EFFECT OF NUTRITION AND MANAGEMENT PRACTICES ON MARBLING DEVELOPMENT BY GROWING BEEF CATTLE

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GROWING BEEF CATTLE

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INTRODUCTION

The 2005 National Beef Quality Audit Survey reported that "Insufficient Marbling & Low Quality Grades" was the number one quality challenge facing the beef industry (Smith et al., 2006). This survey included the responses from multiple phases of the beef production chain: seedstock generation, cow/calf production, stocker/backgrounding, and feedlot/finishing sectors. Current feeding practices in the beef industry result in production of 2 billion kg of excess fat annually in an attempt to achieve improved quality grades (Smith et al., 2000). Data from the beef quality audit and the Vetlife Benchmark Performance Program have shown a decrease in carcasses grading choice by approximately 6% from 1974 to 2004 and 1999 to 2006, respectively (Smith et al., 2006; Andersen and Gleghorn, 2007). The Vetlife data has also shown an increase in yield grade 4 and 5 carcasses which is probably due to the increase in number of days on feed (Anderson and Gleghorn, 2007). Certified Angus Beef reported a 7.5% increase in cattle grading choice in the past two years (Corah and McCully, 2009). These researchers reported that better genetics and knowledge of feeding distiller by-products are the main reason for the increase in Choice carcasses. However, the Choice-Select price spread has increased in recent months and has been as high as $20/cwt according to the USDA-AMS website. Therefore, improving nutritional and management strategies for growing beef cattle to enhance final carcass quality will not only benefit the beef industry as a whole, but may provide producers with more incentive to produce high-quality beef products for consumer needs.

Studies of nutrition and management practices that influence marbling deposition have primarily focused on the feedlot phase of production (Owens and Gardner, 2000). However, pre-feedyard management strategies (creep feeding, health status, etc.) can influence marbling development (Anderson and Gleghorn, 2007). Therefore, changes in management practices during early phases of the production cycle that improve intramuscular fat deposition and reduce fat deposition in other depots could enhance the efficiency of beef production. Owens and Gardner (2000) reported that protein source, protein level, and fat content of the finishing diet are the primary factors that influence marbling deposition; however, the animal's background, sex, and carcass weight also can impact carcass characteristics.

Smith and Crouse (1984) reported that intramuscular adipocytes preferentially utilize glucose as the primary substrate for fatty acid synthesis; whereas subcutaneous fat utilizes acetate. This lead to studies conducted at the University of Illinois where researchers showed that suckling calves provided a corn-based creep feed had increased marbling scores at the end of finishing compared to calves provided a soyhull-based creep feed suggesting that increased glucose supply from corn supplementation improved marbling deposition (Faulkner et al., 1994). Similarly, Myers et al. (1999) and Shike et al. (2007) reported that early weaned calves placed directly on a finishing diet had greater marbling scores compared with calves that were normal weaned with and without creep feed. These data suggest that an increase in starch intake early in an animal's life may begin to initiate marbling development and improve final carcass quality.

There are numerous production programs that are used to grow newly weaned calves prior to entering the finishing phase. In the Northern Great Plains, cattle are usually either grown on crop residues, dormant grass pastures, or placed in confinement and programmed fed for a moderate rate of gain. However, in the Southern Great Plains, each year thousands of fall-weaned calves are wintered on dormant native range (**DNR**) or winter wheat pasture (**WP**). Cattle that are wintered on DNR are fed a protein supplement to gain 0.23 to 0.45 kg/d through the winter months until spring forage growth occurs. These calves then graze summer pasture in either intensive-early stocking or season-long grazing programs prior to entering the finishing phase. Cattle from these production systems differ considerably in amount of body fat at entry into finishing, which could change maintenance energy requirements during finishing (Hersom et al., 2004). Therefore, the following discussion focuses on the differences among starch- vs. fiber-based energy supplements on glucose supply, body composition and visceral organ mass relative to finishing performance and carcass quality. Also, the development of the fat depots in relation to BW and maturity of the animal to improve carcass quality will be discussed.

CHAPTER II

REVIEW OF LITERATURE

Effect of Glucose Supply and Substrate Availability on Growing Performance of Cattle and Carcass Quality

Early Weaning vs. Creep Feeding. Recent studies have shown that early weaning calves and placing them directly into the finishing phase may increase marbling scores due to the increase in starch content of the diet. Meyers et al. (1999) compared early-weaned steers placed directly into the feedyard and fed a high-concentrate diet to normal weaned steers creep fed a corn-based supplement or were not supplemented. During finishing, the early-weaned steers had greater finishing ADG and marbling scores compared with the normal weaned steers, but steers that were fed the corn-based supplement had greater finishing ADG and similar marbling scores compared with the non-supplemented steers (Myers et al., 1999). Similarly, Shike et al. (2007) examined the differences between early-weaned steers placed directly into the feedyard and fed a high-concentrate diet to normal weaned steers creep fed either a corn-based or fiber-based supplement. There were no differences in finishing performance; however, the early-weaned steers had greater marbling scores compared with the steers normal-weaned (Shike et al., 2007). However, there were no differences in marbling scores between the corn- or fiber-based supplements. Fluharty et al. (1996) showed that early-weaned calves that were placed in the feedyard and fed concentrate diets (100, 90, or

60% concentrate) with various levels of CP (12 or 16% CP) had greater finishing ADG compared with steers that were normal-weaned and either creep fed a corn-based supplement or non-supplemented the final 60 d of the grazing phase. However, steers consuming the lower concentrate diet at 16% CP had lower ADG compared with the other early-weaned treatments. Overall final carcass quality was also greater for the early weaned steers compared with the normal-weaned steers, but there were no differences in carcass quality between the supplemented or non-supplemented normal-weaned steers (Fluharty et al., 1996). Additionally, Schoonmaker et al. (2004) examined the effects of early-weaning calves and placing them directly into a confinement setting and feeding either a concentrate diet at ad libitum intake, limit fed the same concentrate diet, or ad libitum intake of a forage-based diet until 204 d of age. At this same time, a group of steers were normal-weaned (non-supplemented) and placed directly on a finishing diet following weaning. During finishing the early-weaned steers had greater ADG compared with the normal-weaned steers; however, there was no difference in final carcass quality when harvested at similar 12th-rib fat (Schoonmaker et al., 2004). Bedwell et al. (2008) observed that ADG increased linearly with increasing amount of starch when early-weaned calves were placed directly in the feedyard and fed three different levels of starch (low, intermediate, and high level), but there were no differences in marbling scores when heifers were harvested at similar 12th-rib fat. These studies demonstrate discrepancies in the effect of starch supplementation and weaning management strategies on marbling scores, but early weaning has shown to improve final carcass quality grades when calves are placed directly on a high-concentrate diet.

Starch Supplementation. Several studies have evaluated only the starch content of growing diets or different supplementation strategies during grazing on feedlot performance and final carcass characteristics; however, results have been inconsistent. Lake et al. (1974) reported that steers were supplemented with 0.91 or 1.82 kg/d (0.3 or 0.6% of mean BW, respectively) of dry-rolled corn while grazing irrigated cool-season grass pastures had increased final quality grades in experiment 1, but corn supplementation of five different levels between 0.91 to 2.72 kg/d (0.3 to 0.89% of mean BW, respectively) had no effect on final quality grade in experiment 2. Similarly, Gunter and Phillips (2001) reported that 0.45 kg/d (0.19 and 0.16% of mean BW, respectively) of ground corn supplemented to steers grazing bermudagrass in an intensive-early stocked or season-long program did not influence final marbling score. Moreover, Owensby et al. (1995) conducted a four year study evaluating the effects of supplementing sorghum grain at 0, 0.3, and 0.6% of BW (0.91 or 1.82 kg/d, respectively) to steers grazing bluestem range in Kansas and observed that supplementation during grazing did not affect finishing performance or carcass quality. McCann et al. (1991) provided different levels of ruminal escape protein to steers grazing winter annual pastures and reported that ADG during grazing increased as the level of ruminal escape protein increased. However, during finishing, these steers had the lowest rate of gain compared with steers consuming lower ruminal escape proteins. There were no differences in final carcass quality when harvested at a similar 12th-rib fat (McCann et al., 1991). In contrast, Lomas et al. (2009) supplemented three levels (0.00, 0.26, and 0.53% of mean grazing BW) of sorghum grain to steers while grazing smooth bromegrass and showed that the highest level of supplement intake improved final marbling scores compared with the non-supplemented steers. Therefore, research evaluating level of supplement provided to grazing cattle in efforts to influence final marbling scores is inconsistent suggesting that there are factors affecting marbling development other than amount of starch during grazing. Some of the variation from these results could be due to not supplying enough supplement required to stimulate marbling development. Therefore if total energy intake is increased during grazing, final carcass quality may be influenced.

Starch- vs. Fiber-Based Supplements. Many feedstuffs with differing nutrient composition are fed to growing cattle in various production programs as grazing supplements or part of a total mixed ration. These feeds provide varying levels of protein and can alter the VFA profile in the rumen. Feeds, such as cereal grains that are high in starch, can decrease the acetate:propionate ratio and provide more propionate for gluconeogenesis. Smith and Crouse (1984) reported that steers fed either a high-concentrate diet or a lower energy diet (corn silage-based) had an increase in fatty acid synthesis from glucose in intramuscular adipose tissue compared with subcutaneous adipose tissue. However, the subcutaneous adipose tissue had increased fatty acid synthesis from acetate, which suggests that an increase in propionate production may influence marbling development (Smith and Crouse, 1984). Faulkner et al. (1994) showed that suckling-calves that were allowed to graze endophyte-infected tall fescue pastures for 113 d and supplemented with either a corn- or soyhull-based creep feed at limited or unlimited intakes or were not supplemented at all during the grazing phase. Supplement intakes for the corn- and soyhull-based supplements averaged 0.93 and 0.79% of mean grazing BW, respectively. Following grazing, steers were weaned and fed a growing diet for 77 d prior to receiving a finishing diet for 167 d. There was no difference in grazing ADG between types of supplement (0.98 vs. 0.94 kg/d for the corn- vs. soyhull-based supplement, respectively), but as supplement intake increased, ADG also increased. Creep feeding either type of supplement had no effect on performance in the feedyard, but the steers fed the corn-based creep feed had higher quality grades at the end of finishing compared with the soyhull-based creep feed (10.7 vs. 10.2 for the corn- vs. soyhull-based supplement, respectively; 10 = Low Choice). Additionally, as supplement intake increased, marbling scores increased as well, suggesting that higher consumption of an energy supplement early in the growing phase may improve final carcass quality. Faulkner et al. (1994) also conducted a digestion study and showed that the total VFA and propionate concentration increased as supplement intake increased. However, they reported no differences for total VFA and propionate concentrations among the differing types of supplements that were fed. Bodine et al. (2001) either supplemented steers with a protein supplement to meet their degradable intake protein requirement, a high-fiber based supplement, or a high-concentrate supplement while grazing bermudagrass pastures for 90 d beginning at the end of the summer and observed no difference in grazing ADG among the supplemented steers (0.74 vs. 0.70 kg/d, respectively). These steers were not followed through finishing, but an in-situ experiment was conducted using the same treatments as previously described and no difference in total VFA concentration for the supplemented steers was observed. However, the high-concentrate supplement had greater propionate concentration compared with the high-fiber based supplement, with both supplements having higher propionate concentrations compared with steers consuming the protein supplement (Bodine et al., 2001). These data suggest that the amount of grazing supplement provided may not influence the rumen VFA concentrations, but Faulkner et al. (1994) showed that the additional energy can initiate marbling development prior to finishing.

Bumpus (2006) fed steers either a soyhull- or corn-based supplement while grazing irrigated ryegrass pastures for 140 d and reported no difference in grazing ADG (0.95 vs. 0.96 kg/d). However, at the end of finishing the corn-based supplement had numerically greater marbling scores compared with soyhull-based supplement. Also, the two supplemented treatments had greater marbling scores compared with the non-supplemented controls (Bumpus, 2006). Elizade et al. (1998) supplemented steers with either cracked corn or corn gluten feed at levels of 1.4 and 2.8 kg/d (0.5 and 1.0% of mean grazing BW) while grazing endophyte-infected tall fescue and observed that supplemented steers had greater grazing ADG compared with the non-supplemented steers, but there was no difference in ADG between types of supplement. Type or level of grazing supplement had no effect on subsequent finishing performance or on final carcass quality (Elizade et al., 1998). In contrast, Horn et al. (1995) conducted three separate experiments evaluating a high-starch vs. a high-fiber based energy supplement for steers grazing winter wheat pasture. Steers grazed wheat pasture for 115, 107, and 84 d and supplement intakes averaged 0.71, 0.65, and 0.40% of mean grazing BW for each of the years, respectively. In year 1 and 3, the fiber-based energy supplemented had greater ADG compared with the starch-based energy supplement; however, in year 2 there were no differences in ADG. In year 2 and 3, the steers were followed through finishing and there were no differences between the energy supplemented treatments for finishing performance, and in year 2 there were no differences in final marbling score. Similarly, Sharman et al. (2012) supplemented with 1.13 kg/d of either whole corn, pelleted soyhulls, or dried distillers grains with solubles (**DDGS**) to steers grazing winter wheat pasture and observed that supplementation increased grazing ADG, but the fiber-based supplements (soyhulls and DDGS) had greater ADG compared with the starch supplemented steers. Following finishing, the fiber-based supplemented steers tended to have greater final marbling scores compared with the starch supplemented steers (Sharman et al., 2012). These data suggest that supplementing a starch-based supplement to calves grazing winter wheat pasture may not improve ADG and compared with fiber-based supplements, the final marbling scores are lower for the corn-based supplements. Therefore, in a wheat pasture program, total energy intake rather than starch intake may have greater effects on marbling development during grazing.

Effect of Body Composition and Visceral Organ Mass on Subsequent Finishing Performance

Body Composition. The previous section suggests that energy intake prior to finishing can improve marbling deposition, but how do changes in body composition and visceral organ mass from differing management or nutritional strategies have on finishing performance and final carcass characteristics. The differing rates of gain from various production programs can alter the partitioning and metabolism of nutrients. Development of bone has the top priority for nutrients followed by muscle then fat (Taylor and Field, 1999). As an animal matures, the amount of tissue accretion for muscle begins to plateau, whereas fat accretion increases with an increase in BW (Taylor and Field, 1999). In the past, the general rule of thumb for feedlot producers has been that as initial body fat/condition increases upon entry into finishing, there may be a decrease in feedlot efficiency (Mies, 1992). Drouillard and Kuhl (1999) reported inconclusive results regarding effects of previous management strategies during the grazing phase on subsequent finishing performance. Baker et al. (1992) observed that steers that were restricted during the growing phase on a silage based-diet had decreased BW and HCW compared with steers fed the same diet at ad libitum intakes. The restricted steers also had 34% less carcass fat and 8% more protein compared with steers fed ad libitum. Following the period of restriction, the steers from both treatments were allowed to graze ryegrass pastures for 172 d and at the end of grazing, the restricted steers had similar BW, but 18% greater empty body fat and 6% lower protein content compared with the non-restricted steers (Baker et al., 1992). Fox et al. (1972) reported that steers restricted in both energy and protein for 190 or 154 d had greater ADG and G:F during re-alimentation during finishing compared with steers that were not restricted when grown to either 364 or 454 kg of BW. These researchers also reported that at 364 kg of live BW, the restricted steers had more protein and less fat content compared with steers not previously restricted, but when grown to heavier live BW (454 kg) the restricted steers had similar body composition as the non-restricted steers. Carstens et al. (1991) restricted steers to only gain 0.4 kg/d for 189 d during the growing phase. The restricted steers in the finishing phase had a 33% greater ADG compared with steers that were not nutritionally restricted (1.54 vs. 1.16 kg/d, respectively). The restricted steers deposited more protein and less fat in both noncarcass and carcass tissues compared with steers not restricted. Because of these changes in tissue composition, NE_g requirements of the restricted steers was reduced by 18% compared with non-restricted steers (Carstens et al., 1991). Yambayamba and Price (1991) demonstrated that the length of restriction has an effect on body composition. Heifers were grown to 400 kg BW by feeding a concentrate diet at ad libitum intake, restricted intake for an ADG of 0.5 kg/d for two months and then fed the ad libitum intake, or restricted intake for an ADG of 0.5 kg/d for two months and then restricted intake to maintain BW another two months prior to ad libitum intake with the concentrate diet. As the length of nutrient restriction increased, ADG during finishing increased linearly compared with heifers not restricted to achieve similar final BW for all treatments. At the end of the restricted phase, there were no differences in muscle mass among the treatments, but the heifers that were restricted for four months had lower fat composition. At the end of finishing, there were no differences in body composition among the treatments (Yambayamba and Price, 1991). Similarly, Drouillard et al. (1991a) examined the effects of nutrient restriction (protein or energy restriction) on beef steers for either 77 or 154 d and reported that finishing ADG was greater for restricted compared with the non-restricted steers suggesting a compensatory gain response. Protein or energy restriction had no effect on subsequent finishing performance, but that protein restricted steers may require higher dietary protein levels during finishing to replace body nitrogen that was lost during restriction (Drouillard et al., 1991a). Drouillard et al. (1991b) restricted (energy or protein) lambs for 35 d to elicit a compensatory gain response upon re-alimentation and reported no difference in carcass fat deposition during the realimentation phase between type of nutrient restriction. However, there was a greater fat deposition rate in the non-visceral component compared with the visceral component (Drouillard et al., 1991b).

