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Effect of rate of body weight gain in steers during the stocker phase. I. Growth, partitioning of fat among depots, and carcass characteristics of growing-finishing beef cattle¹

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ABSTRACT: Two experiments were conducted to examine the effect of growth rate to similar age or BW on fat deposition in stocker cattle grazing dormant native range (DNR) or winter wheat pasture (WP). In each experiment, fall-weaned Angus steers were randomly allotted to 1 of 4 stocker production programs: 1) control, 1.02 kg/d of a 40% CP cottonseed meal-based supplement during grazing of DNR (CON); 2) corn/soybean meal-based supplement fed at 1% of BW during grazing of DNR (CORN); 3) grazing WP at a high stocking rate to achieve a low rate of BW gain (LGWP); and 4) grazing WP at a low stocking rate to achieve a high rate of BW gain (HGWP). In Exp. 1, a subset of steers (3 steers per treatment) was harvested after winter grazing (138 d) at similar age. The remaining WP steers were transitioned into the finishing phase, whereas DNR steers were allowed to graze the same native range pastures for another 115 d without supplementation before entering the feedyard. In Exp. 2, steers grazed their respective pastures until each treatment reached an estimated HCW of 200 kg (262, 180, 142, and 74 d, respectively, for the CON, CORN, LGWP, and HGWP treatments), at which time a subset of steers (4 steers per treatment) were selected for

intermediate harvest before finishing. In both experiments, the remaining steers were fed a finishing diet to a common 12th-rib fat thickness of 1.27 cm. In Exp. 1, winter grazing ADG was 0.19, 0.52, 0.68, and 1.37 ± 0.03 kg/d; and in Exp. 2, winter/summer grazing ADG was 0.46, 0.61, 0.83, and 1.29 ± 0.02 kg/d, respectively for CON, CORN, LGWP, and HGWP treatments. At intermediate harvest in Exp. 1, HGWP steers had greater ($P < 0.01$) 12th-rib fat thickness and marbling scores, compared with the other treatments. However, in Exp. 2, LGWP steers had greater ($P < 0.01$) marbling scores compared with HGWP steers, which were greater than DNR steers. At final harvest in Exp. 1, LGWP steers had greater ($P < 0.01$) 12th-rib fat thickness and smaller LM area, compared with the other treatments; however, there were no differences ($P = 0.99$) in final marbling scores. In Exp. 2, CON steers had lower ($P < 0.05$) 12th-rib fat thickness and tended ($P = 0.10$) to have greater marbling scores, compared with the other treatments. These data suggest that changes in the partitioning of fat among depots during the stocker phase may not be reflected after finishing when steers are fed to a common 12th-rib fat thickness.

Key words: dormant native range, energy supplementation, growing beef cattle, marbling deposition, rate of gain, winter wheat pasture

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INTRODUCTION

Marbling is the last fat depot to mature in the growing beef animal (McPhee et al., 2008) and pre-feedyard management practices can influence intramuscular fat deposition (Anderson and Gleghorn, 2007). Each year,

thousands of fall-weaned calves are wintered on dormant native range (**DNR**) or winter wheat pasture (**WP**) in the Southern Great Plains. Smith and Crouse (1984) reported that intramuscular adipocytes preferentially use glucose as the primary substrate for fatty acid synthesis, whereas subcutaneous fat uses acetate. Cattle grazing WP have 70% lower acetate:propionate ratio compared with cattle grazing DNR, which could influence substrate availability for gluconeogenesis (Choat et al., 2003). These 2 grazing programs result in differing rates of BW gain that affect the amount of body fat at the end of grazing (Hersom et al., 2004). Moreover, studies have shown that increasing ADG during backgrounding improves marbling score before finishing but also significantly increases 12th-rib fat thickness (Sainz et al., 1995). Additionally, marbling score increases linearly with BW, whereas 12th-rib fat thickness increases curvilinearly (Bruns et al., 2004). Therefore, we hypothesized that steers grown at low to moderate rates of BW gain during the stocker phase would achieve similar marbling scores but lower rib fat thickness when grown to similar BW before finishing, which would carry over to greater marbling scores when harvested at similar 12th-rib fat thickness endpoint after finishing. The objective of this study was to examine the effect of rate of BW gain to similar age or BW on intramuscular fat deposition relative to other fat depots in stocker cattle grazing DNR or WP.

MATERIALS AND METHODS

Before initiation of these studies, procedures for animal care, handling, and sampling were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Study Site and Vegetation

Two experiments were conducted in consecutive years using stocker cattle production systems on DNR or WP to compare differing rates of BW gain during the stocker phase on carcass characteristics at similar age and BW before finishing. The Crosstimbers-Bluestem Stocker Range is located 11 km west of Stillwater, OK. The vegetation and climate of this site has been previously described in detail by Bodine and Purvis (2003). The Stillwater Wheat Pasture Unit is located 2 km west of Stillwater, OK, and consists of 35 ha of clean-tilled farm ground that was planted to hard red winter wheat (*Triticum aestivum* L.; var. Endurance). The farm ground was divided into 4 pastures (8.74 to 9.67 ha) for winter grazing.

Animals and Management

An illustration depicting the management of steers from weaning through winter and summer grazing phases, and the finishing phase in Exp. 1 and 2 is presented in Fig. 1.

Experiment 1. Seventy-three fall-weaned Angus steers (258 ± 29 kg) from the Oklahoma State University Range Cow South Range Research Unit near Stillwater, OK, were used in the experiment. Steers were weaned 2 October 2008, transported 10 km to the Crosstimbers-Bluestem Stocker Range, vaccinated with Bovi-Shield Gold 5 (Zoetis, Exton, PA), and allowed to graze DNR pastures before initiation of the experiment. Steers were revaccinated on 20 October 2008 with Bovi-Shield Gold 5, hip branded, and full BW measured. Steers were not implanted before weaning or during the grazing phase.

After revaccination, 4 steers were randomly selected for measurement of initial carcass characteristics and the remaining 69 steers (276 ± 18 d of age) were stratified by BW and allotted to 1 of 4 winter grazing treatments: 1) control, 1.02 kg/d of a 40% CP cottonseed meal-based supplement to meet their degradable intake protein (**DIP**) requirement during grazing of DNR (**CON**); 2) ground corn/soybean meal-based supplement fed at 1% of BW during grazing of DNR (**CORN**); 3) grazing WP at a high stocking rate (3.21 steers/ha) to achieve a low rate of BW gain (**LGWP**); and 4) grazing WP at a low stocking rate (0.99 steer/ha) to achieve a high rate of BW gain (**HGWP**). Steers were also equally stratified across treatments by known sire for selection of steers for intermediate harvests to minimize genetic differences among treatments. The CON and CORN steers were placed on DNR pastures and trained to enter individual feeding stalls 2 or 3 d/wk by offering 0.57 kg/steer of a 40% CP supplement. The LGWP and HGWP steers were placed on a separate dormant tallgrass pasture until initiation of WP grazing and were group fed the same CP supplement that was offered to CON and CORN steers.

