Heifer BW, BW gain, and growth data are displayed in Table 4 and Fig. 1. Heifers averaged 232 ± 17.5 d of

Table 3. Mean nutritional composition (±SD) of pastures during the fall, spring, and summer periods[1] and haylage and soybean hulls

Item, % of DM	Fall[2] LO	Fall[2] HI	Spring	Summer	Haylage	Soybean hulls
CP, %	17.3 ± 2.7	17.1 ± 2.8	24.4 ± 4.1	19.5 ± 4.1	12.0 ± 2.4	14.8 ± 1.6
NDF, %	52.3 ± 3.9	51.3 ± 4.4	48.5 ± 7.0	53.6 ± 4.9	61.3 ± 5.1	61.9 ± 2.4
IVTDMD48,[3] %	78.1 ± 5.0	78.4 ± 4.4	84.2 ± 6.8	78.3 ± 5.8	71.7 ± 4.3	–
TDN, %	66.5 ± 3.7	66.9 ± 3.8	67.6 ± 6.1	63.5 ± 5.6	59.3 ± 2.5	–
ADF, %	30.0 ± 4.3	29.9 ± 3.9	29.0 ± 5.9	33.4 ± 4.5	40.6 ± 2.5	45.3 ± 2.2
EE,[4] %	1.1 ± 0.4	2.1 ± 0.4	2.5 ± 0.7	2.5 ± 0.7	2.5 ± 0.6	2.4 ± 0.3
Ash, %	7.4 ± 1.1	7.5 ± 1.3	9.5 ± 1.7	8.0 ± 1.3	7.9 ± 2.0	4.2 ± 0.3

[1]*n* = 33 samples (fall), *n* = 38 samples (spring), and *n* = 50 samples (summer).

[2]LO = daily pasture DM allowance of 3.5% of BW; HI = daily pasture DM allowance of 7.0% of BW.

[3]IVTDMD48 = in vitro true dry matter digestibility at 48 h.

[4]EE = ether extract.

age and 246 ± 28.9 kg at trial initiation across all years. Initial BW did not differ between treatments: 246 kg for LO and 245 kg for HI ($P = 0.93$). There was a significant treatment × period interaction for heifer ADG ($P < 0.001$), which was to be expected given that the different pasture allowances were only applied to the fall season. Heifers on the HI treatment gained more weight (0.40 kg/d) than did heifers on the LO treatment (0.12 kg/d; $P < 0.0001$) during the fall grazing period. At the end of the fall grazing period heifers on the HI treatment weighed 266 kg, whereas heifers on the LO treatment weighed 251 kg ($P = 0.0004$). Poore et al. (2006) reported ADG for unsupplemented heifers strip-grazing stockpiled fescue from early December to late February of 0.35 (yr 1) and 0.18 kg/d (yr 2) with stocking rates of 5.9 and 7.8 heifers/ha, respectively. The stocking rates and ADG reported by Poore et al. (2006) are similar to those in this study. In contrast, a study by Drewnoski et al. (2009) reported that ADG of heifers strip-grazing stockpiled fescue from December through February was 0.60 kg/d (average of 4 yr). In that study, heifers were moved every day and the strip size was adjusted based on residue from the previous day, which could have contributed to greater ADG than seen in this study. Residual forage was not measured in the current study, but visual observations indicated that forage allocation was limiting, at least for the LO treatment. Also, occasional wet conditions resulted in trampling of pasture, which could have led to reduced intakes.

As mentioned previously, although forage quality was very similar for the 2 treatments, there was a numerically larger difference between treatments for NDF ($P = 0.06$; B. L. Bailey, T. C. Griggs, E. B. Rayburn, and K. M. Krause, West Virginia University unpublished data for statistical comparison of pasture quality for the 2 treatments) than for IVTDMD and TDN. Because cell walls contribute to rumen fill, NDF concentration of herbage is a determinant of dietary intake (Jung and Allen, 1995). However, at the high level of diet quality in the current study we would expect physical extension of the rumen to play a minor role in regulating intake. Regardless, there was a significant relationship between fall ADG and NDF content of the pasture (across treatments). For each 10 g increase in NDF/kg fall pasture (DM basis), fall ADG decreased by 0.14 kg ($P = 0.01$).