Sainz et al. (1995) conducted an experiment where steers were either fed a high-concentrate diet ad libitum, restricted intake of the concentrate diet, or fed a forage-based diet ad libitum during the growing phase. The steers that were fed the forage-based diet or restricted intake of the concentrate diet had less empty body fat and more empty body protein compared with steers fed the high-concentrate diet ad libitum to approximately 293 kg of empty BW prior to finishing. During finishing the restricted steers had greater ADG and G:F compared with the non-restricted steers. There were no differences among the treatments for empty body fat or empty body protein at the end of finishing (Sainz et al., 1995). Hersom et al. (2004a) conducted two separate experiments in which steers grazed winter wheat pasture to produce high- or low-rates of gain due to differences in stocking rate, or fed a protein supplement while grazing dormant native range. During winter grazing, ADG was greatest for the high-rate of gain wheat pasture steers followed by the low-rate of gain wheat pastures steers and then steers grazing dormant native range (1.21, 0.61, and 0.16 kg/d, respectively). Upon entry into the feedyard (at the end of winter grazing), the steers grazing wheat pasture at the high rate of gain had greater empty body fat and lower empty body fat-free organic matter content (g/kg empty BW) compared with the low rate of gain wheat pasture steers. The low rate of gain wheat pasture steers was greater than the dormant native range steers. Even though there were differences in empty body fat and fat-free organic matter content upon arrival at the feedyard, there were no differences in finishing performance among the treatments. At final harvest, there were conflicting results for empty body composition between experiments. In the first experiment, there were no differences between treatments for empty body fat and fat-free organic matter, but in the second experiment the low rate of gain wheat pasture steers and the steers grazing dormant native range had greater empty body fat content compared with steers grazing wheat pasture to produce a high-rate of gain (Hersom et al., 2004a). McCurdy et al. (2010a) reported no difference in empty body fat-free organic matter in steers that were grown at similar rates of gain either on winter wheat pasture, fed a silage-based diet in a confinement setting, or programmed fed a high-concentrate diet in a confinement setting. However, steers grazing wheat pasture had lower empty body fat compared with the steers fed in a confinement setting. The steers grown on the silage-based diet had greater finishing ADG compared with the steers that were programmed fed, with the steers grazing wheat pasture having the lowest finishing ADG. The steers fed the silage-based diet and programmed fed had greater G:F compared with the steers grazing wheat pasture. However, the differences in finishing performance did not affect final empty body fat or empty body fat-free organic matter (g/kg empty BW; McCurdy et al., 2010a). These studies show that different production programs can produce different rates of gain and fat composition prior to entering the finishing phase. However, the effects on performance during finishing was inconsistent suggesting that more research is needed to understand the effects of compensatory gain and body composition on finishing performance.

Visceral Organ Mass. Higher rates of protein synthesis and energy demand, visceral organs and liver comprise approximately 50% of the whole-body energy expenditure for maintenance (McBride and Kelly, 1990), even though these two organs represent a small percentage of the total body weight of the animal (Ferrell and Jenkins, 1985). Maintenance requirements have been shown to increase with increases in visceral organ mass (Ferrell and Jenkins, 1998), which is dependent on physical and chemical signals from the gastrointestinal tract due to plane of nutrition (Sainz and Bentley, 1997).

Ferrell et al. (1986) observed that lambs that were fed a common diet for 42 d at levels to achieve 16 (H), 5 (M), or -6 (L) kg of BW gain, followed by the lambs from the

H and M groups were fed to achieve 16 (HH, MH), 5 (HM, MM) or -6 (HL, ML) kg of BW gain for a second 42-d period. Lambs in the low rate of gain group were fed to achieve 27 (LS), 16 (LH), or 5 (LM) kg of BW gain. The design of the experiment resulted in lambs of different treatments during the first 42-d period having similar live weights after 84-d. Due to each treatment group having similar final BW, there were no differences in body composition. However, higher planes of nutrition during the first period resulted in increased liver mass and portal-drained viscera. Organ mass was dependent on rate of gain in the first period and was not a constant function of BW. Thus increased rate of gain in period one resulted directly in an increase in maintenance requirements for period two (Ferrell et al., 1986). McLeod and Baldwin (2000) reported that supplementing either a forage- or concentrate-based diet to growing lambs for 52 d resulted in the forage-based lambs having greater total digestive tract mass compared with the concentrate-based lambs. However, liver mass was greater in the lambs fed the concentrate-based diet. McLeod and Baldwin (2000) concluded that the lower partial efficiency for metabolizable energy use in tissues for the forage-based diet was due to an increase in heat production by the portal-drained viscera.

Similar results have been observed for beef cattle. Sainz and Bentley (1997) conducted an experiment where steers were grown on a high-concentrate diet with ad libitum intake, limit-fed the concentrate diet, or fed a forage-based diet ad libitum. At the end of the growing phase, the restricted fed concentrate treatment had the lowest liver mass compared with the forage-based diet, with the ad libitum concentrate treatment having the greatest liver mass. Also, steers fed the forage-based diet had greater forestomach mass (rumen, reticulum, omasum, and abomasum) and intestinal mass compared with the other two growing treatments. However, at the end of finishing the steers fed the concentrate diet at ad libitum intake had the lowest liver and intestine mass and heaviest forestomach mass compared with the other treatments. These data suggest that the nutrient intake from the diet can affect the size of different organs, but may depend upon dietary factors (fiber content of the diet, chemical signals in the GIT) influencing the metabolic workload that provided to each organ (Sainz and Bentley, 1997). Reynolds et al. (1991) examined the effects of high forage or a high concentrate based diet on growing heifers and observed that heifers fed a high concentrate diet produced less heat energy and retain more tissue energy compared with the high forage diet. Heifers fed the forage based diet had greater portal-drained viscera and liver oxygen uptake, which could explain the differences in nutrient efficiency between these two diet types (Reynolds et al., 1991). McCurdy et al. (2010b) grown steers at similar rates of gain on winter wheat pasture, fed a silage-based diet in a confinement setting, or programmed fed a high-concentrate diet in a confinement setting and reported that at the end of the growing phase, there were no differences in total viscera or total splanchnic tissue mass among the treatments. However, liver mass was greater for the steers that grazed wheat pasture compared with the other treatments. At the end of finishing, a similar trend was observed as there were no differences in total viscera or total splanchnic tissue mass among the treatments, but liver mass was still greater for the steers that previously grazed wheat pasture. McCurdy et al. (2010b) concluded that the different growing diets affected splanchnic organ mass, which could affect feedlot performance when comparing the program fed diet to a forage-based growing diet. Hersom et al. (2004b) reported that at the end of winter grazing, steers grazing dormant native range had greater total gastrointestinal tract mass (g/kg of empty BW) compared with low gain wheat pasture steers, with high gain wheat pasture steers having the lowest GIT mass. In the first experiment, liver mass was greater for the high gain wheat pasture steers, but there were no differences in liver mass in the second experiment at the end of winter grazing. At the end of finishing, there were no differences in total gastrointestinal tract or liver mass among the previous grazing treatments. In the first experiment, the high gain wheat pasture steers had greater total splanchnic tissue content compared with the other treatments, but in the second experiment the high gain wheat pasture steers had the lowest total splanchnic tissue content, which was primarily due to differences in mesenteric fat mass (Hersom et al., 2004b). These data show that there are rate of gain and energy intake during the growing phase affect visceral organ mass and energy expenditure, but further research is need to determine the mechanisms causing these changes.

Development of Fat Depots

Whole Body. There are four major fat depots in beef cattle that are studied to determine the effects each has on feedlot performance and carcass quality. These depots are visceral, subcutaneous, intermuscular, and intramuscular fat. These adipose depots can be affected by various nutrition and management strategies through nutrient composition and energy density of the diet (Smith, 1995). The fat depots in growing beef cattle have long been thought of as maturing in the order of visceral, intermuscular, subcutaneous, and intramuscular fat (Andrews, 1958). Similarly, McPhee et al. (2008) reported that from regression equations on thousands of growing cattle, intramuscular fat is the last fat depot to mature. Bruns et al. (2004) conducted an experiment in which steers were serially harvested throughout finishing and intramuscular fat developed in a linear manner throughout the entire finishing phase instead of a late-developing tissue as previously thought. Bruns et al. (2004) also showed that 12th-rib fat was deposited in a curvelinear manner throughout finishing and subcutaneous fat deposition increased rapidly at the end of finishing. Harper and Pethick (2004) reported that producers should focus on initiating preadipocytes in the muscle during the growing phase. An increase in the number of multipotent stem cells and preadipocytes may potentially produce a greater amount of final marbling deposition due to the fact that intramuscular fat increases in a linear rate during finishing (Harper and Pethick, 2004). Pethick et al. (2004) reported that marbling development occurs in three separate stages on data from British and Japanese Black type cattle. The first stage is when the animal is born and grows up to approximately 200 kg HCW where the rate of intramuscular fat accretion is minimal. During the second stage, the animal is between the range of 200 to 450 kg HCW and intramuscular rate increases linearly as the animal matures. The third stage of intramuscular fat development is when the fat depot begins to plateau due to reaching a HCW around 500 kg, which is mature body size. Pethick et al. (2004) showed that intramuscular fat is not a late maturing fat depot, but a fat depot that develops linearly as the animal matures. All of the fat depots may develop at similar rates during finishing, but each depot matures at different points on the growth curve. McCann et al. (2011) observed that postnatal metabolic imprinting may affect marbling deposition. Steers were either normal-weaned with no supplementation or early-weaned and drylotted to allow consumption of a 20% CP diet for 146 d. At the normal weaning age, all steers were comingled and allowed to grazed summer pastures for approximately five months followed by finishing. The early-weaned metabolically imprinted steers had greater final marbling scores when harvested at similar 12th-rib fat thickness. These data suggest that marbling development can be initiated early in life and be maintained until finishing when adequate energy is provided for maturation.

Owens et al. (1995) showed that protein accretion declines to zero when the animal reaches mature body weight, which is close to 36% empty body fat. Therefore, as protein accretion plateaus, fat synthesis is increasing among the various depots as the animal is growing in body size. Short et al. (1999) reported that genetics can also affect the rate of protein accretion or fat synthesis. Calves from moderate growth rate sires can become fatter and produce a higher-quality carcass at the end of finishing compared with calves from high-growth rate potential sires. Therefore, the older literature is maybe correct as in regards to the order of fat depots maturing, but all fat depots may be developing throughout the animal's life and can be nutritionally influenced prior to finishing to improve carcass quality.

Marbling, 12th-Rib Fat, Visceral. Carter et al. (2002) reported that accretion of intramuscular fat begins at approximately 378 kg of BW regardless of growth rate during the stocker phase and BW at feedlot entry, which corresponds to 64% of mature BW for the steers used in the study. Evaluating the published studies relative to final BW during the stocker phase, it appears that by providing an energy supplement during grazing to an older (more mature) animal may result in greater final marbling scores, but not when steers are younger (less mature). Greenquist et al. (2009) and Lomas et al. (2009) reported that energy supplemented steers with a final grazing BW of 477 and 417 kg had greater final marbling scores than non-supplemented steers with a final grazing BW of

437 and 386 kg, respectively. In contrast, Elizalde et al. (1998), Gunter and Phillips (2001), and Griffin et al. (2010) reported no difference in final marbling scores when final grazing BW of supplemented and non-supplemented steers were 308 vs. 302 kg, 336 vs. 303 kg, and 386 vs. 360 kg, respectively. Furthermore, Coleman et al. (1995), Sainz et al. (1995), and McCurdy et al. (2010a) reported that grain content of a growing diet had no influence on final marbling score when final growing BW for all treatments was less than 380 kg. However, this theory appears to contradict the results of Bruns et al. (2004) who demonstrated that marbling score increased linearly with HCW, but the initial harvest group weighed 365 kg and possibly did not allow these researchers to detect an inflection point.

Hersom et al. (2004a; 2004b) reported that at the end of winter grazing, steers grazing wheat pasture to produce a high rate of gain had greater 12th-rib fat, KPH, and mesenteric/omental fat at entry into finishing compared with steers grazing wheat pasture to produce a low rate of gain and steers supplemented with a protein supplement while grazing dormant native range. However, in the second experiment, the low gain wheat pasture steers had similar 12th-rib fat but higher KPH and mesenteric/omental fat compared with the steers grazing dormant native range. Furthermore, for both experiments, the high gain wheat pasture steers had greater marbling scores than the low gain wheat pasture steers, with the low gain wheat pasture steers having greater marbling scores than the dormant native range steers. However, at final harvest, when steers were harvested at similar 12th-rib fat and there were no differences in marbling score, but the steers grazing wheat pasture at a high-rate of gain had the greatest mesenteric/omental fat in year 1, but in year 2 these steers had the lowest mesenteric/omental fat (Hersom et al.

2004a; 2004b). Additionally, Sainz et al. (1995) reported that steers consuming a concentrate diet ad libitum had greater 12th-rib fat, KPH, abdominal fat, and marbling score following the growing phase compared with steers program fed the concentrate diet, which was greater than the steers consuming the forage-based diet ad libitum. At final harvest, there were no differences among treatments for any of the fat depots (Sainz et al., 1995). In contrast, McCurdy et al. (2010a; 2010b) reported that when steers were grown at similar rates of gain during the growing phase on wheat pasture or programmed fed in a confinement setting that there were no differences in 12th-rib fat, KPH, mesenteric/omental fat, or marbling score at the end of the growing phase. Similarly at final harvest there were no differences among the fat depots, except that the steers that previously grazed wheat pasture had lower final marbling scores compared with the other treatments (McCurdy et al., 2010a; 2010b). These data show that differences in rate of gain (total energy intake) can affect the various fat depots during the growing phase. However, type of production program may not influence fat deposition when steers have similar rates of gain and are harvested at a similar BW.

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 even when harvested at similar carcass weight or age of the animal. Additionally, LM area developed in a curvilinear manner as the animals matured suggesting that age of the animal and carcass weight are major factors. Guenther et al. (1965) also reported that as the feeding period is extended, 12th-rib fat is deposited at an increasing rate. Henrickson et al. (1965) and Guenther et al. (1965) showed that marbling scores increased with an increase in energy intake when steers were grown on a high or moderate plane of nutrition and harvested at a similar BW. Henrickson et al. (1965) also reported that 12th-rib fat tended to decrease when plane of nutrition decreased during finishing. Similarly, Choat et al. (2003) observed that steers previously grazed on wheat pasture had greater final marbling scores and KPH compared with steers previously grazed on dormant native range, but differences among the other fat depots were not observed at a similar final body composition. In contrast, Ridenour et al. (1982) reported no difference in carcass characteristics when steers were grown to either 273 or 364 kg prior to finishing on a 50% concentrate diet in a confinement setting or while grazing wheat pasture. Similarly, Lewis et al. (1990) reported no differences in carcass characteristics when harvested at a similar age following different rates of gain from protein supplementation during winter grazing on crop residues. Furthermore, Smith and Crouse (1984) observed that cattle fed a more energy dense diet had greater *in vitro* fatty acid synthesis rates in subcutaneous fat, but not in intramuscular fat compared with cattle fed a lower energy dense diet. These data suggest that energy density of the diet and rate of gain has a greater influence on 12th-rib fat than marbling score. However, growing programs that affect growth rate may have little influence on final marbling score when cattle are fed a high-energy diet during finishing and are harvested at a similar 12th-rib fat. Studies have shown that when steers are harvested at a similar 12th-rib fat, any differences in final marbling scores may not be seen suggesting that cattle wintered at low planes of nutrition can have adequate marbling scores if finished to adequate 12th-rib fat thickness based upon genetic potential even though there may be an increase in days on feed.

Summary and Conclusion

Growing programs are very important to the Southern Great Plains and will continue to be valuable due to the high cost of gain in the feedyards. Energy supplementation during the grazing phase improves ADG and can influence marbling deposition in growing beef cattle. The dormant native range and winter wheat pasture programs result in various rates of gain and fat content at entry into the finishing phase. These programs have been shown to affect nutrient metabolism during finishing due to changes in body composition and visceral organ mass, but when steers are harvested at a similar 12th-rib fat thickness, marbling scores appear to be similar. Therefore, a better understanding of nutrition and management strategies used prior to finishing to influence carcass quality in the beef industry is beneficial economically and can provide consumers with high-quality beef products.