On 9 December 2008, the 4 steers selected for measurement of initial carcass characteristics were harvested at the Oklahoma State University Food and Agricultural Products Center (**FAPC**) abattoir in Stillwater, OK, as described by Hersom et al. (2004). Carcass data (HCW, LM area, 12th-rib fat thickness, KPH, marbling score, and calculated USDA Yield Grade; USDA, 1997) were collected by trained personnel from Oklahoma State University. On 10 December 2008, the remaining 69 steers began their treatment regimens. The CON and CORN treatment groups were allowed to graze together at a stocking rate of 0.55 steer/ha. Supplements were individually fed 5 d/wk (Table 1). The WP steers were transported 9 km to the Stillwater Wheat Pasture Unit near Stillwater, OK, and sorted and placed in their respective pastures for winter grazing. Steers were weighed after a 5-h fast every 2 wk during winter grazing. Each day,

Figure 1. Illustration depicting winter and summer grazing and finishing phases for wheat pasture and dormant native range steers during Exp. 1 and 2. CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range. CON and CORN steers were not fed supplements during summer grazing.

supplement was offered, the CORN steers were sorted into 1 of 3 groups based on BW (light, medium, and heavy BW groups) to better ensure steers were consuming 1% of BW instead of offering supplement based on the average BW of the entire treatment. The amount of supplement offered was adjusted based on intermediate BW. Any supplement refusals from the CORN treatment were weighed, recorded, and discarded. There were no feed refusals from the CON treatment. Steers in the WP treatments were offered free choice access to a nonmedicated mineral mix during winter grazing. Intermediate BW measurements were also used to adjust the stocking rate of LGWP steers to achieve the desired rate of BW gain, which was accomplished by adjusting the size of the grazing area based on forage availability and previous rate of BW gain, and ranged from 4.98 to 5.79 ha. The HGWP steers were rotated between 2 adjacent pastures (~9 ha each) to ensure that ADG was not limited by forage availability throughout the entire grazing phase. One steer that was assigned to the LGWP treatment was removed from the experiment at the end of winter grazing due to poor growth for unknown reasons. All data for this steer were removed from analysis; however, the steer was included in calculation of stocking rate.

At the end of the winter grazing phase (138 d), ultrasound measurements of 12th-rib fat thickness, LM area,

Table 1. Ingredient and chemical composition of supplements fed to steers grazing dormant native range for Exp. 1 and 2

Item	Treatment ¹			
	CON		CORN	
Ingredient composition, % as-fed				
Cottonseed meal	80.5		–	
Rolled corn	–		67.0	
Soybean meal, 47.5% CP	11.9		32.0	
Wheat middlings	7.6		–	
Limestone	–		1.0	
Chemical composition ²				
	Exp. 1	Exp. 2	Exp. 1	Exp. 2
DM, %	92.2	92.6	90.6	91.0
CP, % DM	44.7	44.4	23.9	25.6
NE _m , ³ Mcal/kg DM	1.98	1.96	2.07	2.12
NE _g , ³ Mcal/kg DM	1.34	1.32	1.41	1.43
ADF, % DM	14.4	13.6	4.80	3.10
NDF, % DM	21.7	24.8	12.4	9.70
TDN, ³ % DM	80.0	79.0	83.0	84.0
Starch, % DM	23.0	22.6	63.6	65.0
Degradable intake protein, % of CP	68.9	70.9	59.3	59.5

¹CON = 40% CP supplement; CORN = corn-based supplement.

²Chemical composition was performed at a commercial lab (Dairy One, Ithaca, NY), except for starch and degradable intake protein assays that were conducted at Oklahoma State University.

³Net energy and TDN values were calculated by Dairy One (Ithaca, NY).

and intramuscular fat were taken on the left side of each steer by a Ultrasound Guideline Council-certified technician, using an Aloka 500V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2-cm, 3.5-MHz linear transducer. Images were interpreted with Beef Image Analysis Pro Plus software (Designer Genes Technologies, LLC, Harrison, AR). Additionally, at the end of the winter grazing phase, 3 steers per treatment from the same sire were harvested at the FAPC abattoir (first intermediate harvest), as previously described for the initial harvest to compare carcass characteristics of steers at similar age.

After the first intermediate harvest, the remaining LGWP and HGWP steers were transported 154 km to the USDA-ARS Grazinglands Research Laboratory (El Reno, OK) for finishing. Within treatment, steers were allotted to 1 of 3 pens (4 to 5 steers/pen) and fed twice daily (60% in the morning and 40% in the afternoon). Steers were implanted with Revalor-S (24 mg of estradiol and 120 mg trenbolone acetate; Merck Animal Health, Summit, NJ), vaccinated with Titanium-5 (Diamond Animal Health, Inc., Des Moines, IA), and given a pour-on dewormer [Ivomec Eprinex (5 mg eprinomectin/mL); Merial, Duluth, GA]. Individual full BW were measured every 21 d during finishing and a pencil shrink of 4% was applied to each BW. The finishing diet that was fed at the El Reno feedlot is presented in Table 2. The HGWP and LGWP steers were fed 83 and 138 d, respectively, to reach a visually predicted 12th-rib fat thickness of 1.27 cm. At the end of finishing, 3 steers from LGWP and HGWP treatments were harvested at the FAPC abattoir where carcass measurements were collected, as previously described for the initial harvest steers. The remaining steers from each treatment were harvested at a commercial abattoir (Creekstone Farms, Arkansas City, KS) and carcass data (HCW, LM area, 12th-rib fat thickness, KPH, marbling score, and calculated USDA Yield Grade; USDA, 1997) were collected by trained Oklahoma State University personnel.

After the first intermediate harvest, the remaining CON and CORN steers were placed on a summer grazing program using the same native grass pastures as described for winter grazing, but winter supplements were not fed. The DNR steers were dewormed on 14 May 2009 using Cydectin (5 mg moxidectin/mL; Fort Dodge Animal Health, Fort Dodge, IA). These steers grazed summer pasture for 115 d and on d 92 (July 15) of summer grazing, steers were group fed 0.5 kg/d of a 40% CP cottonseed meal-based supplement 3 d/wk to meet their DIP requirement. When the average BW of the CON and CORN steers was similar to that of the LGWP and HGWP steers, respectively, 3 steers from the CON and CORN treatments were harvested at the FAPC abattoir (second intermediate harvest before finishing), as previously described for the

Table 2. Ingredient and chemical composition of finishing diets fed to steers after the grazing phase for Exp. 1 and 2

Item	Exp. 1 ¹		Exp. 2
	El Reno ²	Stillwater ³	Stillwater ³
Ingredient composition, % DM			
Rolled corn	80.0	70.0	70.0
Dried distillers grains with solubles	—	12.0	12.0
Cottonseed meal	5.5	—	—
Prairie hay	—	6.0	6.0
Alfalfa hay	8.0	—	—
Supplement	2.5 ⁴	6.0 ⁵	6.0 ⁵
Molasses	4.0	—	—
Synergy 19 to 14 ⁶	—	6.0	6.0
Chemical composition			
DM, %	88.1	80.5	80.0
CP, % DM	15.6	13.9	13.7
NE _m , ⁷ Mcal/kg DM	1.92	1.89	1.83
NE _g , ⁷ Mcal/kg DM	1.28	1.25	1.19
ADF, % DM	6.18	7.10	9.14
NDF, % DM	13.3	16.6	18.0
TDN, ⁷ % DM	78.0	77.0	75.0

¹HGWP and LGWP treatments were fed at the El Reno feedlot and the CON (40% CP supplement) and CORN (corn-based supplement) treatments were fed at the Stillwater feedlot. LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture.

²El Reno feedlot was located at the USDA-ARS Grazinglands Research Laboratory (El Reno, OK).

³Stillwater feedlot was located at the Willard Sparks Beef Cattle Research Center in Stillwater, OK. For each experiment, 6.85% water on an as-fed basis was added to the finishing diet.

⁴Supplement contained: 0.5% NH₄Cl, 0.5% urea, and 1.5% R-1500 medicated mineral mix (Cargill Animal Nutrition, Minneapolis, MN). Finishing diet was formulated to contain 22 g monensin/t.

⁵Supplement contained: 2.87% rolled corn, 1.04% wheat midds, 0.19% urea, 1.43% limestone, 0.23% NaCl, 0.001% MgO, 0.0001% ZnSO₄, 0.10% KCl, 0.00003% MnO, 0.00003% vitamin A, 0.00002% vitamin E, 0.0002% monensin (Elanco Animal Health, Indianapolis, IN), and 0.0001% Tylosin (Elanco Animal Health). Finishing diet was formulated to contain 33 g monensin/t (Elanco Animal Health).

⁶Liquid supplement that is manufactured by Westway Feed Products, Inc., New Orleans, LA.

⁷Net energy and TDN values were calculated by Dairy One (Ithaca, NY).

initial harvest comparing carcass characteristics of steers at similar BW.