Table 4. Body weight, BCS, and hip height at treatment initiation and at breeding following either HI[1] or LO[2] fall forage allocation

Trait	LO	HI	SEM	*P*-value
Initial BW, kg	246	245	2.90	0.93
Initial BCS	4.3	4.3	0.08	0.50
Initial hip height, cm	109.2	109.0	1.88	0.68
BW at end of fall grazing period, kg	251	266	4.68	0.0004
BW at end of winter period, kg	281	304	8.33	<0.0001
BW at breeding, kg	335	356	10.0	<0.0001
BCS at breeding	5.6	5.8	0.10	0.0057
Hip height at breeding, cm	121.4	122.7	0.13	0.0055
Pregnancy diagnosis BW, kg	402	415	10.2	0.0055

[1]HI = daily pasture DM allowance of 7.0% of BW.

[2]LO = daily pasture DM allowance of 3.5% of BW.

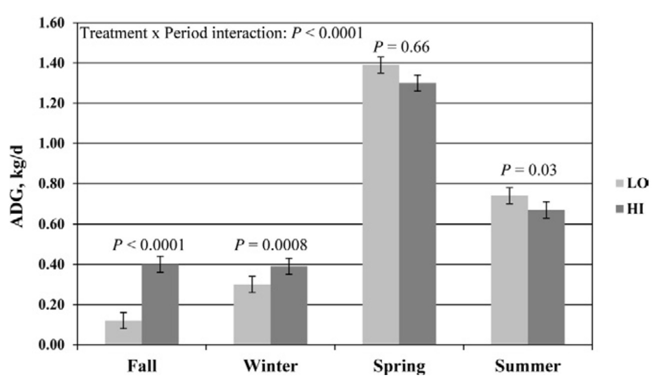

Figure 1. Heifer ADG for daily pasture DM allowance of 7.0% of BW (HI) and daily pasture DM allowance of 3.5% of BW (LO) treatment groups during the fall, winter, spring, and summer periods. Error bars indicate SEM values. The *P*-values above bars indicate differences between HI and LO within each season.

Although the difference in fall ADG between treatments was most likely caused by the difference in pasture allowance and therefore diet selection, it is possible that the slight difference in NDF concentration between the 2 treatments could have affected ADG. Although pasture intake is influenced primarily by DM allowance, percent NDF of available pasture has relevance in grazing-based systems because it is negatively associated with potential intake (Vazquez and Smith, 2000). Thus, the amount of dietary fiber may have an impact on pasture use.

At the beginning of the winter feeding period, both HI and LO heifers lost BW for approximately the first 35 d (data not shown), which suggests that there may be an adjustment phase for feeding haylage. During the winter feeding period, ADG was 0.30 and 0.39 kg/d for LO vs. HI heifers, respectively ($P = 0.0008$), resulting in a BW of 281 and 304 kg at the end of the winter period for LO vs. HI heifers, respectively ($P < 0.0001$). Heifers in the LO treatment group gained 0.18 kg/d more during the winter than in the fall grazing period and ADG for HI heifers in the winter remained basically the same as ADG during the fall. Hip height (122.7 vs. 121.4 cm; $P = 0.0055$) and BCS (5.8 vs. 5.6; $P = 0.0057$) at the end of spring grazing (time of AI breeding) was greater for HI heifers than LO heifers, respectively. During the spring grazing period, LO heifers had numerically greater ADG than HI heifers (1.39 vs. 1.31 kg/d; $P = 0.66$). This difference in ADG persisted during the summer grazing period, where heifers on the LO treatment had greater ADG than heifers on the HI treatment (0.74 vs. 0.67 kg/d; $P = 0.03$). Heifers grazed an average of 38 d during the spring grazing period and 75 d during the summer grazing period. Differences in ADG for the spring grazing period may have been larger (as seen during the summer grazing period) had the period lasted longer than 38 d.