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CHAPTER III

EFFECTS OF STARCH- VS. FIBER-BASED ENERGY SUPPLEMENTS DURING WINTER GRAZING ON PERFORMANCE, CARCASS CHARACTERISTICS, VISCERAL ORGAN MASS, AND ADIPOSE TISSUE GENE EXPRESSION IN GROWING BEEF CATTLE

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ABSTRACT

Fifty-seven Angus crossbred steers (269 ± 22 kg) were used to evaluate the effects of starch vs. fiber-based energy supplements for stocker cattle grazing low-quality dormant native range on performance, body composition, and adipose tissue development. Steers were randomly allotted to four treatments: (1) 1.02 kg·steer^{-1}·d^{-1} of a 40% CP cottonseed meal-based supplement (**CON**); (2) corn/soybean meal-based supplement fed at 1% of BW (**CORN**); (3) soybean hull/soybean meal-based supplement fed at 1% of BW (**SBH**); or (4) dried distillers grains with solubles fed at 1% of BW (**DDGS**). All supplements were individually fed 5 d/wk during the 121 d winter grazing phase. Following winter grazing, 3 steers per treatment were harvested to determine body composition and carcass characteristics, and collect subcutaneous (**SC**) and perirenal (**PR**) adipose tissue samples. The remaining steers grazed cool-season grass pastures for 74 d without supplementation prior to finishing. Steers were fed a common finishing diet for 113 d prior to harvest, at which time carcass characteristics were collected at a commercial abattoir. Energy supplementation increased winter grazing ADG compared with CON steers, and CORN steers had greater ADG than SBH and DDGS steers. Energy supplementation increased mesenteric/omental fat mass, but did not influence 12th-rib fat thickness or marbling score at intermediate harvest compared with CON steers. mRNA expression of genes involved in lipogenesis and markers of adipogenesis were greater in PR of energy supplemented steers compared with CON steers, but not in SC. SBH steers had greater mRNA expression of fatty acid synthase and fatty acid binding protein 4 compared with CORN and DDGS steers in PR, but not SC. At final harvest, energy supplemented steers had greater KPH and higher yield grade than CON steers, but no differences in marbling score were observed. Providing energy supplements increased ADG during winter grazing; however, intramuscular fat was not influenced in stocker cattle grazing dormant native range. These data suggest that the total energy intake and the stage of animal maturity in this production system were too low to influence marbling deposition.

Key words: gene expression, growing beef cattle, marbling deposition, supplementation, winter grazing

INTRODUCTION

The current feeding practices in the beef industry result in production of 2 billion kg of excess fat annually in an attempt to achieve improved quality grades (Smith et al., 2000). Data from a beef quality audit and the Vetlife Benchmark Performance Program have shown a decrease in carcasses grading choice by approximately 6% from 1974 to 2004 and 1999 to 2006, respectively (Smith et al., 2006; Andersen and Gleghorn, 2007), and the Vetlife data has shown an increase in yield grade 4 and 5 carcasses. Studies of nutrition and management practices that influence marbling deposition have primarily focused on the feedlot phase of production (Owens and Gardner, 2000). However, pre-feedyard management strategies can influence marbling development (Anderson and Gleghorn, 2007). Therefore, management strategies that improve marbling deposition relative to other fat depots during the stocker phase could enhance the efficiency of beef production.

Marbling development begins early in an animal's life (Bruns et al., 2004) and intramuscular adipocytes preferentially utilize glucose as a substrate for fatty acid synthesis, whereas, subcutaneous fat utilizes acetate (Smith and Crouse, 1984). Myers et al. (1999) and Shike et al. (2007) reported that early weaned calves placed directly on a finishing diet had greater marbling scores compared to calves that were normal weaned with and without creep feed. Moreover, Faulkner et al. (1994) reported that suckling calves provided a corn-based creep feed had increased marbling scores at the end of finishing compared to calves provided a soyhull-based creep feed suggesting that the increased glucose supply from corn supplementation improved marbling deposition. Therefore, the objective of this experiment was to examine the effects of high-starch vs. high-fiber based energy supplements for growing cattle wintered on dormant tallgrass native range on grazing and finishing performance, carcass characteristics, visceral organ mass, and adipose tissue gene expression.

MATERIALS AND METHODS

Prior to the initiation of this study, procedures for animal care, handling, and sampling were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Study Site and Vegetation

Steers grazed 130 ha of dormant tallgrass native range that was deferred from grazing the previous growing season at the Crosstimbers Bluestem Stocker Research Range located 11 km southwest of Stillwater, OK (long 36°10′N, lat 97°5′W; elevation, 271 m). Pastures are equipped with improved water sources, as well as seasonal streams and ponds. The dominant forage grass species were big bluestem (*Andropogon gerardii*

Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), and indiangrass (*Sorghastrum nutans* [L.] Nash). The subdominant grass species included switchgrass (*Panicum virgatum* L.), tall dropseed (*Sporobolus asper* [Michx.] Kunth), sideoats grama (*Bouteloua curtipendula* [Michx.] Nash), and Scribner's dicanthelium (*Dicanthelium oligosanthes* [J.A. Schultes] Gould). Forbs included invasive species Sericea Lespedeza (*Lespedeza cuneata*) and western ragweed (*Ambrosia psilostachya* DC). Woody plant species included eastern red cedar (*Juniperus virginiana* L.), post oak (*Quercus stellata* Wangenh.), blackjack oak (*Quercus marilandica* Muenchh), pecan (*Carya illinoinensis*), blackberry (*Rubus fruticosus*), eastern red bud (*Cercis canadensis*), and honey locust (*Gleditsia triacanthos*).

Steer Source and Adaptation

Fifty-seven Angus steers from the Range Cow Research Center-South Range Unit near Stillwater, OK were utilized in the experiment. Steers were weaned October 3, 2007, vaccinated with Titanium® 5 (Diamond Animal Health Inc., Des Moines, IA) and Clostri Shield® 7 (Novartis Animal Health Inc., Larchwood, IA), and allowed to graze cool-season grass traps prior to initiation of the experiment. Steers were re-vaccinated on October 23 with Titanium® 5 and were dewormed with Cydectin® (Fort Dodge Animal Health, Overland Park, KS). Steers were not implanted prior to weaning or during the grazing phase of the experiment. Following re-vaccination, steers were transitioned to the dormant tallgrass pastures and were trained to enter individual feeding stalls two or three days per week by offering 0.57 kg/hd of a 40% CP supplement.

Initial Harvest

On November 4, four steers were randomly selected and ultrasound measurements of 12th-rib fat, LM area, and intramuscular fat were taken on the left side of the steer 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 taken by a technician who is certified by the Ultrasound Guideline Council and the images were interpreted using the software package Beef Image Analysis Pro Plus (Designer Genes Technologies, LLC., Harrison, AR). The steers were then harvested at the Food and Agricultural Products Center (**FAPC**) for collection of initial carcass characteristics as described by Hersom et al. (2004). Carcass data were collected by trained personnel from Oklahoma State University.

Winter Grazing Phase

On December 4, the remaining steers (averaging 269 ± 22 kg; 266 ± 16 d of age) were stratified by body weight and randomly allotted to one of four supplementation treatments: (1) 1.02 $kg \cdot steer^{-1} \cdot d^{-1}$ of a 40% CP cottonseed meal-based supplement (**CON**); (2) corn/soybean meal-based supplement fed at 1% of BW (**CORN**); (3) soybean hull/soybean meal-based supplement fed at 1% of BW (**SBH**); or (4) dried distillers grains with solubles fed at 1% of BW (**DDGS**). The ingredient and nutrient composition of the supplements are shown in Table 1. Using the Level 1 Model (NRC, 1996) and "winter range" (Feed No. 144) and a microbial efficiency of 10%, calculated degradable intake protein (**DIP**) balances were 71, 83, 80, and -60 for treatments 1 through 4, respectively. Supplements were individually fed 5 d/wk during the 121 d winter grazing. Amount of supplement offered was adjusted monthly following the collection of 12-hr shrunk body weights. Steers were allowed to graze as a single group and had free-choice access to a trace mineral supplement.

At the end of winter grazing, ultrasound measurements were measured on all steers as previously described for the initial harvest steers. Three steers per treatment were randomly selected for intermediate harvest as previously described for the initial harvest steers. Immediately after hide removal, the gastrointestinal tracts were collected and dissected into each individual anatomical part, emptied of contents, and weighed. Internal organs (heart, lungs, kidney, liver, spleen, and pancreas) and mesenteric/omental fat were also weighed. Empty body weight was calculated as final shrunk BW from winter grazing multiplied by 0.891 (NRC, 1996). Total gastrointestinal tract (**GIT**) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine. Total viscera was calculated as the sum of the total GIT and mesenteric/omental fat. Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas. Immediately following weighing of the liver, a sub-sample was collected and immediately frozen in liquid nitrogen and stored at -80°C. Samples of subcutaneous (**SC)** and perirenal (**PR**; kidney) adipose were also collected, immediately frozen in liquid nitrogen, and stored at -80°C.

Summer Grazing Phase

On April 11, 2008 the remaining steers were transported to the Expanded Wheat Pasture Research Unit (Marshall, OK) for continuous grazing of a 40-ha cool-season grass pasture for 74 days with only a trace mineral supplement offered. The trace mineral supplement contained 1764 g/metric ton of monensin (Forage Pro RU1600; Hi-Pro Feeds; Friona, TX). The pasture consisted of Lincoln smooth brome (*Bromus inermis*

Leyss.) and manska pubescent wheatgrass (*Thinopyrum intermedium barbulatum*). Steers grazed cool-season grass to reach a heavier BW prior to placement into the feedlot.

Finishing Phase

Thirty-nine steers (375 ± 32 kg) were transported to the Willard Sparks Beef Research Center near Stillwater, OK. Two steers from CORN treatment were removed from the trial prior to transitioning into the finishing phase due to that these steers were significantly heavier than their counterparts (greater than 2 times the SD of the mean) and the owner of the cattle would not allow them to continue through the production phase. Upon arrival, steers were weighed, dewormed with Ivomec® (Ivermectin injectable; Merial, Duluth, GA), and implanted with Revalor®-S (120 mg of trenbolone acetate and 24 mg of estradiol; Intervet Inc., Millsboro, DE). Steers were stratified by BW within treatments and were randomly allotted to one of three pens per treatment. Each pen was 12.2 x 30.5 m and two pens shared an automatic water fountain. Steers were fed a 65% concentrate starter diet and gradually stepped up to a dry rolled corn-based finishing diet. Ingredient composition of the finishing diet was 73% dry-rolled corn, 15% wet distiller grains with solubles, 6% prairie hay, and 6% supplement and the chemical composition was 71.67% DM, 15.57% CP, 16.80% NDF, 7.10% ADF, 1.26 Mcal/kg NE_g, and 76.67% TDN. Steers were fed twice daily at 0800 and 1400 h in amounts that allowed ad libitum access to feed throughout the day. Individual full BW were collected every 28 d before the morning feeding. Steers were fed for 113 d prior to harvest at a commercial abattoir (Creekstone Farms; Arkansas City, KS). Three red-hided steers from CON were removed from the final carcass data analysis due to the abattoir only accepting blackhided cattle. Standard carcass data were collected by trained personnel from Oklahoma State University.

Laboratory Analysis

Supplements and finishing diet samples were collected weekly and composited by month for analysis. Dry matter, crude protein, ADF, NDF, calculated net energy measurements, and TDN for the supplements and finishing diet were all analyzed by a commercial laboratory (Basic Wet Chemistry Package Analysis; Dairy One, Ithaca, NY). Amount of starch in the supplements was analyzed using the assay adapted from Galyean (2010). Briefly, 0.2 g of supplement was placed into a 125 mL Erlenmeyer flask and was gelatinized in 50 mL of deionized water using a water bath at 100°C for 90 minutes. After gelatization of the sample, 50 mL of an acetate buffer (0.2 M) and 1 mL of the enzyme solution [1:0.8 ratio of deionized water to Validase GA 400L (glucoamylase; Valley Research, South Bend, IN)] were added to each flask. The flasks were reweighed, incubated in a drying oven at 60°C for 24-h, allowed to cool to room temperature, and weighed again. A 0.1 mL aliquot from each flask was measured in duplicate and 4 mL of o-Toluidine reagent was added to each sample and placed in a water bath at 100°C for 15 min. The samples were cooled to room temperature and absorption was determined at 630 nm using a spectrophotometer.

Degradable intake protein of the supplements was analyzed using a *Streptomyces griseus* (Type XIV Bacterial; Sigma-Aldrich, Co., St. Louis, MO) protease assay adapted from Krishnamoorthy et al. (1983). Briefly, the equivalent of 15 mg of N from each supplement sample was weighed into 125-mL Erlenmeyer flasks. Forty milliliters of a borate-phosphate buffer was added to each flask and then incubated in a shaker water bath at 39°C for 1 h. Following the incubation period, 10 mL of the protease solution was added to each flask and then incubated in the shaker water bath at 39°C for 18 h. Following the second incubation period, the samples are filtered through Whatman #541 filter paper using a cone-shaped funnel. The residue was rinsed with 400 mL of distilled water to remove any incubation media. Samples were then dried at 90°C for 48 h to record a dry-matter residue weight. The sample was then analyzed for N content using the Kjeldahl assay with a 2400 Kjeltec Analyzer Unit Foss Tecator (Hoganas, Sweeden). The DIP percentage was calculated by dividing the mg of residual N by mg of total N from the supplement and multiplied by 100. The result was then subtracted from 100 to determine DIP as a percent of CP in each sample.

Gene Expression Analysis

Total RNA was isolated from tissue samples using TRIzol® (Invitrogen Corp., Carlsbad, CA) following the manufacturer's instructions. Following isolation of RNA with TRIzol, a clean-up procedure was used to remove additional fat from the sample and remove any guanidine isothiocyanate carryover from the TRIzol procedure. Phenol:chloroform:isoamyl alcohol (25:24:1) was added (1:1 ratio) to the isolated RNA and the mixture centrifuged at 20,000 x *g* at 4°C for 5 min. The aqueous phase was transferred to a fresh tube and precipitated with 0.1 volume of sodium acetate (3 M; pH 5.2) and 2.5 volumes of 98% ethanol. Samples were maintained at -80°C for 1 h, centrifuged at 20,000 x *g* at 4°C for 30 min and, after removal of the supernatant, the RNA pellet was washed with 75% ethanol, resuspended in DEPC-treated water, and stored at -80°C. The integrity of the RNA was determined using gel electrophoresis and quantified using a NanoDrop® ND-1000 Spectrophotometer (NanoDrop Technologies, Wilmington, DE).

Total RNA (1.0 μg) was used to synthesize cDNA using a reverse transcriptase kit (QuantiTect, Qiagen Inc., Valencia, CA). Expression levels of mRNA for selected genes were determined using quantitative real-time PCR (**qRT-PCR**) with specific primers designed using Primer3 software package (Rozen and Skaletsky, 2000). The specificity of PCR primers were evaluated by comparing the primer sequences to the nr database of GenBank using the BLAST tool (http://blast.ncbi.nlm.nih.gov/Blast.cgi). Complementarity of forward and reverse primer sequences for each primer pair were evaluated using OligoAnalyzer 3.1 (Integrated DNA Technologies, Coralville, IA). The genes evaluated and primers used for PCR are listed in Table 2. For adipose tissue samples, qRT-PCR reactions contained 7.5 μL of PerfeCTa™ SYBR® Green Supermix for iQ (Quanta Biosciences, Gaithersburg, MD), 0.25 μL of 25 μM forward primer (400 nM), 0.25 μL of 25 μM reverse primer (400 nM), and 100 ng of cDNA were carried out using a MyiQ Real Time PCR detection system (Bio-Rad Laboratories, Hercules, CA). Thermal cycling parameters were 95°C for 5 min, followed by 40 cycles of 95°C for 10 sec, optimum annealing temperature for 30 sec, then 72°C for 30 sec. For liver samples, 7.5 μL of RT^2 SYBR® Green Supermix for iQ (SABiosciences, Frederick, MD) was used in place of the PerfeCTa supermix in qRT-PCR reactions. Thermal cycling parameters were 95°C for 5 min, followed by 40 cycles of 95°C for 15 sec, optimum annealing temperature for 30 sec, then 72°C for 60 sec. Following amplification, a melt curve analysis was performed to verify the specificity of the reaction. For each gene, all reactions displayed a single (± 0.5°C) melt peak temperature indicating a unique product was amplified. 18S ribosomal RNA was used as the reference gene for normalization in liver and adipose tissue. The relative quantification of mRNA expression was computed using the procedure described by Vandesompele et al. (2002). Briefly, threshold cycle (Ct) values of each gene were converted to quantitative expression values relative to the sample with the lowest Ct value using the qRT-PCR reaction efficiency factor of each gene. The quantitative expression values of the target genes were then divided by the quantitative expression value of the reference gene to calculate normalized mRNA expression. Relative fold change was then calculated as the normalized mRNA expression of each target gene relative to the average mRNA expression in subcutaneous adipose tissue of CON steers for comparison of adipose tissue gene expression, and relative to average mRNA expression of CON steers for comparison of liver gene expression. This procedure allowed statistical analysis of linear mRNA expression values relative to the control treatment after adjusting for differences in reaction efficiency.