After the second intermediate harvest, the remaining CON and CORN steers were transported 11 km to the Willard Sparks Beef Research Center in Stillwater, OK, for finishing. Within treatment, steers were allotted to 1 of 3 pens (3 to 4 steers/pen) and fed twice daily. Steers were implanted and vaccinated as described for LGWP and HGWP steers, and given a pour-on dewormer (Cydectin). Individual full BW were measured as described for LGWP and HGWP steers. The finishing diet that was fed at the Stillwater feedlot is presented in Table 2. Steers were fed 112 d to achieve a visually predicted 1.27 cm of 12th-rib fat thickness before harvest at a commercial abattoir (Creekstone Farms) and carcass data (HCW, LM

area, 12th-rib fat thickness, KPH, marbling score, and calculated USDA Yield Grade; USDA, 1997) were collected by trained Oklahoma State University personnel. No steers were harvested at the FAPC abattoir from the CON and CORN treatments at final harvest. The same personnel from Oklahoma State University collected all carcass data at each harvest date and at both abattoirs throughout the experiment to minimize variation in carcass grading.

Experiment 2. Seventy-six fall-weaned Angus steers (258 ± 28 kg) from the same Oklahoma State University cow herd as Exp. 1 were used in the experiment. Steers were weaned 12 October 2009, transported 40 km to the Marshall Wheat Pasture Research Unit near Marshall, OK, vaccinated with Bovi-Shield Gold 5, and allowed to graze cool-season grass pastures before initiation of the experiment. Steers were revaccinated on 6 November 2009 with Titanium 5 (Diamond Animal Health Inc., Des Moines, IA) and Clostri Shield 7 (Novartis Animal Health Inc., Larchwood, IA), hip branded, and individually weighed. Steers were not implanted before weaning or during the grazing phase of the experiment. On 23 November 2009, steers were held off water for 5 h and individually weighed. Four steers were randomly selected for measurement of initial carcass characteristics. The remaining 72 steers (265 ± 20 d of age) were stratified by BW and allotted to 1 of 4 winter grazing treatments described in Exp. 1. Steers were equally stratified across treatments by known sire for selection of steers for intermediate and final harvests at the FAPC abattoir to minimize genetic differences among treatments. The CON and CORN steers were transported 40 km to the Crosstimbers-Bluestem Stocker Range, placed on DNR, and trained to enter individual feeding stalls, as described in Exp. 1. The LGWP and HGWP steers remained at the Marshall Wheat Pasture Research Unit until initiation of WP grazing and were not fed any supplement.

On 1 December 2009, the 4 steers selected for measurement of initial carcass characteristics were harvested as described in Exp. 1, and on 4 December 2009, the remaining 72 steers began their treatment regimens. Steers in each treatment grazed their respective pastures to a target HCW of 200 kg before finishing. Estimated HCW was determined from the shrunk live BW and an average dressing percentage reported in previous experiments, using similar types of cattle and grazing production programs (Exp. 1; [Hersom et al., 2004](#)). Hot carcass weight was used as the end point, rather than shrunk BW to account for differences in gut fill and visceral organ mass. The number of days grazing for steers in each treatment to reach the target HCW was 74 (17 February), 142 (26 April), 180 (2 June), and 262 d (24 August) for the HGWP, LGWP, CORN, and CON treatments, respectively.

The WP steers were transported 40 km to the Stillwater Wheat Pasture Unit, sorted, and placed in their respective pastures for winter grazing. Stocking rates for the LGWP and HGWP steers were 2.97 and 0.99 steers/ha, respectively. Eleven extra steers (similar type and size) were used as additional grazers with the LGWP steers when necessary, depending on forage availability and previous rate of BW gain to achieve the desired rate of gain. The HGWP steers were managed as described in Exp. 1. During winter grazing, the CON and CORN steers were managed as described in Exp. 1. Intermediate BW were measured and supplements were fed as described in Exp. 1. On 13 April (130 d), CON and CORN steers were dewormed with Cydectin and placed on a summer grazing program with no supplements. Due to an infestation of ticks during summer grazing, the CON steers were dewormed on 10 June with Ivomec Plus injection (1% wt/vol ivermectin and 10% wt/vol clorsulon in a sterile solution; Merial), and with a Corathon ear tag with FyberTek (Bayer Healthcare LL, Animal Health Division, Shawnee Mission, KS), and dewormed on 23 July with StandGuard (Elanco Animal Health, Greenfield, IN). Starting on d 98 (20 July), the CON steers were group fed 0.5 kg/d of a 40% CP supplement as described in Exp. 1. When the steers in each treatment reached an estimated HCW of 200 kg, steers were removed from the grazing phase and transitioned into the finishing phase. At the end of the grazing phase, steers were individually weighed, and ultrasound measurements of 12th-rib fat thickness, LM area, and intramuscular fat were taken on the left side of each steer, and 4 steers per treatment from the same sire were harvested at the FAPC abattoir, as described in Exp. 1, to compare carcass characteristics of steers at similar HCW before finishing.

After the grazing phase, steers within each treatment were randomly allotted to 1 of 3 pens (4 to 5 steers/pen) at the Willard Sparks Beef Research Center. Steers were implanted with Revalor-S, vaccinated with Vision 7 with SPUR (Merck Animal Health) and Bovi-Shield Gold 5, and given an oral dewormer [Panacur (fenbendazole, 100 mg/mL); Merck Animal Health]. Individual full BW was measured, as described in Exp. 1, and all steers were fed the same finishing diet twice daily (Table 2). The HGWP, LGWP, CORN, and CON steers were fed to reach a predicted common 12th-rib fat thickness of 1.27 cm based on an ultrasound measurement 30 d before harvest. After finishing, 4 steers from each treatment were harvested at the FAPC abattoir, as described in Exp. 1. The same trained personnel from Oklahoma State University collected carcass characteristics at the FAPC abattoir throughout the experiment to minimize variation in carcass grading. The remaining steers from each treatment were harvested at a commercial abattoir (Creekstone Farms) and carcass data (HCW, LM

area, 12th-rib fat thickness, marbling score, and calculated USDA Yield Grade; USDA, 1997) were collected by trained Creekstone personnel, using an E + V Vision Grading camera (VBG2000, E + V Technology; Oranienburg, Germany).

Forage and Supplement Collection, and Laboratory Analysis

For each experiment, supplement and finishing diet samples were collected weekly, ground through a 2-mm screen in a Wiley mill (Thomas Scientific, Philadelphia, PA), and composited by month for analysis. Chemical analyses of the supplements and finishing diets were conducted by a commercial laboratory (Basic Wet Chemistry Package Analysis; Dairy One, Ithaca, NY). Forage quality and standing crop samples (1 sample per 1.4 ha) were collected within each wheat pasture every other week during winter grazing. Forage quality samples were collected at 3 time points during both the winter and summer grazing phases from the DNR pastures. Forage quality samples were oven dried at 55°C, ground through a 2-mm screen in a Wiley mill, composited by pasture within clipping date, and analyzed at Oklahoma State University for CP (% N $\times$ 6.25; TruSpec-CN LECO Corporation, St. Joseph, MI) and NDF-ADF sequentially (Ankom Tech Corporation, Fairport, NY). The forage standing crop samples were collected using a 0.19-m² quadrant by hand clipping forage to ground level. Samples were dried at 55°C to constant weights and used to calculate kilograms of DM per hectare.

Starch content of the supplements was analyzed using the assay adapted from Galyean (2010), with the modifications described by Sharman et al. (2013). Degradable intake protein of supplements was analyzed using a *Streptomyces griseus* (Type XIV Bacterial; Sigma-Aldrich, Co., St. Louis, MO) protease assay adapted from Krishnamoorthy et al. (1983), with modifications described by Sharman et al. (2013) to determine DIP as a percent of CP.