Heifer ADG from treatment initiation (November) through breeding (May) was greater for the HI treatment group than the LO (0.56 ± 0.04 vs. 0.46 ± 0.04 kg/d [(least squares means) {**LSMEAN**} ± SEM]; $P < 0.001$) as was total ADG from treatment initiation (November) through pregnancy diagnosis in August (0.61 ± 10.2 vs. 0.55 ± 10.0 kg/d [LSMEAN ± SEM]; $P < 0.001$; data not shown). Allen et al. (2000) demonstrated that steers grazing an alfalfa–orchardgrass pasture from mid November through mid December, fed alfalfa–orchardgrass hay until about April 8 to April 27, and then grazed bluegrass–white clover pasture through mid October gained 0.49 kg/d for the entire period (mid November through mid October). The ADG reported by Allen et al. (2000) is less than the ADG in the current study and could be due to overstocking that occurred while steers were grazing the bluegrass–white clover pasture.

Although heifers on the LO treatment gained more during spring and summer, their BW at the end of the summer grazing period (time of pregnancy diagnosis) was less than the BW of heifers on the HI treatment (402 vs. 415 kg; $P = 0.0055$). However, this difference in BW between treatment groups at the time of pregnancy diagnosis had been reduced compared to the difference in BW at the end of the spring grazing period (335 kg for LO heifers vs. 356 kg for HI heifers; $P < 0.0001$). This indicates that the LO heifers were able to compensate for 61% of the restriction at the end of spring during the breeding season (Fig. 1), which is similar to observations by Klopfenstein et al. (1999), who reported that full season grazing gives 50 to 60% compensation on average.

Heifers developed extensively, that is, under conditions of dormant or scarce forage, low precipitation, undulating terrain, and large pastures, or those that are restricted-gain pen developed often exhibit compensatory gain during the summer grazing period (Endecott et al., 2013). Studies have shown that range-developed heifers with minimal prebreeding ADG compensate during the breeding season and gain more BW than feedlot-developed heifers due to decreased maintenance requirements and the ability to respond to a seasonal improvement in forage quality (Marston et al., 1995; Ciccioli et al., 2005). Mulliniks et al. (2013) demonstrated that heifers developed in a dry lot had greater ADG (0.69 kg/d) from initiation of the study to breeding compared to heifers developed on low-quality forage with protein supplementation, who only gained 0.26 kg/d. However, the range-developed heifers compensated during the breeding season and had greater ADG (0.83 kg/d) than dry lot heifers (0.61 kg/d). Research conducted by Larson et al. (2011) evaluated the effect of heifers grazing corn residue (**CR**) compared with winter range (**WR**). Heifers grazing CR tended to have less ADG than WR heifers during the winter grazing and prebreeding period (0.14 vs. 0.24 kg/d and 0.29 vs. 0.38 kg/d) but had similar BW at breeding as WR heifers. Heifers grazing CR were approximately 52% of mature BW at breeding and WR heifers were 55%. During the summer, heifers grazing CR tended to compensate with greater ADG (0.73 kg/d) than WR heifers (0.67 kg/d).

Outcomes from grazing systems are variable and will change depending on site, climate, soils, forage species, kinds and classes of livestock, and other influencing factors (Allen et al., 2000). Because grazing systems function as a whole and are the result of interactions among their components, it is difficult to make direct comparisons, especially with naturalized pastures. However, evaluating the relationships within system components and overall system results can allow for better educated decisions when designing systems to match livestock feed requirements to forage types.

Table 5. Effects of fall forage allocation (HI[1] vs. LO[2]) on heifer reproduction

Trait	LO	HI	SEM	*P*-value
Pubertal by time of AI, %	34	34	13	0.93
Pregnant to AI, %	32	44	8	0.13
Pregnant to bull,[3] %	61	59	6	0.80
Final pregnancy rate, %	74	77	5	0.61

[1]HI = daily pasture DM allowance of 7.0% of BW.

[2]LO = daily pasture DM allowance of 3.5% of BW.

[3]Expressed as percentage of heifers eligible to become pregnant.