Statistical Analysis

Individual steer ADG during winter grazing and finishing was computed by linear regression of BW on day of experiment (Proc GLM; SAS Inst. Inc., Cary, NC). Winter grazing performance, ultrasound carcass measurements, intermediate and final carcass characteristics, and organ mass data were analyzed using a general linear model (Proc Mixed; SAS Inst. Inc., Cary, NC) with steer as the experimental unit. Finishing performance data were analyzed using the same model with pen as the experimental unit. The models included treatment as a fixed effect. The average initial BW for winter grazing was used as a covariate when analyzing winter grazing performance and was removed from the model if not significant at $P < 0.05$. Final carcass characteristics are reported as unadjusted and 12th-rib-fat-adjusted by covariate analysis. Quality grade distribution was analyzed with PROC GLIMMIX (SAS Inst. Inc., Cary, NC) using a binomial distribution. Relative fold change of mRNA expression was analyzed using a general linear model (Proc GLM; SAS Inst. Inc., Cary, NC) that included the fixed effects of treatment, adipose tissue, and the interaction term for genes evaluated in adipose tissue, and the fixed effect of treatment for genes evaluated in liver. Contrasts were used to test differences among preplanned treatment comparisons. Contrast one (**C1**) compared CON with the average of the three energy supplement treatments. Contrast two (**C2**) compared CORN supplement (high starch) with the average of the two high fiber-based supplements (SBH and DDGS). Contrast three (**C3**) compared the two fiber-based supplements (SBH vs. DDGS). Contrasts were evaluated using an alpha of 0.05 only when F-test was significant at $P < 0.05$.

RESULTS AND DISCUSSION

Winter Grazing Phase

Performance. Supplement consumption was 0.36, 0.91, 0.92, and 0.81% of mean BW for CON, CORN, SBH, and DDGS, respectively (Table 3). Average daily gain was greater ($P < 0.001$) for energy and protein supplemented steers compared with CON steers, and ADG of CORN steers was greater ($P < 0.001$) than the SBH and DDGS steers. There were no negative associative effects due to supplementing a corn/soybean meal-based supplement to steers grazing DNR. Bodine and Purvis (2003) reported that steers supplemented with a corn-based supplement balanced for total diet degradable intake protein in relation to total diet TDN while grazing dormant native range had the greatest ADG compared with steers only supplemented to meet their supplemental TDN or supplemental DIP requirements. Several other studies (Morris et al., 2005; Gustad et al., 2006) have showed that energy plus protein supplementation to cattle consuming low-quality forage improves ADG. In contrast, Chase and Hibberd (1987) reported that cows fed a corn-based supplement formulated to equalize supplemental protein level based upon cows receiving only a cottonseed meal supplement decreased forage utilization which decreased the overall energy status of the cow. Similarly, Sanson et al. (1990) observed that cows supplemented with ear corn or ear corn plus protein supplement had lower forage intake levels and lost BW during winter grazing compared with cows fed a protein supplement. These studies (Chase and Hibberd, 1987; Sanson et al., 1990) demonstrate the importance of formulating to meet the animals DIP requirement when grazing low quality forage to offset any negative associative effects of grain supplementation. In the current experiment, the greater (P = 0.002) gain response to CORN compared with SBH and DDGS in our study is most likely due to the greater energy content of the CORN supplement, which resulted in greater energy intake of CORN steers.

However, no studies have evaluated type of energy supplement for growing steers consuming low-quality forage. Bodine et al. (2001) reported no difference in ADG between soyhull/wheat middlings and sorghum grain-based supplements fed to heifers grazing late-summer bermudagrass (10-15% CP); no protein source was added to the energy supplements. Horn et al. (1995) reported that a soyhull/wheat middling-based energy supplement improved ADG of steers grazing winter wheat pasture (typically greater than 20% CP) compared with a corn-based supplement in 2 of 3 experiments. Bumpus (2006) reported no difference in ADG of steers grazing irrigated ryegrass pasture (27% CP) supplemented with either soyhull- or corn-based supplements. Additionally, Swanson et al. (2004) observed no difference in ADG of steers fed medium-quality meadow hay and supplemented with either dry-rolled corn or dry-rolled barley at 0.25 or 0.50% of BW. However, supplementation at a high rate (1% of BW) may not be economical. Vendramini et al. (2006) reported that early weaned calves supplemented with 10, 15, or 20 $g•kg^{-1}$ BW of a wheat middling/soybean hull-concentrate pellet improved rates of gain on rye-ryegrass pastures for 145 d grazing phase. However, the researchers concluded that supplementation above 10 $g•kg^{-1}$ BW (1% of BW) did not increase gross returns because of the increased supplement cost even though there were increases in ADG and stocking rate.

Intermediate Carcass Characteristics. Compared to the initial ultrasound carcass measurements, LM area increased, 12th-rib fat thickness decreased, but intramuscular fat percentage was maintained during winter grazing (Tables 4 and 5). In contrast, intermediate carcass characteristics indicate that LM area, 12th-rib fat thickness, and marbling score increased compared with carcass characteristics of the initial harvest steers. Even though energy supplemented steers had greater ADG during winter grazing neither HCW nor dressing percentage were affected by supplementation. In addition, 12th-rib fat thickness from ultrasound or carcass measurements was not influenced by supplementation. Energy supplemented steers did have greater ($P < 0.05$) LM area based on ultrasound and carcass measurements compared to the CON steers. There were no differences in ultrasound or carcass characteristics between starch- and fiber-based energy supplements for LM area. When comparing the two fiber-based supplements, DDGS steers had a smaller ($P < 0.05$) LM area and a higher ($P < 0.05$) yield grade compared with SBH steers. Neither marbling score nor intramuscular fat percentage was influenced by type of supplement following winter grazing.

No previous studies have evaluated the effects of energy supplementation or type of energy supplement on intramuscular fat development in weaned calves grazing low-quality forage. In addition, only a few studies have determined differences in carcass characteristics at the end of the growing phase in cattle fed different diets. Coleman et al. (1995) and Sainz et al. (1995) reported that steers limit-fed a corn grain-based diet for similar rate of gain to those fed a corn silage or alfalfa hay-based diet had increased quality grades and marbling scores following the growing phase. McCurdy et al. (2010a) reported no statistical difference between steers limit-fed a corn grain or sorghum silage diet, although the numeric trend is similar to that of Coleman et al. (1995) and Sainz et al. (1995). In each study, 12th-rib fat thickness was also greater for the grain-fed steers.

Considerable research has been conducted evaluating starch level in the diet for early-weaned steers; however, results are inconsistent. Schoonmaker et al. (2003; Exp. 1) reported that early-weaned steers fed a high-concentrate diet at ad libitum, had greater intramuscular fat percentage measured via ultrasound at normal weaning than those limit-fed a high-concentrate diet or ad libitum fed a soyhull/brome hay diet. Retallick et al. (2010) reported a linear increase in intramuscular fat percentage measured via ultrasound at the end of a 111-d growing phase as starch content of the diet increased from no high-moisture corn up to levels of 20 and 40% high-moisture corn within the growing diet. In contrast, Schoonmaker et al. (2003; Exp. 2) and Schoonmaker et al. (2004) reported no improvement in intramuscular fat percentage measured via ultrasound of steers fed a high concentrate diet ad libitum. Moreover, Bedwell et al. (2008) reported no difference in intramuscular fat percentage measured via ultrasound in early weaned heifers fed diets with increasing amounts of starch, which the calculated levels of starch was 12, 41, and 63% of the growing diet. These researchers also reported that rates of gain were similar among dietary treatments. However, heifers maintained on pasture during the growing phase had lower intramuscular fat percentage compared to those fed concentrate diets in drylot. The pasture heifers also had lower ADG (0.30 vs. 1.48 kg/d) compared with those fed in drylot. In the current study, energy supplemented steers had ADG of 0.43 kg/d compared with 0.20 kg/d for CON steers. Thus, the improvement in ADG may have not been enough to stimulate an increase in intramuscular fat deposition.

Organ Mass. Control steers had greater omasum mass, and tended ($P < 0.10$) to have smaller small intestine mass than energy supplemented steers (Table 6). Starch supplemented steers tended to have smaller abomasum and liver mass compared with SBH and DDGS steers. Steers supplemented with DDGS had smaller esophagus mass than SBH steers; the reason for this is not known. Reynolds et al. (1991) and McLeod and Baldwin (2000) reported that oxygen consumption and mass of the portal drained viscera, particularly the forestomach, increases significantly when ruminants are fed high roughage diets. Hersom et al. (2004b) observed that steers grazing low-quality dormant forage had greater reticulo-rumen, omasum, and total gastrointestinal tract mass than steers grazing wheat pasture indicating that the bulk density and ruminal digestibility of forage affects mass of these organs. McLeod and Baldwin (2000) reported that mass of the small intestine responds to total ME intake primarily through changes in mass of epithelial tissue. In our study, energy supplementation most likely replaced forage in the diet (Bodine and Purvis, 2003) and increased ME intake resulting in lower mass of the omasum and greater mass of the small intestine. Mass of the liver is primarily a result of metabolic load. Reynolds et al. (1991) and McLeod and Baldwin (2000) showed that liver mass increases with increasing ME intake. McCurdy et al. (2010b) reported that liver mass of steers grazing wheat pasture was 20% greater than those fed a silage or corn-based diet even though ME intake was similar among treatment groups. The researchers contributed this to the much greater CP in the diet of wheat pasture steers and the increased metabolic load on the liver to metabolize the increased ammonia. In the current study, the trend for greater liver mass of SBH and DDGS compared with CORN may be due to increased gluconeogenesis to supply glucose for NADPH generation and glycerol synthesis due to increased fat synthesis from acetate.

Energy supplemented steers had significantly greater ($P < 0.05$) mesenteric/omental fat mass compared with CON steers, but as mentioned previously no improvement in marbling score or 12th-rib fat thickness was evident at the intermediate harvest. The lack of differences in subcutaneous and intramuscular fat deposition may be due to the low rate of gain of steers grazing dormant native range. The order of fat depot development is thought to be visceral > intermuscular > subcutaneous > intramuscular (Andrews, 1958). Thus, as energy intake and rate of gain increases visceral fat depots would deposit fat prior to subcutaneous and intramuscular fat depots. Owens et al. (1995) showed that empty body fat accretion increases linearly as rate of gain increases, but this analysis only evaluated rates of gain of 0.8 kg/d and greater. Hersom et al. (2004a; 2004b) reported that increasing rate of gain (0.16, 0.61, and 1.20 kg/d) resulted in a linear increase in mesenteric fat and marbling score, but 12th-rib fat thickness increased quadratically such that fat thickness did not appreciably increase except at the highest rate of gain. Therefore, the lack of any significant increase in subcutaneous or intramuscular fat deposition between energy supplemented and CON steers may be due to the low energy intakes and ADG in the current study.

Gene Expression. There was a treatment by tissue interaction ($P < 0.05$) for glucose transporter 4 (GLUT4) such that energy supplementation increased mRNA expression in PR compared with CON steers, but not in SC (Table 7; Figure 1). In addition, GLUT4 mRNA expression was greater ($P < 0.05$) in PR of SBH steers compared with DDGS steers. mRNA expression of glucose-6-phosphate dehydrogenase was greater in PR compared with SC, but was not affected by treatment. However, mRNA expression of glucose-6-phosphate isomerase and pyruvate kinase 2 (Figure 2) were not affected by treatment or adipose tissue. mRNA expression of ATP-citrate lyase was greater in PR compared with SC, but similar among treatments. There was a treatment by adipose tissue interaction for mRNA expression of acetyl-CoA synthetase with energy supplemented steers having greater ($P < 0.05$) mRNA expression compared with CON steers in PR, but not in SC. mRNA expression of glycerol-3-phosphate dehydrogenase (GPDH) was greater ($P < 0.05$) in PR than SC (Figure 3). There tended ($P = 0.06$) to be a difference among treatments in GPDH primarily due to greater mRNA expression in PR of energy supplemented steers compared with CON steers. There was a significant treatment by adipose tissue interaction for mRNA expression of fatty acid synthase. Fatty acid synthase mRNA expression was greater ($P < 0.05$) in energy supplemented compared with CON steers, fiber-based supplements compared with starch-based CORN supplement, and SBH steers compared with DDGS steers in PR, but no differences among treatments were observed in SC. These results indicate that energy

supplementation with corn or soyhulls increased lipid synthesis from acetate, but DDGS supplementation increased lipid synthesis from dietary fat more than from acetate.
Few studies have evaluated expression of lipogenic genes in adipose tissue of growing steers; however, several studies have evaluated lipogenic enzyme activity (Scott and Prior, 1980; Smith and Crouse, 1984; Smith et al., 1984). Smith and Crouse (1984) reported that enzyme activity of fatty acid synthase and citrate lyase were greater in subcutaneous adipose tissue of steers fed a corn-based diet compared with a corn silage-based diet, but glucose-6-phosphate dehydrogenase was not affected. Smith et al. (1984) showed that activity of fatty acid synthase and citrate lyase was greater in subcutaneous adipose tissue of steers fed a corn-based diet compared with alfalfa hay-based diet, but pyruvate kinase was not affected. These results are similar to the current study in that greater energy intake increased lipogenic enzyme activity, but citrate lyase was not affected in our study. Scott and Prior (1980) reported that increasing energy intake resulted in greater activity of glucose-6-phosphate dehydrogenase and fatty acid synthase in subcutaneous and perirenal adipose tissue, whereas in our study greater energy intake only increased gene expression in perirenal adipose tissue. However, steers in the study by Scott and Prior (1980) were gaining over 1.0 kg/d and had 12th-rib fat thicknesses over 1.0 cm at the time of tissue sampling.

There was a treatment by adipose tissue interaction for the late markers of adipogenesis, adipocyte fatty acid binding protein, and stearoyl-CoA desaturase 1, but not for the early markers of adipogenesis, sterol regulatory element binding factor 1 and CAATT/enhancer binding protein beta. mRNA expression of adipocyte fatty acid binding protein and stearoyl-CoA desaturase 1 were greater ($P < 0.05$) for energy supplemented steers compared with CON steers, fiber- compared with starch-based supplements, and SBH steers compared with DDGS steers in PR, but no differences among treatments was observed in SC (Figure 4). These differences are primarily due to a dramatic increase in mRNA expression in PR of SBH steers, but the reason for this is not apparent. Robelin (1981) reported that a new population of adipocytes was identified when the mean cell diameter reached 80 – 90 μm between 35 to 45% of mature weight, which occurred following a period of primarily lipid filling. Perirenal adipose tissue of SBH steers had the greatest expression of lipogenic genes of all the treatments indicating the greatest rate of lipid synthesis. A positive relationship between adipocyte diameter and rate of lipogenesis from acetate has been reported in subcutaneous adipose tissue of wethers (Hood and Thornton, 1980). Thus, the greater mRNA expression of lipogenic genes may indicate that adipocytes in PR of SBH steers had reached a critical size to initiate differentiation of new adipocytes, whereas perirenal adipocytes in other treatments had not yet reached that point. However, these new adipocytes had not yet contributed to increasing kidney fat indicated by the similar percent KPH among treatments. Perirenal adipose tissue had greater mRNA expression of both early and late markers of adipogenesis compared with SC. Similarly, Ortiz-Colon et al. (2009) reported that stromal vascular cells collected from perirenal adipose tissue had greater adipogenic capacity than those collected from subcutaneous adipose tissue.

In general, expression of genes involved in lipid synthesis and adipogenesis were up-regulated in perirenal compared with subcutaneous adipose tissue, which corresponds to the greater mesenteric fat in energy supplemented compared with CON steers, but no difference in 12th-rib fat thickness at the intermediate harvest. As discussed previously, this may be due to the low energy intake of steers in this study; however, it indicates that adipose tissue development through adipogenesis and/or lipogenesis is energy dependent and suggests that a minimum level of energy intake is required to initiate development of each fat depot.

There was no significant difference in mRNA expression of genes involved in gluconeogenesis in the liver of steers (Table 8; Figure 5). We expected energy supplemented steers to have greater mRNA expression than CON steers, and CORN steers to have greater mRNA expression compared with SBH and DDGS steers due to increased gluconeogenic substrates. No studies have previously evaluated gluconeogenic gene expression in liver of growing beef steers. In dairy cattle, phosphoenolpyruvate carboxykinase 1 mRNA levels are responsive to monensin inclusion in the diet (Karcher et al., 2007) and to propionate in hepatic cell culture (Koser et al., 2008). An explanation for the lack of a response in the current study is not apparent.

Finishing Phase

Performance. There were no differences among treatments for feedlot performance, even though the supplemented steers were heavier ($P < 0.02$) at the start of finishing; however, this weight advantage was not carried through the feeding period (Table 9). Several studies have evaluated the effect of supplementation strategies during the grazing phase on subsequent feedlot performance. Lake et al. (1974) reported no difference in ADG during finishing among steers that had been supplemented 0 to 2.72 kg/d of a corn supplement while grazing irrigated cool-season pasture during the stocker phase. Horn et al. (1995) reported that steers supplemented with an energy supplement while grazing winter wheat pasture had lower ADG during finishing in one experiment but not in another. Feed intake and feed efficiency were not influenced by type of energy supplement during winter grazing (*P* > 0.12). Gunter and Phillips (2001) and Lomas et al. (2009) reported no differences in feedlot performance among steers previously fed a corn supplement while grazing summer bermudagrass pasture or supplemented with sorghum grain while grazing smooth bromegrass pasture.

Final Carcass Characteristics. There were no differences among treatments for HCW, dressing percentage, 12th-rib fat, or LM area (*P* > 0.14; Table 10). The energy supplemented steers had numerically greater 12th-rib fat thickness and did have a greater (*P* < 0.02) KPH compared with the CON steers, which resulted in a higher yield grade (*P* < 0.05) for the energy supplemented steers. Even when adjusted to similar 12th-rib fat thickness, energy supplemented steers still had significantly higher KPH and yield grades. Final marbling scores were not affected by winter supplementation treatment (*P* > 0.75). In addition, 12^{th}-rib-fat adjusted marbling scores were similar among treatments probably because 12th-rib fat thickness was not a significant covariate for marbling score. This further illustrates that marbling score is not linked with 12th-rib fat, but treatments imposed in this study were not able to improve marbling score when steers were harvested at similar 12th-rib fat endpoint.