Statistical Analysis

Experiment 1. Individual steer initial and final BW, and ADG during winter grazing were computed by linear regression (Proc GLM; SAS Inst. Inc., Cary, NC) of BW on day of experiment. Body weight and growth rate data during the grazing phase and intermediate carcass characteristics were analyzed as a completely randomized design, using a general linear model (Proc GLM), which included treatment as a fixed effect and steer as the experimental unit. Homogeneity of variance for feedlot and abattoir location was tested using a general linear model (Proc GLM) and Levene's test. Variances were found to be different ($P < 0.05$) for finishing BW, growth rate, feed intake and efficiency, and final carcass data between

feedlot locations, but variances for final carcass data were similar ($P > 0.10$) between abattoir locations. The finishing BW, growth rate, feed intake and efficiency, and final carcass data were analyzed, using a general linear model (Proc MIXED; SAS), with treatment as a fixed effect and the group option in the repeated statement used to account for heterogeneous variance among feedlot locations. Pen was the experimental unit for finishing growth, feed intake, and feed efficiency data, and steer was the experimental unit for final carcass data. The initial BW for winter grazing was used as a covariate when analyzing winter growth rate and BW data, and was removed from the model when not significant ($P > 0.10$). Final carcass characteristics were adjusted to a common 12th-rib fat thickness by covariate analysis; both unadjusted and 12th-rib-fat-adjusted carcass data are reported. Least squares means were separated using Fisher's protected LSD at an α equal to 0.05. The USDA Quality Grade distribution was analyzed using a general linear model (Proc GLIMMIX; SAS) with a binomial distribution.

Experiment 2. Similar to Exp. 1, individual steer initial and final BW, and ADG were calculated, using polynomial regression (Proc GLM) of BW on day of experiment due to the biphasic growth curve of steers grazing DNR. Body weight and growth rate data during the grazing phase and intermediate carcass data were analyzed as a completely randomized design, using a general linear model (Proc GLM) that included treatment as a fixed effect and steer as the experimental unit. Finishing BW, growth rate, feed intake, and feed efficiency data were analyzed as a completely randomized design, using a general linear model (Proc MIXED). Homogeneity of variance for abattoir location was tested as described in Exp. 1 and variances were found to be different among abattoir locations. Final carcass data were analyzed using a general linear model (Proc MIXED), with treatment as a fixed effect and the group option in the repeated statement used to account for heterogeneous variances among abattoir locations, which included different grading mechanisms (camera vs. subjective grader). Pen was the experimental unit for finishing BW, growth rate, feed intake, and feed efficiency data, and steer was the experimental unit for final carcass data. Initial BW was used as a covariate in the grazing phase as described in Exp. 1. Final carcass characteristics were adjusted to a common 12th-rib fat thickness and USDA Quality Grade distribution was analyzed as described in Exp. 1. Least squares means were separated using Fisher's protected LSD at an α equal to 0.05.

Meta-analysis. A meta-analysis was conducted using grazing performance data, intermediate carcass characteristics from Hersom et al. (2004), and Exp. 1 from the current study. A data set was compiled using carcass data collected at a similar age of the animals after winter grazing. The data set ($n = 36$) consisted of individual steer data from

steers harvested at the end of winter grazing in Exp. 1 and 2 from Hersom et al. (2004), and the first intermediate harvest of Exp. 1 in the current study. Analysis of covariance was conducted using a fixed effect model (Proc GLM) to test the hypothesis of equal slopes of marbling score and 12th-rib fat thickness with ADG or HCW and quadratic terms (ADG^2 or HCW^2) among experiments. Regression analysis was performed using a mixed model (Proc MIXED) that included experiment and experiment by ADG, and ADG^2 or HCW and HCW^2 cross-product terms as random variables to account for differences in intercept and slope among experiments when necessary based on results of ANCOVA (St-Pierre, 2001). The quadratic terms were removed from the model when not significant ($P > 0.10$). The simple variance component structure was adopted for the var-(co)var matrix after evaluating the unstructured and compound symmetry options. An adjusted marbling score and 12th-rib fat thickness were computed using the fixed effect regression coefficients plus the residual to remove the random effects of intercept and slope among experiments. The root mean square error, Mallow's Cp, and R^2 for the regression models were determined by regressing the independent variables on the adjusted marbling score or 12th-rib fat thickness (Proc REG; SAS). Data are presented as the adjusted marbling score and 12th-rib fat thickness with the fixed effect regression line.

RESULTS AND DISCUSSION

Grazing Phase

Forage Analysis. Nutritive value of wheat pasture, winter dormant native range, and summer native range for Exp. 1 and 2 are presented in Table 3. Winter dormant native pastures were low in CP and high in NDF in both Exp. 1 and 2. Summer native pastures had greater nutritive value compared with winter dormant native range but not as good as winter wheat pasture, as would be expected. The nutrient values for WP and native range pastures were similar to those reported by Fieser et al. (2007) and Bodine and Purvis (2003), respectively. In Exp. 1, forage mass for wheat pasture averaged 95 ± 45 and 324 ± 81 kg of DM/100 kg of BW for the LGWP and HGWP treatments, respectively. In Exp. 2, forage mass for wheat pasture averaged 84 ± 40 and 334 ± 28 kg of DM/100 kg of BW for the LGWP and HGWP treatments, respectively.

Performance. For Exp. 1 and 2, the shrunk BW of steers in each treatment during grazing is shown in Fig. 2A and 2B, respectively. In Exp. 1, BW gain of steers was relatively constant during winter grazing, with the exception of the LGWP steers, which gained BW faster earlier in the grazing period than later. After winter grazing, the CON and CORN steers gained BW constantly at the start of summer grazing, but BW gain appeared to slow at the

Table 3. Average nutrient composition of winter wheat pasture and native range during the grazing phase

Item	Grazing programs ¹		
	WP	DNR	SNR
Exp. 1			
DM, %	32.8 ± 6.6	92.7 ± 2.4	39.7 ± 5.0
Ash, % DM	8.59 ± 1.44	4.48 ± 0.71	5.73 ± 0.31
CP, % DM	24.2 ± 3.2	4.73 ± 0.27	10.9 ± 1.9
NDF, % DM	47.4 ± 4.4	80.2 ± 1.1	70.4 ± 0.4
ADF, % DM	21.1 ± 3.3	47.9 ± 0.9	36.7 ± 1.2
Exp. 2			
DM, %	32.1 ± 6.0	87.9 ± 3.2	41.6 ± 4.7
Ash, % DM	9.14 ± 2.14	5.66 ± 0.81	6.60 ± 0.56
CP, % DM	27.1 ± 2.35	5.05 ± 0.30	8.94 ± 0.36
NDF, % DM	45.6 ± 4.75	77.6 ± 1.8	68.8 ± 2.4
ADF, % DM	20.0 ± 3.07	48.0 ± 1.4	38.5 ± 2.1

¹WP = winter wheat pasture; DNR = dormant native range; SNR = summer native range.

end of summer grazing. In Exp. 2, the HGWP and CORN steers gained BW constantly throughout the grazing phase, whereas the LGWP steers gained BW faster earlier and at the end of the grazing period due to adequate seasonal conditions for wheat pasture growth. The CON steers gained BW faster later in the grazing period than earlier due to greater forage quality.

In Exp. 1, final BW and ADG during winter grazing were different ($P < 0.01$) for steers in all treatments (Table 4). In Exp. 2, ADG during grazing followed the same trend

Figure 2. Change in shrunk BW of steers during the winter and summer grazing period in Exp. 1 (A) and Exp. 2 (B). CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture; DNR = dormant native range. $n = 17$ and 18 for Exp. 1 and 2, respectively.