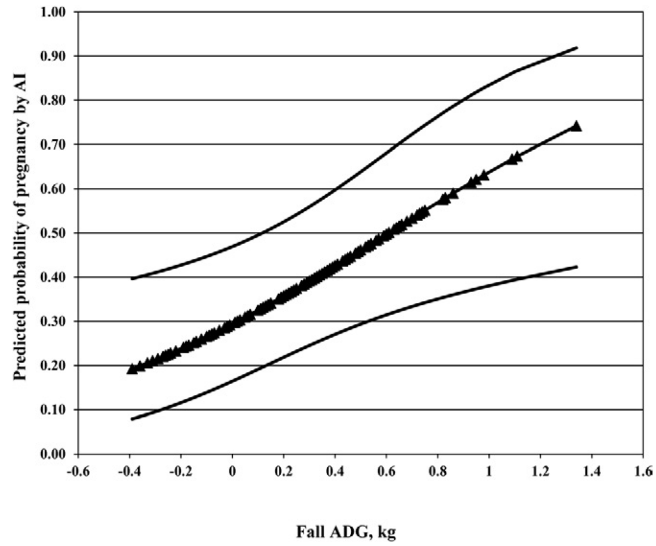

Figure 2. The predicted probability of heifers becoming pregnant to AI based on fall ADG. The triangle (▲) indicates the predicted probability of pregnancy by AI and the upper and lower lines refer to the 95% confidence interval.

Heifer Performance: Reproduction

Heifer reproductive data are presented in Table 5. There was no effect of fall pasture allowance on percentage of heifers reaching puberty by the time of AI (34% for both groups; $P = 0.93$). As mentioned earlier, heifers in the LO treatment group weighed less at breeding than heifers in the HI treatment group (335 vs. 356 kg; $P < 0.0001$) and were approximately 63% of mature BW, whereas those in the HI group were 66% of mature BW (544 kg) at breeding ($P = 0.14$). The percentage of heifers becoming pregnant to AI tended ($P = 0.13$) to be greater (44%) for the HI heifers than for the LO heifers (32%). Heifers that conceive earlier in the breeding season will calve earlier in the calving season, resulting in older and heavier calves at weaning (Lesmeister et al., 1973). Also, heifers that calve early in the calving season with their first calf have increased longevity and kilograms weaned compared with heifers that calve later in the calving season (Cushman et al., 2013). The percentage pregnant by natural service was similar (61% for LO vs. 59% for HI; $P = 0.80$) between the 2 groups. Final pregnancy rate was also not different (74 vs. 77%; $P = 0.61$) among LO and HI heifers, respectively. It is possible the synchronization system used in this study potentially prevented decreased reproductive outcomes because CIDR devices have been shown to induce puberty in noncycling beef females (Lucy et al., 2001).

Research conducted by Funston and Larson (2011) compared traditional postweaning dry lot (**DL**) development with a more extensive winter grazing system using a combination of CR and WR (**EXT**). During the winter grazing period, EXT heifers gained less BW than DL heifers and EXT heifers had lighter BW at breeding. Final pregnancy rates did not differ; however, AI pregnancy rate tended ($P = 0.08$) to be less for EXT heifers. Roberts et al. (2009) offered heifers ad libitum or restricted access to feed for a 140 d period after weaning. Restricted heifers had less ADG (0.53 vs. 0.65 kg/d) than control heifers. Differences in heifer ADG and BW persisted through prebreeding, but from the end of the 140 d restriction at about 12.5 to 19.5 mo of age, ADG was greater (0.51 vs. 0.47 kg/d) in restricted heifers than control heifers. Pregnancy rate from AI tended to be less in restricted (48%) than control heifers (57%); however, overall pregnancy rates did not differ.

As stated previously, the percentage of heifers becoming pregnant to AI tended to be greater for the HI heifers (32 vs. 44%; $P = 0.13$). This tendency in increased AI pregnancy was supported by a positive relationship between fall ADG and AI pregnancy rate ($P = 0.01$). Figure 2 represents the predicted probability of heifers becoming pregnant to AI based on fall ADG. As the ADG increases, the odds of a heifer becoming pregnant increase ($P = 0.01$). For example, the probability of a heifer becoming pregnant by AI with ADG in the fall of 0.6, 0.8, and 1.0 kg is 50, 60, and 64%, respectively. The large range in fall ADG across treatment groups (–0.39 to 1.34 kg/d) probably contributed to the significant relationship between fall ADG and AI pregnancy outcome.