In the current study, consumption of energy supplements by steers grazing dormant native range averaged 0.91, 0.92, and 0.81% of mean BW for CORN, SBH, and DDGS treatments, respectively. Type of energy supplement did not influence (*P* > 0.23) final marbling scores, even though there was a numerical increase in marbling scores at the end of winter grazing compared with the CON. Elizade et al. (1998) also reported no improvements in final quality grade when steers were supplemented with cracked corn or corn gluten feed at 0.50 or 1.00% of mean grazing BW while grazing endophyte-infected tall fescue for 85 d. In contrast, Faulkner et al. (1994) showed that creep-feeding a corn-based supplement at 0.93% of mean grazing BW for 113-d to five-month old steers had increased final marbling scores compared with creep-feeding a soyhull-based supplement at 0.79% of mean feeding BW. Both of these creep-feeding supplements improved final marbling scores compared with the non-supplemented steers. Moreover, Lomas et al. (2009) conducted three experiments using 7-month old steers grazing smooth bromegrass for at least 188 d and were supplemented with two levels of grain sorghum (0.26 and 0.53% of mean grazing BW) and reported that the highest level of supplement improved final marbling scores compared with the non-supplemented steers. Research evaluating type and amount of supplement provided to grazing cattle to influence final marbling scores is inconsistent suggesting that there are factors affecting marbling development other than amount of energy intake during grazing.

Several studies have evaluated the starch content of the growing diet or different supplementation strategies during grazing on growing cattle on final carcass characteristics; however, results have been inconsistent. Lake et al. (1974) reported steers grazing irrigated cool-season grass pastures and supplemented with a 0.91 or 1.82 kg/d of dry-rolled corn had increased final quality grades in experiment 1, but corn supplementation of 0.91 to 2.72 kg/d had no effect on final quality grade in experiment 2. Similarly, Gunter and Phillips (2001) reported that 0.45 kg/d of ground corn supplemented to steers grazing bermudagrass had no effect on final marbling score. In addition, Horn et al. (1995) observed that supplementing steers grazing winter wheat pasture with high-starch or high-fiber supplements did not influence final marbling score.

Bumpus (2006) reported no difference in final marbling score between steers fed a corn- or soyhull-based supplement (1.36 kg·steer^{-1}·d^{-1}) while grazing irrigated ryegrass pasture; however, an interesting trend (P = 0.27) was seen in quality grade distribution. The percentage of steers grading USDA Choice was 39, 50, and 65% (7, 10, and 13 steers, respectively) for non-supplemented, fiber-based, and starch-based supplements, respectively. These data indicate that as energy intake and glucose supply during the stocker phase increased the percentage of steers grading USDA Choice increased. In the current study, no differences in quality grade distribution (P > 0.16) were observed, possibly due to the low number of steers per treatment. Similar to Bumpus (2006), Lomas et al. (2009) reported that marbling score (527, 537, and 554) increased linearly as grain sorghum supplementation (0, 0.82, and 1.64 kg·steer^{-1}·d^{-1}) increased indicating an effect of increasing glucose supply. However, this effect may simply be due to increased energy intake and rate of gain. Several studies (Coleman et al., 1995; Sainz et al., 1995; McCurdy et al., 2010a) have evaluated the effects of starch content in the diet and energy intake of the same diet for steers during the growing phase. These studies have consistently reported no difference in final marbling score or quality grade among steers with regard to starch content or energy intake. Moreover, Hersom et al. (2004a) showed no difference in final marbling score between steers previously grazing dormant native range or winter wheat pasture with rates of gain of 0.16 and 1.20 kg/d, respectively.

The effects of grain content of growing diets and grain supplementation to grazing cattle on intramuscular fat development has received considerable attention; however, results are variable. The variation in results may be due to the level of energy intake or the stage of maturity of the animals during the stocker phase. Lake et al. (1974; Exp. 1), Greenquist et al. (2009), and Lomas et al. (2009) reported that energy supplementation increased ADG from 0.60 to 0.83, 0.67 to 0.92, and 0.74 to 0.88 kg/d, respectively, and improved final quality grade. However, increasing ADG from 0.20 to 0.54 kg/d in the current study did not influence final marbling score. In addition, Horn et al. (1995), Griffin et al. (2010), and Islas et al. (2010) reported that final marbling score was not influenced when supplementation increased ADG during grazing from 0.88 to 1.07, 0.89 to 1.18, and 1.09 to 1.25 kg/d, respectively. These results suggest that energy supplementation may influence intramuscular fat development only when supplementation increases rate of gain above a certain threshold, which may be between 0.8 – 0.9 kg/d. Thus, if ADG of supplemented steers remains below this level as in the current study or if ADG of non-supplemented steers is already greater than this level, as in Horn et al. (1995), then energy supplementation has no influence on intramuscular fat development and final marbling score. However, this theory does not fit with the results of Sainz et al. (1995) and Hersom et al. (2004a) who reported no difference in final marbling score even though ADG ranged from 0.69 to 1.96 kg/d and 0.15 to 1.31 kg/d, respectively.

Carter et al. (2002) reported that intramuscular fat deposition begins to accelerate at approximately 378 kg of live BW regardless of growth rate during the stocker phase and BW at feedlot entry, which corresponds to 64% of mature BW for the steers used in the study. Evaluating the published studies relative to final BW during the stocker phase, it appears that by providing an energy supplement during grazing to an older (more mature) animal may result in greater final marbling scores, but not when steers are younger (less mature). Greenquist et al. (2009) and Lomas et al. (2009) reported that energy supplemented steers with a final grazing BW of 477 and 417 kg had greater final marbling scores than non-supplemented steers with a final grazing BW of 437 and 386 kg, respectively. In contrast, Elizalde et al. (1998), Gunter and Phillips (2001), and Griffin et al. (2010) observed no difference in final marbling scores when final grazing BW of supplemented and non-supplemented steers was 308 vs. 302 kg, 336 vs. 303 kg, and 386 vs. 360 kg, respectively. Moreover, Coleman et al. (1995), Sainz et al. (1995), and McCurdy et al. (2010a) showed no influence of grain content in growing diets when final growing BW for all treatments was less than 380 kg. However, this theory is not in agreement with Bruns et al. (2004) who reported that marbling scores increased linearly with HCW. However, in the study of Bruns et al. (2004) the initial harvest group weighed 365 kg and possibly prevented detection of an inflection point.

In conclusion, the amount and/or type of supplement did not influence final fat deposition among the different fat depots in steers wintered on dormant native grass, even though energy supplementation increased ADG during winter grazing. We expected that providing glucogenic substrates to the high-acetate fermentation of steers grazing dormant native range would increase intramuscular fat deposition. The CORN supplement did not have a negative associative effect during winter grazing, suggesting that when growing cattle are provided a high-starch supplement the DIP content. However, total energy intake in this production system and the stage of animal maturity may have been inadequate to influence intramuscular fat deposition. Therefore, it may not be economical or practical to provide an energy supplement in the amount required to influence marbling deposition in this production system. In addition, it may not be beneficial to provide a starch-based supplement to increase intramuscular fat development in feeder cattle unless an adequate degree of maturity has been achieved.

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Table 1. Ingredient and chemical composition of supplements fed to steers during winter grazing

	Treatment[1]			
Item	CON	CORN	SBH	DDGS
Ingredient composition, % As-fed				
Cottonseed meal	80.50	-	-	-
Rolled corn	-	67.00	-	-
Soybean hulls	-	-	75.00	-
Dried distillers grains with solubles	-	-	-	98.40
Soybean meal, 47.5% CP	11.85	32.00	25.00	-
Wheat middlings	7.65	-	-	-
Limestone	-	1.00	-	1.60
Chemical composition[2]				
DM, %	92.62	91.52	92.67	92.63
CP, % DM	46.30	21.80	19.10	32.90
NE_m, Mcal/kg	1.92	2.07	1.57	1.81
NE_g, Mcal/kg	1.28	1.41	0.95	1.19
ADF, % DM	20.50	5.50	43.50	15.60
NDF, % DM	29.90	12.00	58.90	37.30
TDN, % DM	78	83	69	75
Starch, % DM	19.02	66.22	14.77	14.21
Degradable intake protein, % of CP	81.18	69.11	63.97	36.47
NRC Level 1 Model values				
DIP supplied by supplement[3], g	352	368	306	266
DIP balance[3], g/d	71	83	80	-60
ME allowable ADG[3], kg/d	0.22	0.68	0.62	0.64

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] Chemical composition was performed at a commercial lab (Dairy One, Ithaca, NY), except for starch and degradable intake protein assays, which were conducted in-house.

[3] DIP = degradable intake protein; ME = metabolizable energy.

Table 2. Primers used to quantify mRNA expression of genes in adipose tissue and liver of growing steers using qRT-PCR

Gene Name[1]	Accession	Forward Primer (5'- 3')	Reverse Primer (5' - 3')	Product Size, bases	Reaction Eff., %
Adipose tissue					
GLUT4	NM_174604	CCTGGGGACACTCAATCAAC	TCAGCCAACACCTCAGACAC	264	94.30
G6PDH	XM_583628	TCTACCGCATTGACCACTACC	AGATACACTTCAGCACCTTGACC	300	95.10
GPI	NM_001040471	CATCACGAACGCAGAGACAG	TGGCAGTGTTGGTAGACAGG	101	93.30
GPDH	NM_001035354	ATCAATGGAGACAGGCAGAAG	TTTGGAGAGGGACTAGGCAAC	199	86.60
FASN	NM_001012669	AAGCAGGCACACAATATGGAC	TGAAGTCAAAGAAGAAGGAGAGG	244	82.10
PK2	XM_590109	TTGGGTCGGGTAGTTCAGAG	ACAAAGGAAGGGAAGCAGGA	136	100.30
ACLYS	NM_001037457	CAGCCAAGATGTTCAGCAAG	GTGACCAATGCCCATGATAAG	101	89.00
ACSS2	NM_001105339	TTCTGCTACCTTCCCATTCTTC	CCAGTAATAGCCATCCTTGTCC	229	87.50
FABP4	NM_174314	AGCTGCACTTCTTTCTCACC	TGACACATTCCAGCACCATC	404	85.40
SCD1	NM_173959	TGGAGGGTAGAAGGAATTTTGA	TGATGACCCATTTGAGCTACAC	159	83.90
SREBF1	NM_001113302	ACACCACCAGCATCAACC	CCATTCATCAGCCAGACC	112	93.70
CEBPβ	NM_176788	CTTCTACTACGAGGCGGACTG	TCGTGCTCTCCGATGCTAC	126	93.30
18s rRNA	DQ222453	GACACGGACAGGATTGACAG	CGGACATCTAAGGGCATCAC	243	91.10
Liver					
PCK1	NM_174737	AGTTCTGGGAGGAGGAGGTG	CTGGTGCGTTGTATGGATTG	167	93.00
PC	NM_177946	CCTGCTGGTCAAGGTCATC	AACAGCTCTGGGTTCTCGTC	109	81.00
ACSS3	NM_001102137	AACAGACATTCGCCTTCCAC	CACCAGCCAGCTTAGAGACC	190	89.20
G6Pase	NM_001076124	AGATTTCTGGATGGCTGTGG	TGAGGATTCAGCAGGATGG	161	92.20
18s rRNA	DQ222453	GACACGGACAGGATTGACAG	CGGACATCTAAGGGCATCAC	243	84.40

[1] GLUT4 = glucose transporter 4; G6PDH = glucose-6-phosphate dehydrogenase; GPI = glucose-6-phosphate isomerase; GPDH = glycerol-3-phosphate dehydrogenase; FASN = fatty acid synthase; PK2 = pyruvate kinase 2, muscle; ACLYS = ATP citrate lyase; ACSS2 = acyl-CoA short-chain synthetase 2 (cytosolic acetyl-CoA synthetase); FABP4 = adipocyte fatty acid binding protein 4; SCD1 = stearoyl-CoA desaturase 1 (Δ9-desaturase); SREBF1 = sterol regulatory element binding factor 1; CEBPβ = CAATT/enhancer binding protein beta; PCK1 = phosphoenolpyruvate carboxykinase 1; PC = pyruvate carboxylase; ACSS3 = acyl-CoA short chain synthetase 3 (propionyl-CoA synthetase); G6Pase = glucose-6-phosphatase.

Table 3. Effects of type and amount of supplement on winter grazing performance of growing steers

	Treatment[1]					Contrast, *P*-value[2]		
Item	CON	CORN	SBH	DDGS	SEM	C1	C2	C3
Steers, No.	14	13	13	13	-	-	-	-
Supp. Intake, kg/d	1.01	2.67	2.70	2.39	-	-	-	-
BW, kg								
d 0	266	257	276	274	5.96	0.61	0.02	0.82
d 121[3]	292	331	312	313	5.30	0.001	0.006	0.93
ADG, kg/d	0.20	0.53	0.37	0.39	0.04	0.001	0.002	0.80
Supplement Conversion[4]	-	8.09	15.88	12.58	-	-	-	-

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS.

[3] Initial body weight was a significant covariate ($P < 0.05$).

[4] Supplement conversion is kg of supplement (as-fed) per kg of increased BW gain.

Table 4. Ultrasound measurements and carcass characteristics of steers at initial harvest

Item	Mean	SD
Steers, No.	4	-
Ultrasound measurements		
12th-rib fat, cm	0.33	0.10
LM area, cm^2	39.35	2.93
Intramuscular fat, %	2.81	0.71
Carcass characteristics		
HCW, kg	143	16.05
Dressing percentage, %	51.94	1.73
12th-rib fat, cm	0.03	0.04
KPH, %	1.75	0.29
LM area, cm^2	39.83	3.88
Yield grade	2.05	0.25
Marbling score[1]	58	28.73

[1] Marbling score grid: 0 = Devoid^{00}; 100 = Practically Devoid^{00}.

Table 5. Effects of type and amount of supplement on ultrasound measurements and intermediate carcass characteristics of growing steers

	Treatment[1]					Contrast, *P*-value[2]		
Item	CON	CORN	SBH	DDGS	SEM	C1	C2	C3
Ultrasound measurements								
Steers, No.	14	13	13	13	-	-	-	-
12th-rib fat, cm	0.15	0.16	0.16	0.15	0.008	0.86	0.52	0.77
LM area, cm^2	39.60	47.45	48.87	46.96	1.48	0.001	0.80	0.36
Intramuscular fat, %	3.02	2.85	2.71	2.92	0.11	0.14	0.77	0.18
Intermediate carcass characteristics								
Steers, No.	3	3	3	3	-	-	-	-
HCW, kg	146	152	168	168	8.95	0.14	0.20	0.99
Dressing percentage, %	50.07	50.49	51.77	52.83	1.82	0.46	0.44	0.69
12th-rib fat, cm	0.05	0.12	0.15	0.14	0.04	0.13	0.64	0.79
LM area, cm^2	45.37	52.68	55.69	47.52	2.23	0.03	0.70	0.03
KPH, %	0.50	0.50	0.50	0.50	-	-	-	-
Yield grade	1.62	1.38	1.39	1.78	0.10	0.41	0.14	0.03
Marbling score[3]	120	137	150	157	25.44	0.37	0.61	0.86

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS.

[3] Marbling score grid: 100 = Practically Devoid^{00}; 200 = Traces^{00}.

Table 6. Effects of type and amount of supplement on mass of body components at intermediate harvest for growing steers

Item	Treatment[1]				SEM	Contrast, *P*-value[2]		
	CON	CORN	SBH	DDGS		C1	C2	C3
Empty BW[3], kg	259	269	288	283	9.50	0.10	0.20	0.68
	g/kg of empty BW							
Carcass	562	567	581	593	20.37	0.46	0.44	0.69
Heart	4.48	5.11	4.59	4.54	0.33	0.51	0.21	0.91
Lungs-trachea	11.39	13.50	12.63	12.97	0.46	0.01	0.25	0.62
Esophagus	1.10	0.98	1.29	0.82	0.08	0.42	0.44	0.003
Reticulo-rumen	24.23	22.65	21.83	23.79	0.90	0.19	0.89	0.16
Omasum	13.32	11.30	10.64	10.88	0.85	0.04	0.61	0.85
Abomasum	4.56	3.96	4.34	4.58	0.22	0.32	0.09	0.45
Small intestine	14.56	16.58	17.18	18.91	1.33	0.09	0.39	0.38
Large intestine	11.47	11.50	13.93	10.25	1.43	0.81	0.74	0.11
Total GIT[4]	68.14	65.98	67.92	68.41	2.46	0.81	0.49	0.89
Mesenteric/omental fat	4.18	8.88	7.38	7.00	1.30	0.04	0.32	0.84
Total viscera[5]	72.31	74.86	75.30	75.41	1.80	0.20	0.83	0.97
Pancreas	0.98	0.98	0.76	1.17	0.30	0.99	0.97	0.38
Spleen	2.24	2.06	2.22	2.09	0.26	0.72	0.76	0.73
Liver	12.26	12.00	13.65	13.65	0.63	0.28	0.07	0.99
Total splanchnic tissue[6]	87.78	89.90	91.93	92.32	2.26	0.21	0.44	0.91

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS.