Table 4. Winter and summer grazing performance of steers to the first and second intermediate harvest in Exp. 1 and overall grazing performance of steers in Exp. 2 for the different stocker production programs

Item	Treatment ¹				SEM	P-value
	CON	CORN	LGWP	HGWP		
Exp. 1						
Winter grazing phase						
Steers, no.	17	17	16	18	—	—
Days grazing, no.	138	138	138	138	—	—
Supplement intake, kg/d	1.01	2.74	—	—	—	—
Initial BW, kg	258	262	261	249	7.4	0.52
Final BW, ² kg	281 ^a	323 ^b	341 ^c	430 ^d	3.5	0.01
ADG, kg/d	0.19 ^a	0.52 ^b	0.68 ^c	1.37 ^d	0.03	0.01
Summer grazing phase						
Steers, no.	14	14	—	—	—	—
Days grazing, no.	115	115	—	—	—	—
Initial BW, kg	281	329	—	—	8.5	0.01
Final BW, kg	358	399	—	—	9.9	0.01
ADG, kg/d	0.67	0.61	—	—	0.03	0.19
Exp. 2						
Steers, no.	18	18	18	18	—	—
Days grazing, no.	262	180	142	74	—	—
Supplement intake, kg/d	1.02	2.65	—	—	—	—
Initial BW, kg	265	257	257	254	6.7	0.67
Final BW, ² kg	380 ^b	370 ^{ab}	381 ^b	366 ^a	4.3	0.04
ADG, kg/	0.46 ^a	0.61 ^b	0.83 ^c	1.29 ^d	0.02	0.01

^{a-d}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range.

²Initial BW was a significant covariate ($P < 0.05$).

as Exp. 1, with a difference ($P < 0.01$) among all treatments. The CON and CORN steers had faster ADG in Exp. 2 than in Exp. 1, due to combining winter and summer grazing phases. In Exp. 2, ADG during winter grazing was 0.25 and 0.55 kg/d and summer ADG was 0.64 and 0.74 kg/d for the CON and CORN steers, respectively. Summer ADG in Exp. 1 for the CON and CORN treatments was 0.67 and 0.61 kg/d, respectively. Although cattle were grown to a similar projected HCW in Exp. 2, differences were observed in final BW. The CON and LGWP steers had heavier ($P < 0.05$) final BW compared with HGWP; CORN steers were intermediate.

Similar to the current experiments, [Hersom et al. \(2004\)](#) reported ADG of 1.31, 0.54, and 0.16 kg/d in yr 1, and 1.10, 0.68, and 0.15 kg/d in yr 2 for high rate of gain on wheat pasture, low-rate of BW gain on wheat pasture, and steers fed a protein supplement during grazing dormant native range, respectively. Additionally, [Phillips et al. \(1991, 2001\)](#) and [Choat et al. \(2003\)](#) reported ADG similar to those from the current experiments for steers grazing WP and DNR. [Sharman et al. \(2013\)](#) reported that steers fed similar treatments as CON and CORN had rates of BW

Table 5. Carcass characteristics of steers at initial harvest for Exp. 1 and 2

Item	Exp. 1		Exp. 2	
	Mean	SD	Mean	SD
Steers, no.	4	—	4	—
HCW, kg	126	10.8	138	29.2
Dressing percentage, %	49.6	2.20	52.4	2.74
12th-rib fat thickness, cm	0.03	0.05	0.27	0.17
KPH, %	0.88	0.25	0.55	0.06
LM area, cm ²	43.1	5.25	45.0	5.97
USDA Yield Grade	1.60	0.08	1.80	0.29
Marbling score ¹	220	34.6	148	48.6

¹Marbling score: 100 = practically devoid⁰⁰; 200 = traces⁰⁰; 300 = slight⁰⁰.

gain of 0.20 and 0.53 kg/d, respectively, which were similar to the current study.

Intermediate Carcass Characteristics. The initial and intermediate carcass characteristics are presented in Tables 5 and 6, respectively. In Exp. 1, WP steers at intermediate harvest had greater LM area, 12th-rib fat thickness, and marbling score, relative to steers at initial harvest. In Exp. 2, WP steers had greater LM area and marbling score in relation to their counterparts at initial harvest; however, LGWP steers had relatively similar 12th-rib fat thickness at the end of grazing compared with the initial harvest steers because the initial harvest steers had substantial 12th-rib fat thickness. In both experiments, DNR steers had relatively similar LM area, 12th-rib fat thickness, and marbling scores, compared with the initial harvest steers, suggesting that the restricted growth of these steers only maintained body composition.

At the first intermediate harvest in Exp. 1, HGWP steers had heavier HCW and greater dressing percent ($P < 0.01$), compared with steers grazing DNR; LGWP steers were similar to HGWP steers (Table 6). The HGWP, LGWP, and CORN steers had similar LM area, but larger ($P < 0.01$) LM area, compared with the CON steers. Additionally, ultrasound measurements collected at the end of winter grazing showed that the HGWP steers had larger ($P < 0.01$) LM area compared with the CON steers, with the CORN and LGWP steers being intermediate (Table 7). When the CON and CORN steers reached similar HCW as the WP treatments at the second intermediate harvest, there were no differences in LM area.

In Exp. 2, the LGWP steers gained a significant amount of BW the final 2 wk of grazing due to increased forage availability and conflicts with scheduling harvest dates, such that the LGWP steers tended ($P = 0.09$) to have heavier HCW compared with steers from the other 3 treatments, even though steers were targeted to be harvested at a similar HCW of 200 kg (Table 6). The LGWP and HGWP steers had greater ($P < 0.01$) dressing percentage compared with the CON and CORN steers, but there was

Table 6. Intermediate carcass characteristics of steers after the winter and summer grazing phases for Exp. 1 and 2

Item	Treatment ¹						SEM	<i>P</i> -value
	First intermediate				Second intermediate			
	CON	CORN	LGWP	HGWP	CON	CORN		
Exp. 1								
Steers, no.	3	3	3	3	3	3	-	-
Age, d	406	411	411	404	518	523	-	-
HCW, kg	150 ^a	180 ^{ab}	210 ^{bc}	238 ^c	188 ^b	208 ^{bc}	11.6	0.01
Dressing percent, %	52.7 ^a	55.6 ^b	59.3 ^c	59.5 ^c	51.9 ^a	51.4 ^a	0.67	0.01
12th-rib fat thickness, cm	0.03 ^a	0.10 ^{ab}	0.17 ^{ab}	0.85 ^c	0.17 ^{ab}	0.27 ^b	0.06	0.01
KPH, %	0.50 ^a	0.50 ^a	0.67 ^a	1.33 ^b	0.67 ^a	0.83 ^a	0.14	0.01
LM area, cm ²	37.2 ^a	51.0 ^b	58.3 ^b	60.6 ^b	55.7 ^b	55.5 ^b	3.23	0.01
USDA Yield Grade	2.07 ^{ab}	1.67 ^a	1.70 ^a	2.57 ^b	1.60 ^a	1.93 ^a	0.18	0.02
Marbling score ²	180 ^a	217 ^{ab}	280 ^c	340 ^d	233 ^{ab}	240 ^{bc}	18.4	0.01
Exp. 2								
Steers, no.	4	4	4	4	-	-	-	-
Age, d	528	445	406	344	-	-	-	-
HCW, kg	207	201	226	204	-	-	6.9	0.09
Dressing percent, %	52.1 ^a	52.3 ^a	59.2 ^c	55.0 ^b	-	-	0.36	0.01
12th-rib fat thickness, cm	0.36	0.06	0.36	0.46	-	-	0.09	0.06
KPH, %	0.63 ^a	0.50 ^a	1.13 ^b	1.38 ^c	-	-	0.11	0.01
LM area, cm ²	53.1	57.7	60.6	55.2	-	-	2.52	0.22
USDA Yield Grade	2.05 ^b	1.45 ^a	2.03 ^b	2.28 ^b	-	-	0.18	0.03
Marbling score ²	158 ^a	143 ^a	315 ^c	228 ^b	-	-	21.8	0.01

^{a-c}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range.