In the aforementioned study by Roberts et al. (2009), it was demonstrated that the covariate of BW at the initiation of the feeding trial indicated a 0.17 increase in percent pregnancy rate from AI and a 0.089 decrease in day of the breeding season that conception occurred for each additional kilogram of BW. These results indicated that BW at 7 to 8 mo of age may influence time of conception in the first breeding season. This supports the results from our study where ADG of heifers averaging 7 to 8 mo of age during the fall grazing period influenced the probability of pregnancy by timed AI. Roberts et al. (2009) further evaluated this concept by conducting another analysis of pregnancy measures using a model that included covariates of ADG from birth to weaning, ADG from weaning to beginning of the feeding treatment, and within-treatment ADG during the 140-d trial. Results indicated a 3.9 and 3.4 increase in percentage pregnancy rate from AI with each 0.1 kg/d increase in ADG from birth to weaning and from weaning to beginning of treatment, respectively. Pregnancy rate from AI was not influenced by within-treatment ADG during the 140-d trial. Final pregnancy rate was not influenced by any of the covariates. It was concluded that rate of growth during the preweaning and early postweaning phase have a greater effect on when heifers become pregnant than rate of growth during the latter part of the postweaning period.

The current study suggests that overall reproductive performance is not adversely affected when virtually all of the postweaning weight gain is achieved through compensatory gain during the summer breeding period; however, fall ADG may affect first service conception rates. The percentage of heifers becoming pregnant to AI tended to be greater for HI heifers than LO heifers ($P = 0.13$) while final pregnancy rates were similar for both LO and HI treatments (74 vs. 77%, respectively; $P = 0.61$). However, the importance of first service conception rate is supported by the abovementioned relationship: earlier heifer conception leads to earlier calving, which subsequently improves weaning weight of the calves and longevity of the heifer.

As discussed by Larson et al. (2011), most of the current research on heifer development has been conducted in a traditional dry lot setting and limited to no data exist comparing development systems using standing forage. Increasing costs of feeds have prompted producers to consider heifer development systems using low-cost/low-input feedstuffs including extended-season grazing using stockpiled forage. These data and previously published data indicate that delaying the majority of gain until 35 to 44 d before breeding has the potential to result in adequate overall pregnancy rates; however, fall forage allowance and ADG must be adequate for acceptable first service conception rates. Also, producers can use stockpiled fall and winter forage as conditions allow. Moreover, heifers developed in this manner still reached 63 to 66% of mature BW by breeding.

Additionally, this system did not require dry-lot or barn feeding; therefore, nutrients were recycled directly back to the soil to support forage growth. Also, it is important to note that heifers were only supplemented with the equivalent of 0.24 kg of protein/d during the winter period (approximately 73 d) and gained between 0.30 and 0.39 kg/d during the winter period. However, once placed on high quality spring pasture, heifers gained 1.31 to 1.39 kg/d prebreeding and 0.67 to 0.74 kg/d during and after the breeding season. Regardless of these compensatory BW gains, LO heifers weighed 6% less before breeding than HI heifers, had achieved approximately 63% of mature BW, and had similar pregnancy rates at the end of the breeding season. The large range in age at breeding across treatment groups (373 d to 465 d) may have contributed to less than satisfactory AI and final pregnancy rates for both LO and HI treatment groups.

These findings suggest that delaying selection of replacement heifers until pregnancy evaluation may be a potential management strategy that would provide producers the opportunity to select heifers capable of achieving acceptable reproductive performance under restricted conditions. The goal of heifer development programs should not be to produce heifers with the greatest BW gain but instead to produce a functional, pregnant heifer with the ability to have a live calf and rebreed the following breeding season using low-cost methods. Even though it may be impractical to remove hay from the winter feed system, using stockpiled forages to increase the number of days that grazing can replace stored feed as the source of nutrients has the potential to reduce costs of production while still achieving acceptable heifer performance.