[3] Empty BW was calculated as shrunk BW multiplied by 0.891.

[4] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[5] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[6] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

Table 7. Analysis of variance for mRNA expression in subcutaneous (SC) and perirenal (PR) adipose tissue of growing steers

			Effect *P*-value			Contrast *P*-value for SC[1]			Contrast *P*-value for PR		
Gene Name[2]	Error df	MSE[3]	Treatment	Tissue	Trt*Tissue	C1	C2	C3	C1	C2	C3
GLUT4	16	2.51	0.01	0.01	0.01	0.55	0.78	0.80	0.02	0.56	0.01
G6PDH	16	2.08	0.21	0.01	0.14	0.62	0.33	0.24	0.05	0.54	0.08
GPI	16	0.27	0.75	0.56	0.39	0.35	0.25	0.28	0.48	0.83	0.61
GPDH	16	352.91	0.06	0.01	0.11	0.78	0.77	0.84	0.01	0.62	0.15
FASN	16	14.11	0.01	0.01	0.01	0.54	0.42	0.58	0.01	0.01	0.01
PK2	16	0.49	0.75	0.17	0.34	0.87	0.71	0.09	0.41	0.77	0.43
ACLYS	16	2.32	0.52	0.01	0.19	0.63	0.48	0.36	0.16	0.48	0.08
ACSS2	16	523.64	0.02	0.01	0.03	0.86	0.78	0.79	0.01	0.62	0.09
FABP4	16	63.75	0.01	0.01	0.01	0.69	0.68	0.95	0.01	0.01	0.01
SCD1	16	210.22	0.01	0.01	0.01	0.45	0.29	0.49	0.01	0.01	0.01
SREBF1	16	6.89	0.33	0.01	0.15	0.62	0.30	0.44	0.06	0.53	0.08
CEBPβ	15	10.21	0.89	0.01	0.21	0.44	0.33	0.13	0.99	0.54	0.32

[1] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS

[2] GLUT4 = glucose transporter 4; G6PDH = glucose-6-phosphate dehydrogenase; GPI = glucose-6-phosphate isomerase; GPDH = glycerol-3-phosphate dehydrogenase; FASN = fatty acid synthase; PK2 = pyruvate kinase 2, muscle; ACLYS = ATP citrate lyase; ACSS2 = acyl-CoA short-chain synthetase 2 (cytosolic acetyl-CoA synthetase); FABP4 = adipocyte fatty acid binding protein 4; SCD1 = stearoyl-CoA desaturase 1 (Δ9-desaturase); SREBF1 = sterol regulatory element binding factor 1; CEBPβ = CAATT/enhancer binding protein beta.

[3] MSE = mean square error.

Table 8. Analysis of variance for mRNA expression in liver of growing steers

Gene Name[2]	Error df	MSE[3]	Treatment *P*-value	Contrast *P*-value[1] C1	C2	C3
PCK1	8	0.61	0.65	0.78	0.26	0.68
PC	8	0.15	0.56	0.25	0.45	0.84
ACSS3	8	0.29	0.72	0.62	0.36	0.70
G6Pase	8	0.33	0.63	0.44	0.31	0.95

[1] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS

[2] PCK1 = phosphoenolpyruvate carboxykinase 1; PC = pyruvate carboxylase; ACSS3 = acyl-CoA short chain synthetase 3 (propionyl-CoA synthetase); G6Pase = glucose-6-phosphatase.

[3] MSE = mean square error.

Table 9. Effects of type and amount of supplement on subsequent feedlot performance of growing steers

	Treatment[1]					Contrast, *P*-value[2]		
Item	CON	CORN	SBH	DDGS	SEM	C1	C2	C3
Steers, No.	11	8	10	10	-	-	-	-
Pens, No.	3	3	3	3	-	-	-	-
BW, kg								
d 0	362	385	381	393	6.91	0.02	0.82	0.24
d 113	559	595	583	585	13.86	0.12	0.54	0.93
DMI, kg/d	10.74	11.33	10.48	10.91	0.30	0.64	0.12	0.33
ADG, kg/d	1.77	1.81	1.72	1.66	0.11	0.73	0.39	0.74
Gain:Feed	0.163	0.164	0.171	0.156	0.005	0.85	0.89	0.06

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS.

Table 10. Effects of type and amount of supplement on final carcass characteristics of growing steers

Item	Treatment[1]				SEM	Contrast, *P*-value[2]		
	CON	CORN	SBH	DDGS		C1	C2	C3
Steers, No.	8	8	10	10	-	-	-	-
Unadjusted carcass characteristics								
HCW, kg	342	360	354	357	9.06	0.14	0.66	0.80
Dressing percentage	60.97	60.61	60.62	61.07	0.45	0.69	0.67	0.44
12th-rib fat, cm	1.31	1.40	1.42	1.53	0.12	0.31	0.58	0.47
KPH, %	1.63	2.31	2.25	2.10	0.21	0.02	0.59	0.58
LM area, cm^2	87.57	88.38	86.31	84.64	2.38	0.67	0.31	0.58
Yield grade	2.63	2.97	3.04	3.23	0.20	0.05	0.49	0.45
Marbling score[3]	385	373	406	399	20.83	0.75	0.23	0.79
Quality grade distribution								
$Choice^0$, %	12.50	0.00	20.00	0.00	12.65	0.97	0.99	0.98
$Choice^-$, %	25.00	25.00	10.00	40.00	15.49	0.89	0.84	0.16
Select, %	62.50	75.00	70.00	60.00	17.12	0.75	0.62	0.64
Adjusted to 12th-rib fat								
KPH, %	1.60	2.31	2.25	2.12	0.22	0.02	0.63	0.64
LM area[4], cm^2	86.38	88.11	86.31	85.81	2.07	0.88	0.40	0.85
Yield grade[4]	2.78	3.01	3.04	3.08	0.12	0.06	0.70	0.77
Marbling score[3]	386	373	406	398	21.42	0.80	0.25	0.77

[1] CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

[2] C1 = CON vs. supplement treatments; C2 = CORN vs. SBH and DDGS; C3 = SBH vs. DDGS.

[3] Marbling score grid: 300 = $Slight^{00}$; 400 = $Small^{00}$.

[4] 12th-Rib Fat was a significant covariate at $P < 0.05$.

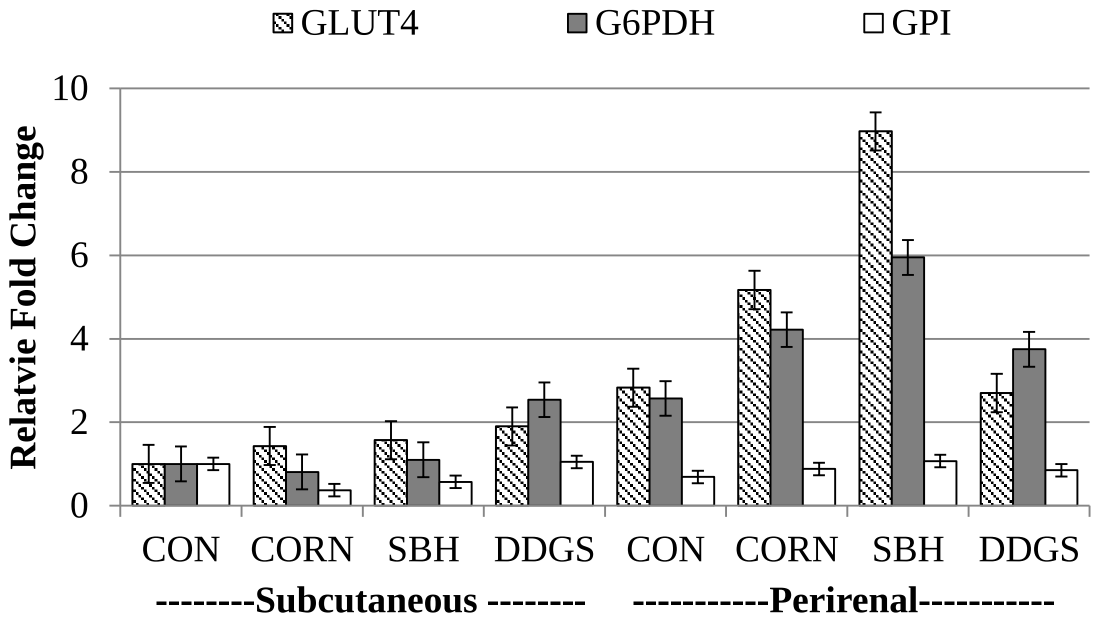

Figure 1. Effects of type and amount of supplement on mRNA expression of genes involved in glycolysis and pentose cycle in subcutaneous and perirenal adipose tissue of growing steers. GLUT4 = glucose transporter 4 (SEM = 0.91); G6PDH = glucose-6-phosphate dehydrogenase (SEM = 0.83); GPI = glucose-6-phosphate isomerase (SEM = 0.30). CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

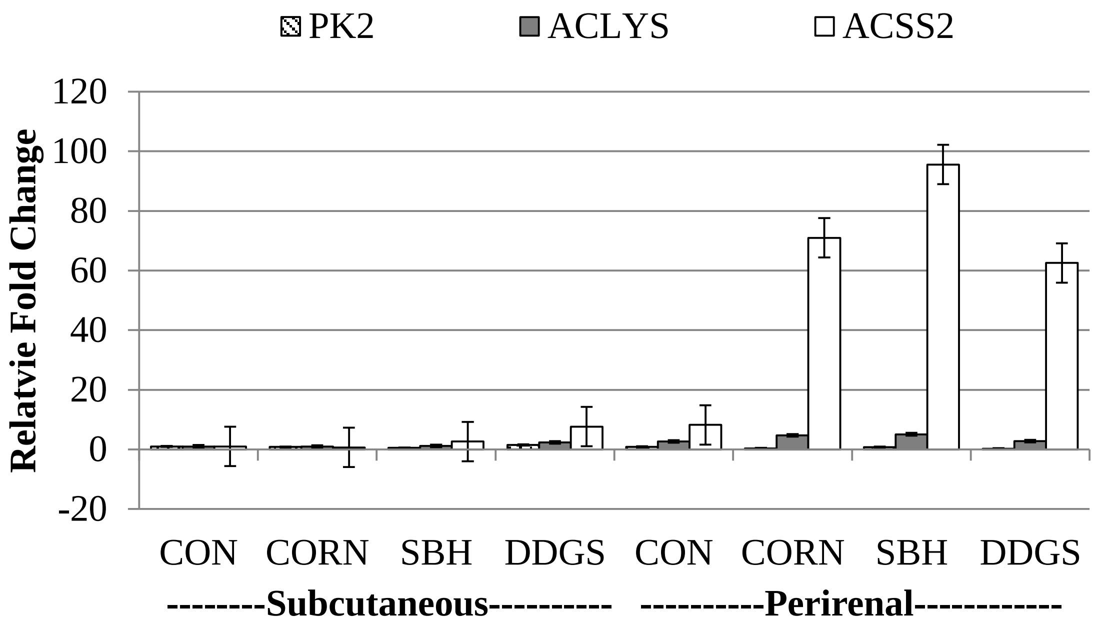

Figure 2. Effects of type and amount of supplement on mRNA expression of genes involved in substrate utilization for fatty acid synthesis in subcutaneous and perirenal adipose tissue of growing steers. PK2 = pyruvate kinase 2, muscle (SEM = 0.41); ACLYS = ATP citrate lyase (SEM = 0.88); ACSS2 = acyl-CoA short chain synthetase 2 (cytosolic acetyl-CoA synthetase; SEM = 13.21). CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

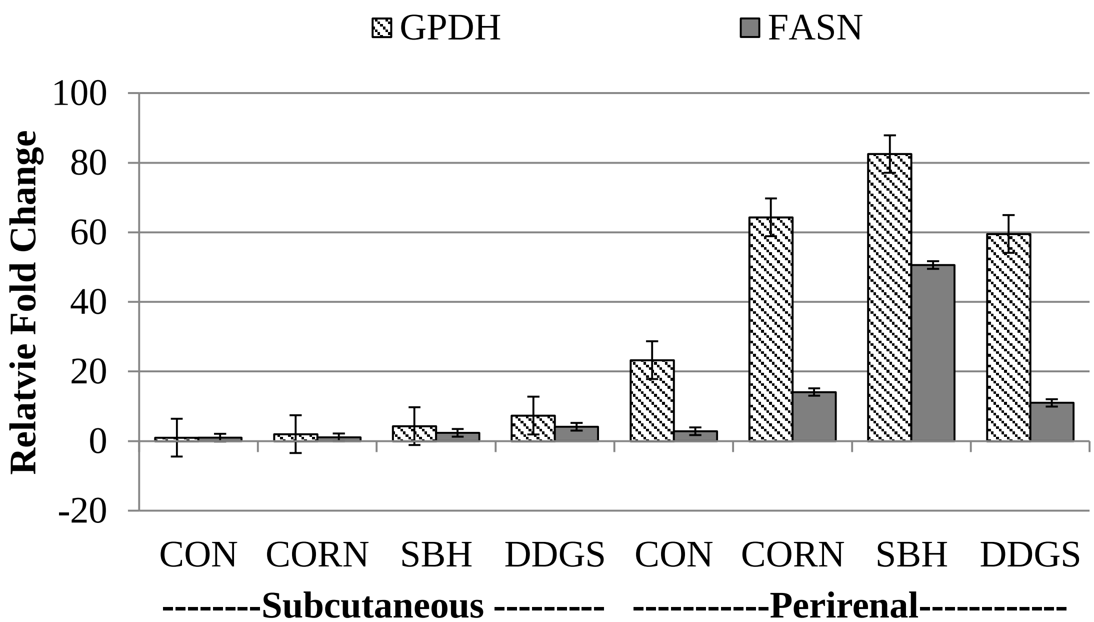

Figure 3. Effects of type and amount of supplement on mRNA expression of genes involved in triacylglycerol synthesis in subcutaneous and perirenal adipose tissue of growing steers. GPDH = glycerol-3-phosphate dehydrogenase (SEM = 10.84); FASN = fatty acid synthase (SEM = 2.17). CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

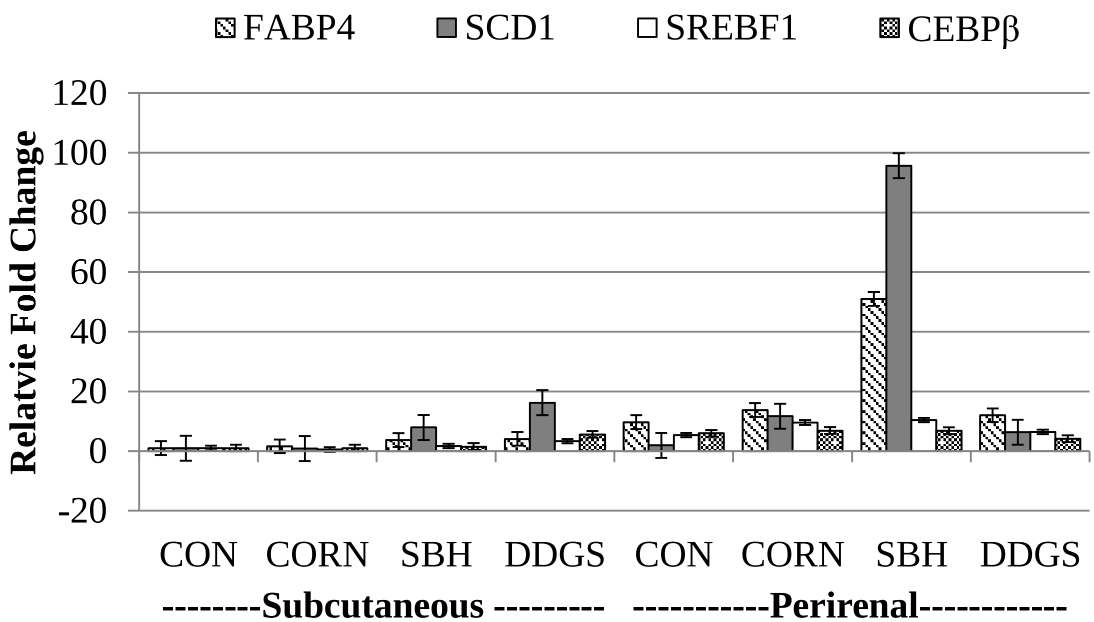

Figure 4. Effects of type and amount of supplement on mRNA expression of gene markers for early (SREBF1 and CEBPβ) and late (FABP4 SCD1) stages of adipogenesis in subcutaneous and perirenal adipose tissue of growing steers. FABP4 = adipocyte fatty acid binding protein 4 (SEM = 4.61); SCD1 = stearoyl-CoA desaturase 1 (Δ9-desaturase; SEM = 8.37); SREBF1 = sterol regulatory element binding factor 1 (SEM = 1.52); CEBPβ = CAATT/enhancer binding protein beta (SEM = 2.26). CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