²Marbling score: 100 = practically devoid⁰⁰; 200 = traces⁰⁰; 300 = slight⁰⁰; 400 = small⁰⁰.

no difference ($P = 0.22$) in LM area. Unexpectedly, the ultrasound measurements for LM area showed that the LGWP steers had a larger ($P < 0.01$) LM area compared with the HGWP steers, which were greater than the CON and CORN steers (Table 7). The reason for the difference

Table 7. Ultrasound measurements of steers at the time of first intermediate harvest in Exp. 1 and intermediate harvest in Exp. 2

Item	Treatment ¹				SEM	P-value
	CON	CORN	LGWP	HGWP		
Exp. 1						
Steers, no.	17	17	16	18	—	—
12th-rib fat thickness, cm	0.16 ^a	0.18 ^a	0.29 ^b	0.87 ^c	0.03	0.01
LM area, cm ²	41.4 ^a	50.2 ^b	54.3 ^c	67.9 ^d	1.47	0.01
Intramuscular fat, %	3.42 ^{ab}	3.24 ^a	3.66 ^b	4.83 ^c	0.14	0.01
Exp. 2						
Steers, no.	18	18	18	18	—	—
12th-rib fat thickness, cm	0.30 ^b	0.18 ^a	0.35 ^b	0.49 ^c	0.02	0.01
LM area, cm ²	48.7 ^a	49.4 ^a	58.2 ^c	54.2 ^b	1.30	0.01
Intramuscular fat, %	2.62 ^a	2.73 ^a	2.91 ^a	3.43 ^b	0.12	0.01

^{a-d}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range.

between the WP treatments could be due to the LGWP steers having heavier HCW than the HGWP steers when ultrasound measurements were taken, but this does not explain the smaller LM area of the CON and CORN steers.

In Exp. 1, 12th-rib fat thickness and KPH were greater ($P < 0.01$) for HGWP steers than steers in the other treatments at both intermediate harvests; and the CON, CORN, and LGWP were similar at both harvests, except the CON steers had the lowest 12th-rib fat thickness at the first intermediate harvest (Table 6). The HGWP steers had greater ($P < 0.05$) calculated USDA Yield Grade compared with CORN and LGWP steers at the first intermediate harvest, and greater than CON and CORN steers at the second intermediate harvest. The accuracy of the USDA Yield Grade equation at these intermediate weights is unknown but does provide a comparison of the relative body fat content of steers among treatments. Marbling score was greater ($P < 0.01$) for HGWP than LGWP steers, and LGWP steers had greater marbling score than both the CON and CORN steers at first intermediate harvest. Additionally, HGWP steers had greater ($P < 0.01$) ultrasound 12th-rib fat thickness and intramuscular fat, compared with steers in the other treatments (Table 7). At the second intermediate harvest when the CON and CORN steers had reached a similar HCW compared with the LGWP and HGWP steers, the CORN steers had similar marbling scores compared with the LGWP steers.

In Exp. 2, HGWP steers tended to have greater ($P < 0.06$) 12th-rib fat thickness and had greater ($P < 0.01$) ultrasound 12th-rib fat thickness, compared with the CORN steers with the CON and LGWP steers being intermediate (Table 6 and 7). The CORN steers had reduced ($P < 0.05$) calculated USDA Yield Grade compared with steers in the other treatments. The HGWP steers had greater ($P < 0.01$) KPH fat but reduced ($P < 0.01$) marbling scores, compared with the LGWP steers. The LGWP and HGWP steers had greater ($P < 0.05$) KPH and marbling scores when compared with the CON and CORN steers; CON and CORN steers did not differ. Similarly, the HGWP steers had a greater ($P < 0.01$) percentage of ultrasound intramuscular fat compared with steers in the other 3 treatments.

In Exp. 1, differences in LM area, 12th-rib fat thickness, and marbling score among treatments is most likely due to differences in HCW, which were minimized but not eliminated in Exp. 2 when steers were harvested at similar HCW. Hersom et al. (2004) reported that when steers are harvested at similar age after winter grazing, high rate of BW gain steers grazing wheat pasture had greater HCW, dressing percentage, LM area, 12th-rib fat thickness, and marbling score, compared with low rate of BW gain steers grazing wheat pasture and control steers supplemented during grazing dormant native range. In contrast, McCurdy et al. (2010) reported no differences in dressing percentage, LM area, 12th-rib fat thickness, or marbling score among steers fed growing diets of differing energy density for similar rates of BW gain when steers were harvested before finishing. Sainz et al. (1995) also observed no differences in HCW or LM area between growing programs varying in dietary energy density and energy intake when steers were harvested at similar empty BW before entering the finishing phase. Similar to the current study, Sainz et al. (1995) reported that steers fed more energy-dense diets had greater 12th-rib fat thickness and marbling score, compared with steers fed a less energy-dense diet.

Finishing Phase

Performance. Finishing BW, growth rate, feed intake, and feed efficiency data are presented in Table 8. In Exp. 1, there were no differences ($P > 0.10$) in ADG or DMI, but CON steers tended ($P = 0.09$) to have greater G:F compared with the other steers during finishing when steers were fed to a common 12th-rib fat thickness. However, in Exp. 2, the CON steers had faster ($P < 0.01$) ADG and greater DMI, compared with steers in the other treatments. There was no difference ($P = 0.39$) in G:F among steers in Exp. 2. The reason for the ADG and DMI differences in Exp. 2 could be due to the seasonal differences of when each treatment was finished; however, this also applied to CON steers in Exp. 1. The CON steers were finished during the early fall and winter months, whereas the CORN,

Table 8. Finishing performance of steers from different stocker production programs for Exp. 1 and 2

Item	Treatment ¹				SEM	P-value
	CON	CORN	LGWP	HGWP		
Exp. 1						
Steers, no.	11	11	13	15	—	—
Days on feed	112	112	138	83	—	—
Pens, no.	3	3	3	3	—	—
Initial BW, kg	360 ^a	403 ^b	352 ^a	432 ^c	4.1	0.01
Final BW, kg	597 ^a	632 ^b	610 ^{ab}	588 ^a	8.2	0.04
ADG, kg/d	2.12	2.04	1.87	1.87	0.09	0.16
DMI, kg/d	12.1	12.5	11.8	11.2	0.43	0.16
Gain:feed, kg/kg	0.175	0.163	0.158	0.168	0.005	0.09
Exp. 2						
Steers, No.	14	14	14	14	—	—
Days on feed	112	146	128	131	—	—
Pens, no.	3	3	3	3	—	—
Initial BW, kg	386 ^d	367 ^b	378 ^c	358 ^a	0.5	0.01
Final BW, kg	617 ^b	590 ^a	575 ^a	581 ^a	7.9	0.02
ADG, kg/d	2.06 ^b	1.53 ^a	1.54 ^a	1.70 ^a	0.06	0.01
DMI, kg/d	11.9 ^b	10.0 ^a	10.0 ^a	10.5 ^a	0.25	0.01
Gain:feed, kg/kg	0.173	0.153	0.155	0.162	0.008	0.39

^{a-c}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range.

LGWP, and HGWP steers were exposed to parts of the high heat and humidity that is seen in Stillwater, OK, during summer months. In both experiments, the CON steers had numerically greater G:F, suggesting a compensatory gain effect of previously restricted steers.

In the current experiments, there were few differences in ADG, DMI, or G:F during finishing among treatments. Hersom et al. (2004) also reported no difference in feedlot ADG, DMI, or G:F among the winter grazing treatments implemented before finishing. Similarly, White et al. (1987) and Lewis et al. (1990) reported no difference in finishing ADG, DMI, or G:F among steers previously grown on different planes of nutrition. In contrast, Choat et al. (2003) observed that steers previously grazing dormant native range with a low rate of BW gain had greater ADG and G:F, but similar DMI during finishing compared with steers previously grazing wheat pasture. Sainz et al. (1995) reported that steers fed a high-concentrate diet *ad libitum* with greater ADG during the growing phase and more body fat entering the feedlot had reduced DMI, ADG, and G:F during finishing, compared with steers limited fed a high-concentrate diet or fed an alfalfa hay-based diet during the growing phase. Ridenour et al. (1982) reported that steers grown to heavier BW before finishing had lower ADG during finishing compared with steers at lighter feedlot placement weights. Therefore, the results are inconsistent on whether rate of BW gain during the previous stocker phase affects finishing ADG or G:F.