LITERATURE CITED

Allen, V. G., J. P. Fontenot, and R. A. Brock. 2000. Forage systems for production of stocker steers in the upper south. J. Anim. Sci. 78:1973–1982.

AOAC International. 1995. Official Methods of Analysis. Vol. I, 16th ed. AOAC International, Arlington, VA.

Berardinelli, J. G., R. A. Dailey, R. L. Butcher, and E. K. Inskeep. 1979. Source of progesterone prior to puberty in beef heifers. J. Anim. Sci. 49:1276–1280.

Ciccioli, N. H., S. L. Charles-Edwards, C. Floyd, R. P. Wettemann, H. T. Purvis, K. S. Lusby, G. W. Horn, and D. L. Lalman. 2005. Incidence of puberty in beef heifers fed high- or low-starch diets for different periods before breeding. J. Anim. Sci. 83:2653–2662.

Clark, R. T., K. W. Creighton, H. H. Patterson, and T. N. Barrett. 2005. Symposium paper: Economic and tax implications for managing beef replacement heifers. Prof. Anim. Sci. 21:164–173.

Combellas, J., and J. Hodgson. 1979. Herbage intake and milk production by grazing dairy cows. 1: The effect of variations in herbage mass and daily herbage allowance in a short term trial. Grass Forage Sci. 34:209–214.

Cushman, R. A., L. K. Kill, R. N. Funston, E. M. Mousel, and G. A. Perry. 2013. Heifer calving date positively influences calf weaning weights through six parturitions. J. Anim. Sci. 91:4486–4491.

Denison, R. F., and H. D. Perry. 1990. Seasonal growth rate patterns for orchardgrass and tall fescue on the Appalachian plateau. Agron. J. 82:869–873.

Drewnoski, M. E., E. J. Oliphant, B. T. Marshall, M. H. Poore, J. T. Green, and M. E. Hockett. 2009. Performance of growing cattle grazing stockpiled Jesup tall fescue with varying endophyte status. J. Anim. Sci. 87:1034–1041.

Earle, D. F., and A. A. McGowan. 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. Aust. J. Exp. Agric. Anim. Husb. 19:337–343.

Endecott, R. L., R. N. Funston, J. T. Mulliniks, and A. J. Roberts. 2013. Joint Alpharma-Beef Species symposium: Implications of beef heifer development systems and lifetime productivity. J. Anim. Sci. 91:1329–1335.

Fox, D. G., C. J. Sniffen, and J. D. O'Connor. 1988. Adjusting nutrient requirements of beef cattle for animal and environmental variations. J. Anim. Sci. 66:1475–1495.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2001. Production performance of beef cows raised on three different nutritionally controlled heifer development programs. J. Anim. Sci. 79:819–826.

Funston, R. N., and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J. Anim. Sci. 82:3094–3099.

Funston, R. N., and D. M. Larson. 2011. Heifer development systems: Dry-lot feeding compared with grazing dormant winter forage. J. Anim. Sci. 89:1595–1602.

Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analyses. Agric. handbook no. 379. USDA-ARS, Washington, DC.

Hintze, J. L. 1998. NCSS 2000 statistical system. Number Cruncher Statistical Systems, Kaysville, UT.

Horwitz, W., and G. W. Latimer Jr., editors. 2010. Official methods of analysis of AOAC International. 18th ed. Rev. 3. AOAC International. Gaithersburg, MD.

Jung, H. G., and M. S. Allen. 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. J. Anim. Sci. 73:2774–2790.

Klopfenstein, T. D., J. Jordan, I. Rush, and T. Milton. 1999. Predicting amount of compensatory gain. Nebraska Beef Cattle Rep. MP 71-A. Univ. Nebraska, Lincoln, NE. p. 26–28.

Larson, D. M., A. S. Cupp, and R. N. Funston. 2011. Heifer development systems: A comparison of grazing winter range or corn residue. J. Anim. Sci. 89:2365–2372.

Lesmeister, J. L., P. J. Burfening, and R. L. Blackwell. 1973. Date of first calving in beef cows and subsequent calf production. J. Anim. Sci. 36:1–6.