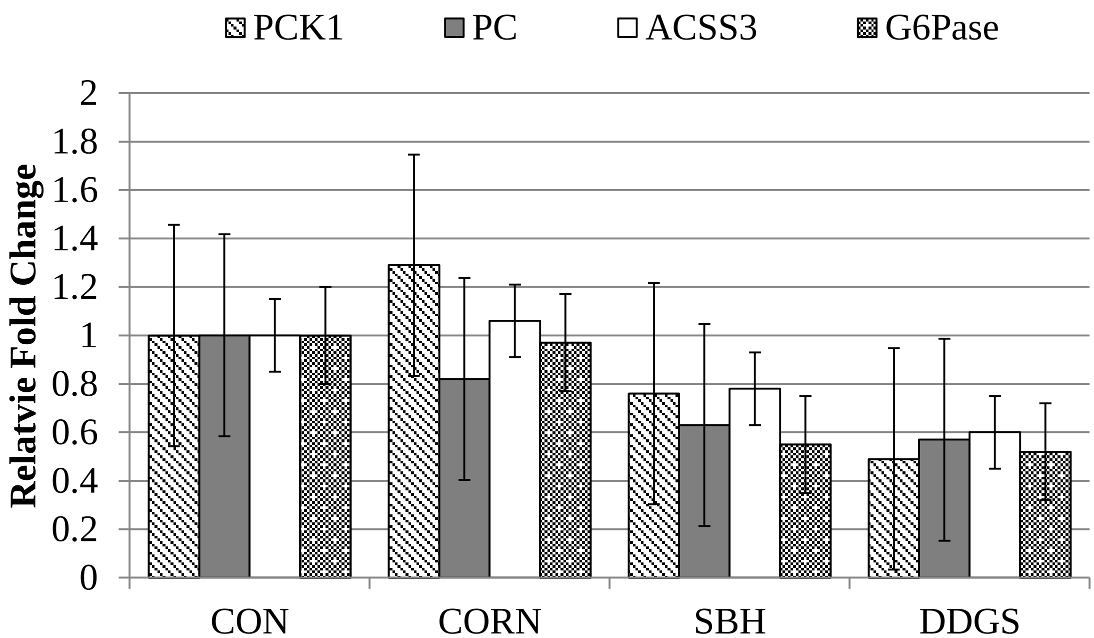

Figure 5. Effects of type and amount of supplement on mRNA expression of genes involved in gluconeogenesis in liver tissue of growing steers. PCK1 = phosphoenolpyruvate carboxykinase 1 (SEM = 0.45); PC = pyruvate carboxylase (SEM = 0.23); ACSS3 = acyl-CoA short chain synthetase 3 (SEM = 0.31); G6Pase = glucose-6-phosphatase (SEM = 0.33). CON = cottonseed meal supplement; CORN = corn supplement; SBH = soybean hull supplement; DDGS = dried distillers grains with solubles supplement.

CHAPTER IV

EFFECTS OF FORAGE ENERGY INTAKE AND SUPPLEMENTATION ON RATE OF GAIN AND FAT DEPOSITION IN GROWING BEEF CATTLE

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ABSTRACT

Two experiments were conducted to examine the effect of forage energy intake and type of fermentation 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 one of the following stocker production programs: (1) control, 1.02 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 40% CP supplement while grazing DNR (**CON**); (2) corn-based supplement fed at 1% BW while grazing 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, 3 steers per treatment were harvested following winter grazing (138 d). The remaining WP steers were transitioned into the finishing phase, whereas DNR steers were allowed to graze the same pastures for another 115 d prior to entering the feedyard. In Exp. 2, steers grazed 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 4 steers per treatment were selected for intermediate harvest prior to finishing. In both experiments, all steers were fed to a common 12th-rib fat of 1.27 cm. In Exp. 1, winter grazing ADG was 0.19, 0.52, 0.68, and 1.37 kg/d and in Exp. 2, winter/summer grazing ADG was 0.49, 0.63, 0.84, and 1.41 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 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. In Exp. 1, there were no differences in finishing performance among the treatments; however, in Exp. 2 CON steers had greater ($P < 0.01$) ADG and DMI compared with the other treatments, but there was no difference in G:F. At final harvest in Exp. 1, LGWP steers had greater ($P < 0.01$) 12th-rib fat 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 and tended ($P = 0.10$) to have higher marbling scores compared with the other treatments. When steers were fed to a common 12th-rib fat endpoint, there were no differences in carcass quality suggesting that changes in the partitioning among fat depots during the stocker phase may not be reflected following finishing.

Key words: dormant native range, energy supplementation, growing beef cattle, forage energy intake, marbling deposition, winter wheat pasture

INTRODUCTION

Smith and Crouse (1984) reported that intramuscular adipocytes preferentially utilize glucose as the primary substrate for fatty acid synthesis; whereas subcutaneous fat utilizes acetate. Lomas et al. (2009) observed that steers supplemented with sorghum grain during the grazing phase increased final marbling scores compared with non-supplemented steers. However, Chapter III reported that supplying steers with an energy supplement at 1% of BW while grazing dormant native range (**DNR**) improved ADG, but did not influence marbling scores at the end of grazing or at the end of finishing.

Marbling development has been considered as the last fat depot to mature in the growing beef animal (McPhee et al., 2008) and that pre-feedyard management practices can influence intramuscular fat deposition (Anderson and Gleghorn, 2007). Thousands of fall-weaned calves are wintered on DNR or winter wheat pasture (**WP**) each year in the Southern Great Plains. Cattle grazing WP have 70% lower acetate:propionate ratio compared to cattle grazing DNR which could influence substrate availability for gluconeogenesis (Choat et al., 2003). These two grazing programs result in differing rates of 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 prior to finishing (Sainz et al., 1995), but when steers are harvested at a similar 12th-rib fat thickness at the end of finishing, no difference in marbling scores were observed (Sainz et al., 1995; Hersom et al., 2004; Taylor et al., 2008; Loken et al., 2009). Therefore, we hypothesized that steers grazing WP would have increased fat deposition resulting in greater marbling scores at the end of grazing compared with steers grazing DNR resulting in differences in performance during finishing, but the DNR steers would have similar carcass quality when harvested at a similar 12th-rib fat. Therefore, the objective of this study was to examine the effect of forage energy intake and type of fermentation on fat deposition in stocker cattle grazing DNR or WP.

MATERIALS AND METHODS

Prior to the 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 separate experiments were conducted in consecutive years using either dormant native range pastures (**DNR**) or winter wheat pastures (**WP**). The Crosstimbers-Bluestem Stocker Research Range is located 11 km west of Stillwater, OK and consists of 130 ha of DNR that is divided into 4 separate pastures. The dominant forage grass species in DNR pastures were big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), indiangrass (*Sorghastrum nutans* [L.] Nash), and switchgrass (*Panicum virgatum* L.). The subdominant grass species, forbs, woody plant species, and other topographical descriptions are all described in detail by Chapter III. The Wheat Pasture Research 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.; variety = Endurance). The farm ground was divided into 4 separate pastures (8.74 to 9.67 ha) for fall/winter grazing. Cattle had ad libitum access to drinking water from seasonal streams and ponds, and improved water sources.

Steer Source and Adaptation

Experiment 1. Seventy-two fall-weaned Angus steers (258 ± 29 kg) from the Range Cow Research Center-South Range Unit near Stillwater, OK were used in the experiment. Steers were weaned October 2, 2008, transported approximately 10 km to the DNR research center, vaccinated with Bovi-Shield Gold 5® (Phizer Animal Health, Exton, PA), and allowed to graze DNR grass traps prior to initiation of the experiment. Steers were re-vaccinated on October 20 with Bovi-Shield Gold 5®, hip branded, and full-individual BW were measured. Steers were not implanted prior to weaning or during the grazing phase of the experiment. Following re-vaccination, steers were randomly sorted into one of two groups based upon BW. The steers that were selected for the DNR grazing program were transitioned to the dormant tallgrass pastures and were trained to enter individual feeding stalls two or three days per week by offering 0.57 kg/hd of a 40% CP supplement. The remaining steers that were selected for the WP grazing program were placed on a separate dormant tallgrass pasture until the initiation of the experiment and were group fed the same CP supplement that was offered to the DNR steers.

Experiment 2. Seventy-six fall-weaned Angus steers (258 ± 28 kg) from the Range Cow Research Center-South Range Unit near Stillwater, OK were used in the experiment. Steers were weaned October 12, 2009, transported approximately 40 km to the Marshall Wheat Pasture Research Unit near Marshall, OK, vaccinated with Bovi-Shield Gold 5® (Phizer Animal Health, Exton, PA), and allowed to graze cool-season grass traps prior to initiation of the experiment. Steers were re-vaccinated on November 6 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 prior to weaning or during the grazing phase of the experiment. On November 23, steers were held off water for 5 h, individually weighed, and sorted into one of two groups based upon previous BW. The steers that were selected for the DNR grazing program were transported 40 km to the DNR research center and placed onto the dormant tallgrass pastures and were trained to enter individual feeding stalls 2 or 3 d/wk by offering 0.57 kg/hd of a 40% CP supplement. The remaining steers that were selected for the WP grazing program remained at the Marshall

Wheat Pasture Research Unit on cool-season grass pastures until the initiation of the experiment. These steers were not fed any type of supplement prior to the initiation of the experiment.

Initial Harvest

Experiment 1and 2. For Experiments 1 and 2, on December 9, 2007 and December 1, 2008, respectively, 4 steers were randomly selected and harvested at the Oklahoma State University Food and Agricultural Products Center (**FAPC**) abattoir in Stillwater, OK for collection of initial carcass characteristics as described by Hersom et al. (2004). Carcass data (LM area, 12th-rib fat thickness, marbling score, and yield grade) were collected by trained personnel from Oklahoma State University. A different set of trained personnel were used for each experiment.

Treatment Allotment for Fall/Winter and Summer Grazing Phases

Experiment 1. On December 10, the remaining sixty-eight steers (276 ± 18 d of age) were stratified by BW and randomly allotted to one of 4 fall/winter grazing treatments at either the DNR or WP research centers. Within the DNR group, steers were assigned to one of the following production programs: (1) control, 1.02 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 40% CP cottonseed meal-based supplement to meet their degradable intake protein (**DIP**) requirement while grazing DNR (**CON**); (2) corn/soybean meal-based supplement fed at 1% BW while grazing DNR (**CORN**). The CON and CORN treatment groups were allowed to graze simultaneously together at a stocking rate of 0.55 steers/ha. Within the WP group, steers were assigned to one of the following production programs: (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 steers/ha) to achieve a high rate of BW gain (**HGWP**). At both research centers, steers were also equally stratified across treatments by known sire for selection of steers for intermediate harvests at the FAPC abattoir to minimize genetic differences among treatments. Following allotment, the WP steers were transported 9 km to the Wheat Pasture Research Center and were sorted and placed in their respective pastures for fall/winter grazing. Five-hour shrunk BW were collected every 2 wk throughout winter grazing to adjust CORN supplement consumption to 1% of BW and to adjust the stocking rate of LGWP steers to achieve a desired rate of BW gain. The rate of gain for the LGWP steers was determined based upon the rate of gain for the CORN steers. Supplements were offered individually 5 d/wk during the 138 d winter grazing phase and are presented in Table 1. Each day supplement was offered, the CORN treatment was sorted into one of 3 groups based upon BW (light, medium, and heavy weight groups) to ensure steers were consuming 1% of BW instead of offering supplement based on the average BW of the entire treatment. Any supplement refusals from the CORN treatment were weighed, recorded, and discarded. There were no feed refusals from the CON treatment. The WP treatments were offered free-choice access to a non-medicated mineral mix during fall/winter grazing. To adjust the rate of gain for the LGWP treatment, the grazing area was adjusted based on forage availability and previous rate of gain, and ranged from 4.98 to 5.79 ha. The HGWP treatment were allowed to graze one pasture (8.94 ha) for the first 40 d and then steers were rotated to an adjacent pasture (9.23 ha), which had not been previously grazed, for 37 d. For the final 61 d of winter grazing, the HGWP steers were moved back into their initial pasture to allow for maximum 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 performance for unknown reasons. Data for this steer was excluded from all data analysis; however, the steer was used in the calculation of stocking rate.

At the end of fall/winter grazing, ultrasound measurements of 12th-rib fat, LM area, and intramuscular fat were taken on the left side of each steer using an Aloka 500V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2-cm, 3.5-MHz linear transducer by a Ultrasound Guideline Council certified technician. The images were interpreted with Beef Image Analysis Pro Plus software (Designer Genes Technologies, LLC., Harrison, AR). Additionally at this time, 3 steers per treatment from the same sire were selected for the first intermediate harvest. Carcass characteristics were collected as previously described for the initial harvest. The remainder of the steers from the WP grazing program were transported 154 km to the USDA-ARS Grazinglands Research Laboratory in El Reno, OK for finishing. The remainder of the steers grazing DNR, were placed on a summer grazing program using the same native grass pastures as described for winter grazing, but no supplement was fed. On May 14, the DNR steers were dewormed 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 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 40% CP supplement 3 d/wk to meet their DIP requirement. The reason for supplementation at the end of summer grazing is due to the declining nutritive value of the forage (McMurphy et al., 2010). At the end of summer grazing, 3 steers from the CON and CORN treatments were randomly selected for a second intermediate harvest prior to finishing. Carcass characteristics were measured as previously described for the initial harvest. The remainder of the steers grazing summer native grass were transported 11 km to the Willard Sparks Beef Research Center in Stillwater, OK for finishing.

Ruminal VFA and Ammonia Measurements. An additional 8 ruminally cannulated steers (250 ± 14 kg; same age and source as experimental steers) were used to measure treatment effects on ruminal VFA and ammonia concentrations in Experiment 1. There were 6 collection periods during winter grazing that consisted of a 13 d adaptation period and 1 d of sample collection. After each collection period, cannulated steers were rotated between treatments within DNR (CON and CORN) or WP (LGWP and HGWP) grazing programs. However, after the second sampling period, one cannulated steer grazing DNR would not consume the CORN supplement and was permanently adapted to the CON supplement for the remainder of the trial. Another steer was randomly selected and permanently adapted to the CORN supplement. Rumen fluid samples were collected on each sampling day at 0700, 1100, and 1600 h for the DNR treatments and at 1100 and 1600 h for the WP treatments. Supplements were fed to the DNR steers at 0800 h, and the WP steers were removed from their respective pastures at 1030 and 1530 h following the morning and afternoon grazing bouts, respectively. Immediately after collection, 1000 mL of rumen fluid was strained through two layers of cheese cloth and pH was measured. After pH was measured, two 40 mL subsamples were strained through two additional layers of cheesecloth and collected into 50 mL conical tubes containing 2.0 mL of 6 *N* HCl. Samples were placed on ice and subsequently stored at -20°C until analyzed for ammonia N and VFA concentrations. Cannulated steers were included when calculating stocking rate.

Experiment 2. On December 4, the remaining seventy-two steers (265 ± 20 d of age) were stratified by BW and randomly allotted to one of 4 fall/winter grazing treatments at either the DNR or WP research centers, which was described previously in Experiment 1. Again, 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 treatment groups were stocked at the same rate as described in Experiment 1. The stocking rates for the WP grazing programs were 2.97 and 0.99 steers/ha for the LGWP and HGWP treatments, respectively. At this time the WP steers were transported 40 km to the Wheat Pasture Research Center, sorted, and placed in their respective pastures for fall/winter grazing. Five-hour shrunk BW measurements were measured as described in Experiment 1. Supplements that were fed to the DNR treatments were offered individually 5 d/wk for the first 130 d of the grazing phase and are presented in Table 1. Measurement of supplement refusals for the CON and CORN treatments and WP mineral supplementation is similar as previously described in Experiment 1. When each grazing program treatment reached an estimated HCW of 200 kg, steers were removed from the grazing phase and transitioned into the finishing phase. 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 (Experiment 1; Hersom et al., 2004). Hot carcass weight was used rather than shrunk BW to account for differences in gut fill and visceral organ mass. The number of days grazing for each treatment to reach this targeted weight was 74, 142, 180, and 262 d for the HGWP, LGWP, CORN, and CON treatments, respectively. At this time, steers were individually weighed, ultrasound measurements of 12th-rib fat, LM area, and intramuscular fat were taken on the left side of the steer as previously described, and 4 steers from the same sire were selected for harvest at the FAPC abattoir as previously described for the initial harvest.

The LGWP steers were allowed to graze a pasture that was 8.94 ha. Eleven extra steers (similar type and size) were used as additional grazers when necessary depending upon forage availability and previous rate of gain to adjust the rate of gain of the LGWP steers to the desired level. The HGWP steers were allowed to graze one pasture (8.94 ha) for the first 31 d and then moved to an adjacent pasture (9.23 ha), which had not been previously grazed, for 16 d. For the final 27 d of winter grazing, the HGWP steers were moved back into their initial pasture to allow for maximum forage availability throughout grazing. Steers grazing DNR were supplemented until April 13 (130 d) at which time, steers were dewormed with Cydectin® and placed onto a summer grazing program using the same native grass pastures as described for winter grazing. Following the removal of the CORN steers from the grazing phase and due to a severe infestation of ticks during summer grazing, the CON treatment was dewormed with Ivomec® Plus injection (1% w/v ivermectin and 10% w/v clorsulon in a sterile solution; Merial LTD., Duluth, GA) and tagged with a Corathon™ ear tag with FyberTek™ (Bayer Healthcare LL, Animal Health Division, Shawnee Mission, KS) on June 10 and dewormed with StandGuard® (Elanco Animal Health, Indianapolis, IN) on July 23. On d 98 (July 20) of summer grazing the CON steers were group fed 0.5 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 40% CP supplement 3 d/wk to meet their DIP requirement as previously described in Experiment 1.