Table 9. Final carcass characteristics of steers from different stocker production programs for Exp. 1

Item	Treatment ¹				SEM	P-value
	CON	CORN	LGWP	HGWP		
Steers, no.	11	11	13	15	—	—
Age, d	632	637	557	494	—	—
Unadjusted carcass characteristics						
HCW, kg	375	397	383	375	9.8	0.32
Dressing percent, %	62.7	63.1	62.8	63.1	0.56	0.80
12th-rib fat thickness, cm	1.59 ^a	1.55 ^a	1.94 ^b	1.37 ^a	0.12	0.01
KPH, %	2.18 ^c	2.09 ^{bc}	1.73 ^a	1.97 ^{ab}	0.09	0.01
LM area, cm ²	91.0 ^b	93.7 ^b	83.9 ^a	95.8 ^b	2.24	0.01
USDA Yield Grade	3.15 ^b	3.13 ^b	3.81 ^c	2.74 ^a	0.16	0.01
Marbling score ²	423	428	427	425	16.1	0.99
USDA Quality Grade distribution						
Upper 2/3 Choice, %	18.2	9.09	7.69	20.0	12.2	0.78
Low Choice, %	36.4	72.7	69.2	53.3	15.2	0.36
Select, %	45.6	18.2	23.1	26.7	15.7	0.58
Adjusted to 12th-rib fat thickness						
KPH, %	2.18 ^b	2.10 ^b	1.70 ^a	1.99 ^b	0.10	0.01
LM area, cm ²	91.0 ^b	93.6 ^b	84.1 ^a	95.7 ^b	2.34	0.01
USDA Yield Grade ³	3.16	3.19	3.43	3.00	0.11	0.07
Marbling score ²	423	428	431	423	16.5	0.98

^{a-c}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture; DNR = dormant native range.

²Marbling score: 300 = slight⁰⁰, 400 = small⁰⁰, 500 = modest⁰⁰.

³12th-rib fat thickness was a significant covariate ($P < 0.05$).

Final Carcass Characteristics. There were no differences in HCW or dressing percentage among steers at final harvest for Exp. 1 (Table 9). Unexpectedly, the LGWP steers had greater ($P < 0.01$) 12th-rib fat thickness, lesser ($P < 0.01$) KPH, and smaller ($P < 0.01$) LM area than steers in the other treatments, which increased ($P < 0.01$) USDA Yield Grade for LGWP steers. There were no differences in final marbling scores ($P = 0.99$) or distribution of carcasses in USDA Quality Grades ($P > 0.36$) among steers in the different treatments. Adjusting carcass characteristics for differences in 12th-rib fat thickness had little effect on LM area or marbling score among steers in the different treatments; however, USDA Yield Grade only tended ($P = 0.07$) to be different among steers compared with the significant difference for unadjusted USDA Yield Grade.

In Exp. 2, there was no difference in HCW; however, CON steers had a lower ($P < 0.02$) dressing percentage and less ($P < 0.05$) 12th-rib fat thickness, compared with steers in the other treatments (Table 10). This difference may have been influenced by the harvesting schedule; CON steers were harvested earlier than desired due to conflicts with scheduling. Unexpectedly, HGWP steers had smaller ($P < 0.01$) LM area compared with steers in the other treatments, which resulted in a greater ($P < 0.01$)

Table 10. Final carcass characteristics of steers from different stocker production programs for Exp. 2

Item	Treatment ¹				SEM	P-value
	CON	CORN	LGWP	HGWP		
Steers, no.	14	14	14	14	—	—
Age, d	640	590	533	475	—	—
Unadjusted carcass characteristics ²						
HCW, kg	374	371	363	364	8.7	0.77
Dressing percent, %	60.8 ^a	63.3 ^b	62.9 ^b	63.1 ^b	0.60	0.02
12th-rib fat thickness, cm	1.19 ^a	1.53 ^b	1.54 ^b	1.65 ^b	0.12	0.05
LM area, cm ²	85.1 ^b	87.8 ^b	85.8 ^b	76.2 ^a	2.10	0.01
USDA Yield Grade	3.10 ^a	3.17 ^a	3.18 ^a	3.86 ^b	0.15	0.01
Marbling score ³	465	402	429	439	17.3	0.10
USDA Quality Grade distribution						
Upper 2/3 Choice, %	28.6	7.14	14.3	28.6	12.1	0.44
Low Choice, %	57.3	56.7	65.2	43.8	14.4	0.78
Select, %	14.3	35.7	21.4	28.6	12.8	0.61
Adjusted to 12th-rib fat thickness						
LM area, cm ²	86.0 ^b	87.7 ^b	86.1 ^b	75.9 ^a	2.12	0.01
USDA Yield Grade ⁴	3.24 ^a	3.12 ^a	3.18 ^a	3.80 ^b	0.14	0.01
Marbling score ³	462	403	428	439	18.2	0.15

^{a-c} Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = DNR plus 40% CP supplement; CORN = DNR plus corn-based supplement; LGWP = low rate of BW gain on wheat pasture; HGWP = high rate of BW gain on wheat pasture; DNR = dormant native range.

²KPH data was not collected by Creekstone personnel using the E + V Vision Grading camera.

³Marbling score: 300 = slight⁰⁰, 400 = small⁰⁰, 500 = modest⁰⁰.

⁴12th-rib fat thickness was a significant covariate ($P < 0.05$).

USDA Yield Grade for HGWP steers. Even though the CON steers were harvested earlier than desired, they tended ($P = 0.10$) to have greater marbling scores compared with the CORN and LGWP steers. However, there was no difference ($P > 0.44$) between steers in the different treatments in distribution of carcasses among the USDA Quality Grades. When adjusting LM area, USDA Yield Grade, and marbling score for differences in 12th-rib fat thickness, differences among steers in the 4 treatments were similar to unadjusted values.

Hersom et al. (2004) reported no differences in HCW, dressing percentage, or LM area at final harvest in yr 2; but in yr 1, the steers grazing wheat pasture at a low rate of BW gain had lighter HCW compared with the steers grazing wheat pasture at a high rate of BW gain and steers supplemented during grazing dormant native range, even though there were no differences in dressing percentage or LM area. McCurdy et al. (2010) reported no difference in HCW, dressing percentage, or LM area at final harvest among steers grown at similar rates of BW gain on different growing diets before the finishing phase. Similarly, Henrickson et al. (1965) reported that steers grown on a high or moderate plane of nutrition had similar dressing percentage and LM area when harvested at a similar final BW. In contrast, Sainz et al. (1995)

Table 11. Regression coefficients ($\pm$ SE) from meta-analysis of marbling score and 12th-rib fat thickness with ADG during the winter grazing phase and HCW at intermediate harvest when steers were harvested at similar age after winter grazing in Exp. 1 and Hersom et al. (2004)

Dependent variable	Intercept	ADG ¹	ADG ²	HCW	HCW ²	RMSE	Cp	R ²
Marbling score	106 $\pm$ 44.9*	171 $\pm$ 18.9*				50.68	2.0	0.72
	–163 $\pm$ 90.9			2.02 $\pm$ 0.310*		43.86	2.0	0.78
	–69.2 $\pm$ 84.3	70.0 $\pm$ 44.5		1.28 $\pm$ 0.518*		46.99	3.0	0.77
12th-rib fat thickness	–0.047 $\pm$ 0.057	0.212 $\pm$ 0.221	0.445 $\pm$ 0.153*			0.163	3.0	0.86
	1.20 $\pm$ 0.92			–0.0188 $\pm$ 0.0101†	0.000073 $\pm$ 0.000027*	0.219	3.0	0.74
	–0.098 $\pm$ 1.160	0.088 $\pm$ 0.301	0.381 $\pm$ 0.215†	–0.0005 $\pm$ 0.0134	0.000007 $\pm$ 0.000037	0.181	5.0	0.83

¹ADG = ADG during the grazing phase; ADG² = ADG during the grazing phase squared; HCW = HCW at intermediate harvest; HCW² = HCW at intermediate harvest squared; RMSE = root mean square error; Cp = Mallows's Cp.