Lucy, M. C., H. J. Billings, W. R. Butler, L. R. Ehnis, M. J. Fields, D. J. Kesler, J. E. Kinder, R. C. Mattos, R. E. Short, W. W. Thatcher, R. P. Wettemann, J. V. Yelich, and H. D. Hafs. 2001. Efficacy of an intravaginal progesterone insert and an injection of PGF2alpha for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers, and dairy heifers. J. Anim. Sci. 79:982–995.

Mannetje, L. T., and K. P. Haydock. 1963. The dry-weight rank method for the botanical analysis of pasture. J. Br. Grassl. Soc. 18:268–275.

Marston, T. T., K. S. Lusby, and R. P. Wettemann. 1995. Effects of postweaning diet on age and weight at puberty and milk production of heifers. J. Anim. Sci. 73:63–68.

Martin, J. L., K. W. Creighton, J. A. Musgrave, T. J. Klopfenstein, R. T. Clark, D. C. Adams, and R. N. Funston. 2008. Effect of prebreeding body weight or progestin exposure before breeding on beef heifer performance through the second breeding season. J. Anim. Sci. 86:451–459.

Melvin, E. J., B. R. Lindsey, J. Quintal-Franco, E. Zanella, K. E. Fike, C. P. Van Tassell, and J. E. Kinder. 1999. Circulating concentrations of estradiol, luteinizing hormone, and follicle stimulating hormone during waves of ovarian follicular development in prepubertal cattle. Biol. Reprod. 60:405–412.

Mertens, D. R. 2002. Gravimetric determination of amylase-treated neutral detergent fibre in feeds with refluxing beakers or crucibles: Collaborative study. J. AOAC Int. 85:1217–1240.

Moser, L. E., and C. S. Hoveland. 1996. Cool-season grass overview. In: L. E. Moser, D. R. Buxton, and M. D. Casler, editors, Cool-season forage grasses. Agron. Monogr. 34. ASA, CSSA, SSSA, Madison, WI. p. 1–14.

Mulliniks, J. T., D. E. Hawkins, K. K. Kane, S. H. Cox, L. A. Torell, E. J. Scholljegerdes, and M. K. Petersen. 2013. Metabolizable protein supply while grazing dormant winter forage during heifer development alters pregnancy and subsequent in-herd retention rate. J. Anim. Sci. 91:1409–1416.

NRC. 2000. Nutrient requirements of beef cattle. 6th rev. ed. National Academy Press, Washington, DC.

NRC. 2001. Nutrient requirements of dairy cattle. 7th Rev ed. Natl. Acad. Sci, Washington, DC.

Patterson, D. J., R. C. Perry, G. H. Kiracofe, R. A. Bellows, R. B. Staigmiller, and L. R. Corah. 1992. Management considerations in heifer development and puberty. J. Anim. Sci. 70:4018–4035.

Peters, J., editor. 2013. Wisconsin procedures for soil testing, plant analysis and feed and forage analysis. University of Wisconsin-Madison Soil Testing Laboratories. http://uwlab.soils.wisc.edu/lab-procedures/. (Accessed 2 August 2013.)

Poore, M. H., M. E. Scott, and J. T. Green Jr. 2006. Performance of beef heifers grazing stockpiled fescue as influenced by supplemental whole cottonseed. J. Anim. Sci. 84:1613–1625.

Roberts, A. J., T. W. Geary, E. E. Grings, R. C. Waterman, and M. D. MacNeil. 2009. Reproductive performance of heifers offered ad libitum or restricted access to feed for a one hundred forty-day period after weaning. J. Anim. Sci. 87:3043–3052.

Shenk, J. S., and M. O. Westerhaus. 1991. Population structuring of near infrared spectra and modified partial least squares regression. Crop Sci. 31:1548–1555.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104–111.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell Univ. Press, Ithaca, NY.

Vazquez, O. P., and T. R. Smith. 2000. Factors affecting pasture intake and total dry matter intake in grazing dairy cows. J. Dairy Sci. 83:2301–2309.

Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wetteman, and L. E. Walters. 1988. Carcass composition in mature Hereford cows: Estimation and effect on daily Metabolizable energy requirement during winter. J. Anim. Sci. 66:603–612.