*Regression coefficient is different from 0 at $P < 0.05$.

†Regression coefficient is different from 0 at $P < 0.10$.

observed that steers fed a forage-based diet during the growing phase had decreased HCW and LM area, compared with steers fed a high-concentrate diet at ad libitum or limited intakes during the growing phase. [Guenther et al. \(1965\)](#) reported that steers on a high plane of nutrition had greater dressing percentages compared with steers on a moderate plane of nutrition when the steers were harvested at similar carcass weights or age of the animal.

Previous studies ([Sainz et al., 1995](#); [Hersom et al., 2004](#); [McCurdy et al., 2010](#)) reported that nutrition and management practices before finishing had minimal effects on final marbling score when steers were harvested at similar 12th-rib fat thickness. Similarly, [Ridenour et al. \(1982\)](#), [White et al. \(1987\)](#) and [Lewis et al. \(1990\)](#) reported no differences in marbling score when steers grown on different planes of nutrition before finishing were harvested at similar 12th-rib fat thickness at the end of finishing. Published data indicate that when steers are harvested at a similar 12th-rib fat thickness, minimal differences in final marbling score are observed, suggesting that cattle wintered at low planes of nutrition can have adequate marbling scores if finished to adequate 12th-rib fat thickness.

Meta-analysis. Results of the meta-analysis are presented in Table 11 and Fig. 3. When steers were harvested at similar age during the stocker phase, marbling score increased linearly with ADG and HCW, whereas 12th-rib fat thickness increased at an increasing rate (curvilinearly) with increasing ADG and HCW (Fig. 3). The coefficient of determination was slightly larger between marbling score and HCW than marbling score and ADG, whereas the coefficient of determination was slightly larger between 12th-rib fat thickness and ADG than 12th-rib fat thickness and HCW (Table 11). However, when steers were harvested at similar age, both ADG and HCW varied among steers, making it difficult to ascertain which factor was responsible for differences in marbling score and 12th-rib fat thickness. The simple correlation between ADG and HCW was 0.92, which would be expected, based on the

design of the study. Therefore, regression models were developed that included both ADG and HCW to predict marbling score or 12th-rib fat thickness at intermediate harvest. Inclusion of ADG and HCW in the model to predict marbling score resulted in a similar R^2 to the model, including HCW alone, indicating that ADG had little influence above that of HCW. Inclusion of linear and quadratic terms for ADG and HCW in the model to predict 12th-rib fat thickness resulted in a similar R^2 to the model, including ADG and ADG² alone. However, the use of R^2 alone to determine which model best explains the variation in marbling score or 12th-rib fat thickness may not be the most useful measure in this instance due to the change in significant random variables and thus their influence on R^2 when both ADG and HCW were included in the model, compared with either ADG or HCW alone. Thus, the significance of the regression coefficients for ADG and HCW, using Type III Sum of Squares, is presented in Table 11. When both ADG and HCW were included in the model to predict marbling score, the regression coefficient for HCW was different from 0 ($P < 0.05$), whereas the coefficient for ADG was not different from 0. In contrast, when the linear and quadratic terms for both ADG and HCW were included in the model to predict 12th-rib fat thickness, the quadratic term for ADG tended ($P < 0.10$) to be different from 0, whereas neither the linear nor quadratic terms for HCW were different from 0. To our knowledge, this is the first study to report such differences in the relationships of marbling score and 12th-rib fat thickness with ADG and HCW, and further research is necessary to verify these relationships in additional groups of cattle.

The intent of the current experiments was to evaluate the effect of different rates of BW gain during the stocker phase on partitioning of fat among depots when compared at a similar age and BW of steers. In the current meta-analysis, marbling score had a stronger linear relationship with HCW than ADG, whereas 12th-rib fat thickness had a stronger curvilinear relationship with

Figure 3. Relationship of marbling score with ADG during the grazing phase (A) or HCW at intermediate harvest (B), and the relationship of 12th-rib fat thickness with ADG during the grazing phase (C) or HCW at intermediate harvest (D) for steers harvested at similar intermediate ages (◆) during the grazing phase. $n = 36$. A) Marbling score at similar age (solid line) = $106 \pm 44.9 + 171 \pm 18.9 \times \text{ADG}$; $R^2 = 0.72$; Root mean square error (RMSE) = 50.70. B) Marbling score at similar age (solid line) = $-163 \pm 90.9 + 2.02 \pm 0.310 \times \text{HCW}$; $R^2 = 0.78$; RMSE = 43.90. C) 12th-rib fat thickness at similar age (solid line) = $-0.047 \pm 0.057 + 0.212 \pm 0.221 \times \text{ADG} + 0.445 \pm 0.153 \times \text{ADG}^2$; $R^2 = 0.86$; RMSE = 0.163. D) 12th-rib fat thickness at similar age (solid line) = $1.20 \pm 0.92 - 0.019 \pm 0.010 \times \text{HCW} + 0.000073 \pm 0.000027 \times \text{HCW}^2$; $R^2 = 0.74$; RMSE = 0.219.

ADG than HCW. This is not to imply that ADG has no impact on marbling score or that HCW does not influence 12th-rib fat thickness, but does suggest that the effect of ADG and HCW differs for 12th-rib fat thickness, compared with marbling score. Bruns et al. (2004) reported that marbling score increased linearly as HCW increased in finishing steers. Henrickson et al. (1965) observed that plane of nutrition had inconsistent results on marbling score; a high plane of nutrition increased marbling score in 1 trial but not in another, compared with a moderate plane of nutrition. Guenther et al. (1965) reported that steers fed a high plane of nutrition had similar marbling scores when harvested at a similar final BW compared with steers fed a moderate plane of nutrition. In Exp. 2, CON and CORN steers at a low rate of BW gain, but not LGWP steers at a more moderate rate of BW gain, had lower marbling scores than HGWP at a high rate of BW gain, even though steers were harvested at similar HCW after the grazing phase. With regard to 12th-rib fat thickness, Bruns et al. (2004) reported that 12th-rib fat thickness increased curvilinearly as HCW increased in finishing steers. Guenther et al. (1965) observed that steers fed a high plane of nutrition had greater 12th-rib fat thickness compared with steers fed a moderate plane of nutrition when harvested at similar age, but 12th-rib fat thickness was similar when harvested at similar BW. In Exp. 1, HGWP steers

had greater 12th-rib fat thickness than the other steers when harvested at a similar age, but HGWP steers still had greater 12th-rib fat thickness compared with CORN steers even though HCW was similar after summer grazing. The difference between results of Guenther et al. (1965) and the current study may be the difference in rates of BW gain; Guenther et al. (1965) compared steers gaining 0.93 vs. 0.80 kg/d, whereas the current study compared steers gaining 1.37 vs. 0.56 kg/d. Young and Kauffman (1978) reported that steers fed a grain-based diet (ADG = 1.44 kg/d) had greater 12th-rib fat thickness when harvested at similar carcass weight compared with steers fed a haylage-corn silage diet (ADG = 0.91 kg/d), but there was no difference in marbling score. Danner et al. (1980) observed that energy density of the diet affected 12th-rib fat thickness in 2 of 3 trials with steers or heifers at similar carcass weights, but did not affect marbling score. Moreover, Smith and Crouse (1984) observed that cattle fed a high energy-dense diet had greater in vitro fatty acid synthesis rates in subcutaneous fat but not in intramuscular fat, compared with cattle fed a moderate energy-dense diet.

In conclusion, the authors infer from the data that intramuscular fat tends to develop in a linear relationship with carcass weight and that only a moderate level of energy intake is required for lipid filling of intramuscular adipocytes to achieve adequate marbling score. Addition-

ally, 12th-rib fat thickness is strongly influenced by energy intake and carcass weight, but unlike marbling score, increasingly greater energy intake will increase 12th-rib fat thickness, even when harvested at similar carcass weight. However, changes in partitioning of fat among depots during the stocker phase may not be fully reflected after finishing when cattle are harvested at a similar 12th-rib fat thickness.

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