Finishing Phase

Experiment 1. Steers on wheat pasture were allotted to one of 3 pens per treatment (4 to 5 steers/pen) at the USDA-ARS Grazinglands Research Laboratory in El Reno, OK and were fed twice daily. Steers were implanted with Revalor®-S (24 mg of estradiol and 120 mg trenbolone acetate; Intervet Inc., Millsboro, DE), 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 location is presented in Table 2. The HGWP and LGWP steers were fed 83 and 138 d, respectively, to reach a visually predicted common 12th-rib fat endpoint of 1.27 cm. All but 3 steers from each treatment were harvested at a commercial abattoir (Creekstone Farms, Arkansas City, KS) and carcass data (LM area, marbling score, 12th-rib fat thickness, and yield grade) were collected by trained Oklahoma State University personnel. The remaining 3 steers from each treatment were harvested at the same time at the FAPC abattoir where carcass measurements were collected as previously described for the initial harvest steers.

Native range treatments were allotted to one of 3 pens per treatment (3 to 4 steers/pen) at the Willard Sparks Beef Research Center in Stillwater, OK and were fed twice daily. Steers were implanted with Revalor®-S, vaccinated with Titanium®-5, and given a pour-on dewormer (Cydectin® **[**5 mg moxidectin/mL]; Fort Dodge Animal Health, Fort Dodge, IA). 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 Stillwater feedyard is presented in Table 2. Steers were fed 112 d to achieve a visually predicted 1.27 cm of 12th-rib fat thickness prior to harvest at a commercial abattoir (Creekstone Farms, Arkansas City, KS) and carcass data (LM area, marbling score, 12th-rib fat thickness, and yield grade) were collected by trained Oklahoma State University personnel. No steers were harvested at the FAPC abattoir from the CON and CORN treatments. The same personnel from Oklahoma State University collected all of the carcass characteristics during each harvest date and at both abattoirs throughout the experiment to eliminate any variation in carcass grading.

Experiment 2. Following grazing, each treatment was randomly allotted to one of 3 pens per treatment (4 to 5 steers/pen) at the Willard Sparks Beef Research Center and were fed twice daily. Steers were implanted with Revalor®-S (24 mg of estradiol and 120 mg trenbolone acetate; Intervet Inc., Millsboro, DE), vaccinated with Vision® 7 with SPUR® (Intervet Inc. Merck Animal Health, Summit, NJ) and Bovi-Shield Gold 5®, and given an oral dewormer (Panacur® [fenbendazole, 100 mg/mL]; Intervet Inc. Merck Animal Health, Summit, NJ). Individual full BW were measured every 21 d during finishing and a pencil shrink of 4% was applied to each BW. The same finishing diet was fed to all 4 treatments and is presented in Table 2. The HGWP, LGWP, CORN, and CON steers were fed for 131, 128, 146, and 112 d, respectively, to reach a predicted common fat endpoint of 1.27 cm of rib fat thickness. Approximately one month prior to harvest, steers were scanned via ultrasound for 12th-rib fat to determine a common fat endpoint and harvest date. All but 4 steers from each treatment were harvested at a commercial abattoir (Creekstone Farms, Arkansas City, KS) and carcass data (LM area, marbling score, 12th-rib fat thickness, and yield grade) were collected by trained Creekstone personnel using an E + V Vision Grading camera (VBG2000, E + V

Technology; Oranienbury, Germany). The remaining 4 steers from each treatment were harvested at the same time as their counterparts at the FAPC abattoir where carcass measurements were collected as previously described by the initial harvest steers. The same trained personnel from Oklahoma State University collected carcass characteristics at each of the harvest dates at the FAPC abattoir throughout the experiment to eliminate any variation in carcass grading.

Forage and Supplement Collection and Laboratory Analysis

For each experiment, supplements 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. Dry matter, crude protein, NDF, ADF, calculated net energy measurements, and TDN for the supplements and finishing diets were all analyzed by a commercial laboratory (Basic Wet Chemistry Package Analysis; Dairy One, Ithaca, NY). Seven quality and seven forage mass wheat pasture samples were collected within each pasture every other week throughout winter grazing. The forage quality samples were dried(oven drying at 115°C), ground through a 2 mm screen in a Wiley mill, composited by pasture within clipping date, and were analyzed in-house for crude protein (% N x 6.25; Truspec-CN LECO Corporation, St. Joseph, MI), and NDF-ADF sequentially (Ankom Tech Corporation, Fairport, NY). The forage mass samples were collected using a 0.19-m^2 quadrant by hand-clipping forage to ground level. The samples were dried and extrapolated to calculate kg of DM on a per-hectare basis in each pasture as described by Fieser et al. (2007). Forage quality samples were collected during winter and summer grazing phases at the DNR pastures at three time points across each grazing phase. For each collection, the samples were ground through a 2 mm screen in a Wiley mill and were analyzed in-house as described previously for WP.

Amount of starch in the supplements was analyzed using the assay adapted from Galyean (2010) and using the modifications described by Chapter III. Degradable intake protein of the supplements was analyzed using a *Streptomyces griseus* (Type XIV Bacterial; Sigma-Aldrich, Co., St. Louis, MO) protease assay adapted from Krishnamoorthy et al. (1983) and using the modifications described by Chapter III to determine DIP as a percent of CP in each sample.

For Experiment 1, ruminal ammonia N and VFA concentrations from the cannulated steers were analyzed using procedures described by Broderick and Kang (1980) and Goetsch and Galyean (1983), respectively.

Statistical Analysis

Experiment 1. Individual steer ADG during winter grazing was computed by linear regression (Proc GLM; SAS Inst. Inc., Cary, NC). Grazing performance and intermediate carcass characteristics were analyzed as a completely randomized design using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC) that included treatment as a fixed effect with steer as the experimental unit. The finishing performance and final carcass data were analyzed using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC) with a repeated statement and the group option to account for heterogeneous variance among treatments due to different feeding locations. Heterogeneity of variance for abattoir location was tested using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC) and was determined not significant ($P > 0.05$) for final carcass characteristics. Pen and steer were the experimental units for finishing performance and final carcass characteristics, respectively. The average initial BW for winter grazing was used as a covariate when analyzing the winter performance data and was removed from the model when not significant (*P* > 0.05). 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. Quality grade distribution was analyzed using a general linear model (Proc GLIMMIX; SAS Inst. Inc., Cary, NC) with a binomial distribution. Ammonia and VFA data were analyzed using a general linear model with repeated measures analysis (Proc MIXED; SAS Inst. Inc., Cary, NC) that included treatment, sampling period, and sampling time.

Experiment 2. Due to the biphasic growth pattern of steers grazing DNR, ADG was calculated as final BW minus initial BW divided by the number of days grazing for all treatments. Grazing performance and intermediate carcass data were analyzed as a completely randomized design using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC) that included treatment as a fixed effect with steer as the experimental unit. Finishing performance data were analyzed as a completely randomized design using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC). Final carcass data were analyzed using a general linear model (Proc MIXED; SAS Inst. Inc., Cary, NC) with repeated measures accounting for heterogeneous variances among treatments due to different abattoir locations and grading mechanisms (camera vs. subjective grader). Pen and steer were the experimental units for finishing performance and final carcass data, respectively. The average initial BW was used as a covariate in the grazing phase performance models as described in Experiment 1. Final carcass characteristics were adjusted to a common 12th-rib fat thickness and quality grade distribution were analyzed as described in Experiment 1.

Meta-Analysis. A meta-analysis was conducted using grazing performance data and intermediate carcass characteristics from Hersom et al. (2004), Experiment 1, and Experiment 2. Two separate data sets were compiled using intermediate carcass data at a similar age of the animals or at a similar BW. The similar age dataset (N = 36) consisted of individual steer data from the initial harvest of trials 1 and 2 from Hersom et al. (2004) and the first intermediate harvest of Experiment 1. The similar BW dataset (N = 28) consisted of individual steer data from HGWP and LGWP steers at the first intermediate harvest of Experiment 1, CON and CORN steers at the second intermediate harvest of Experiment 1, and the intermediate harvest of Experiment 2. Analysis of covariance was conducted using a fixed effect model (Proc GLM; SAS Inst. Inc., Cary, NC) to test the hypothesis of equal slopes of marbling score and 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; SAS Inst. Inc., Cary, NC) that included experiment and experiment by ADG and ADG^2 or HCW and HCW^2 interaction 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 variance component option was used for the var-(co)var matrix structure after evaluating the unstructured and compound symmetry options with experiment as the subject. Adjusted data are presented to remove the variation accounted for by the random effect terms and show the fixed effect regression line.

RESULTS

Grazing Phase

Forage Analysis. Nutrient composition of the forage for each grazing program is presented in Table 3. Wheat pasture averaged 24.23 and 27.14% CP and 47.35 and 45.64% NDF for Experiments 1 and 2, respectively. In Experiment 1, the wheat pasture standing crop averaged 95 ± 45 and 324 ± 81 kg of DM/100 kg of BW for the LGWP and HGWP treatments, respectively. In Experiment 2, the wheat pasture standing crop averaged 84 ± 40 and 334 ± 28 kg of DM/100 kg of BW for the LGWP and HGWP treatments, respectively. Dormant winter native pastures averaged 4.73 and 5.05% CP and 80.23 and 77.64% NDF for Experiments 1 and 2, respectively. Summer native pastures averaged 10.90 and 8.94% CP and 70.44 and 68.78% NDF for Experiments 1 and 2, respectively. The nutrient values for WP are similar to nutritive values reported by Fieser et al. (2007) and Sharman et al. (2012). The nutrient composition of the native range pastures is also similar to that described by Bodine and Purvis (2003).

Grazing Performance. For Experiments 1 and 2, the change in shrunk live BW of each treatment during grazing is shown in Figures 1A and 1B, respectively. In Experiment 1, steers gained BW relatively consistently during winter grazing with the exception of the LGWP steers, which gained weight faster early in the grazing period than later. Following summer grazing, the CON and CORN steers gained weight consistently, but the BW gain appeared to slow at the end of summer grazing. In Experiment 2, the HGWP and CORN steers gained BW consistently throughout the grazing phase, whereas the LGWP steers gained BW faster early 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 higher quality of forage.

In Experiment 1, final BW and ADG during winter grazing were different ($P < 0.01$) for all treatments (Table 4). In Experiment 2, ADG during grazing was similar to Experiment 1 with a difference ($P < 0.01$) among all treatments. The CON and CORN steers had greater ADG in Experiment 2 than in Experiment 1 due to combining winter and summer grazing phases. Average daily gains during winter grazing for Experiment 2 was 0.27 and 0.58 kg/d and summer ADG was 0.76 and 0.78 kg/d for the CON and CORN steers, respectively. Summer ADG in Experiment 1 for the CON and CORN treatments was 0.67 and 0.61 kg/d, respectively. Final BW at the end of grazing for Experiment 2 was relatively similar due to growing each treatment to a similar HCW prior to finishing. However, the CON steers had greater ($P < 0.01$) final BW compared with HGWP and the CORN with the LGWP treatment being intermediate.

Ruminal pH tended ($P = 0.09$) to be higher for the CON steers compared with the HGWP steers, with the CORN and LGWP steers being intermediate. The HGWP steers had the greatest ($P < 0.01$) total VFA concentration compared with the other three treatments (Table 5). The HGWP steers had the greatest ($P < 0.01$) rumen propionate concentration, lowest ($P < 0.01$) acetate concentration, and a lower ($P < 0.01$) acetate:propionate ratio compared with the CON steers and the CORN and LGWP steers were intermediate. The WP treatments also had greater ($P < 0.01$) ruminal ammonia concentrations compared with the DNR treatments.

Intermediate Carcass Characteristics. The initial and intermediate carcass characteristics are presented in Tables 6 and 7. In Experiment 1, the WP treatments had higher LM area, 12th-rib fat, and marbling score compared to the initial harvest. In Experiment 2, the WP treatments had higher LM area and marbling score compared with the initial harvest steers; however, due to the initial harvest steers having more 12th-rib fat cover, the LGWP steers had relatively similar 12th-rib fat at the end of grazing compared with the initial harvest. In both experiments, the DNR treatments had relatively similar LM area, 12th-rib fat, and marbling scores compared with the initial harvest treatments suggesting that when these steers were restricted in growth, they only maintained body composition.

In Experiment 1, HGWP steers had heavier HCW and greater dressing percent ($P < 0.05$) compared to steers grazing DNR at first intermediate harvest; LGWP steers were intermediate (Table 7). The HGWP, LGWP, and CORN steers had similar LM area, but larger ($P < 0.01$) LM area compared to 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 treatments being intermediate (Table 8). 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 Experiment 2, the LGWP steers gained a significant amount of BW the final 2-weeks of grazing due to increase forage availability and conflicts with harvest scheduling dates, such that the LGWP steers tended ($P = 0.09$) to have heavier HCW compared with the steers from the other three treatments even though steers were targeted to be harvested at a similar HCW of 200 kg. When harvested at a similar HCW, the WP treatments had greater ($P < 0.01$) dressing percentage compared with the DNR treatments, but there was 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. The reason for the difference 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 doesn't explain the smaller LM area of the DNR steers.

In Experiment 1, 12th-rib fat and KPH were greater ($P < 0.01$) for HGWP than the other treatments at both intermediate harvests and the CON, CORN, and LGWP were all similar at both harvest times (Table 7). Marbling score was greater ($P < 0.01$) for HGWP than LGWP, and LGWP was greater than both the CORN and CON steers at first intermediate harvest. Additionally, the ultrasound measurements for 12th-rib fat and intramuscular fat showed that the HGWP steers had greater ($P < 0.01$) fat deposition compared with the other treatments (Table 8). At the second intermediate harvest when the DNR steers had reached a similar HCW compared with the WP steers, the CORN steers did have similar marbling scores compared with the LGWP steers. In Experiment 2, HGWP steers had greater ($P < 0.02$) 12th-rib fat and ultrasound 12th-rib fat measurements compared with the CORN steers with the CON and LGWP steers being intermediate. The HGWP steers had greater ($P < 0.01$) KPH fat but lower ($P < 0.01$) marbling scores compared with the LGWP steers. The WP treatments did have greater KPH and marbling scores when compared with the DNR treatments. Similarly, the HGWP steers had a higher ($P < 0.01$) percentage of ultrasound intramuscular fat compared with the other three treatments.

Finishing Phase

Finishing Performance. Feedlot performance data are presented in Table 9. Previous grazing program did not influence ADG, DMI, or G:F when steers were fed to a common 12th-rib fat endpoint in Experiment 1. However, in Experiment 2, the CON steers had greater ($P < 0.01$) ADG and DMI compared with the other treatments. There was no difference ($P > 0.39$) in G:F in Experiment 2. The reason for the performance difference in Experiment 2 could be due to the seasonal variations of when each treatment was finished. The CON steers were finished during the early fall and winter months, whereas the CORN, LGWP, and HGWP steers all were exposed to parts of the extreme heat and humidity that is seen in Stillwater, OK during the summer months. In both experiments, the CON steers had numerically greater G:F suggesting compensatory gain effect of previously restricted steers.

Final Carcass Characteristics. There were no differences in HCW or dressing percentage at final harvest for Experiment 1 (Table 10). Unexpectedly, the LGWP steers had thicker 12th-rib fat, lower KPH, and smaller LM area than the other treatments ($P < 0.01$), which increased ($P < 0.01$) yield grade. There were no differences in final marbling scores ($P = 0.99$) or distribution of carcasses among the USDA quality grades ($P > 0.36$). Adjusting carcass characteristics for differences in 12th-rib fat had little effect on LM area or marbling score among treatments; however, yield grade was no longer different among treatments ($P > 0.07$). In Experiment 2, there was no difference in HCW; however, the CON steers had a lower ($P < 0.01$) dressing percentage and 12th-rib fat compared with the other treatments (Table 11). This difference could be due to the fact that the CON steers were harvested earlier than expected due to conflicts with scheduling. Unexpectedly, the HGWP steers had smaller ($P < 0.01$) LM area compared with the other three treatments, which resulted in a greater yield grade for the HGWP steers. Even though the CON steers were harvested earlier than expected, they tended ($P = 0.10$) to have the highest marbling scores compared with the other treatments. However, there was no difference ($P > 0.44$) in distribution of carcasses among the USDA quality grades. When adjusting LM area, yield grade, and marbling score for differences in 12th-rib fat, differences among treatments were similar to unadjusted values.

Meta-Analysis. Results of the meta-analysis are presented in Figure 2. 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 (quadratically) with increasing ADG and HCW. Interestingly, the coefficient of determination was slightly larger between marbling score and HCW than marbling score and ADG ($R^2 = 0.783$ vs. 0.723), whereas the coefficient of determination was slightly larger between 12th-rib fat thickness and ADG than 12th-rib fat thickness and HCW ($R^2 = 0.856$ vs. 0.737). However, when steers were harvested at similar age, both ADG and HCW differ among treatments making it difficult to ascertain which factor is responsible for differences in marbling score and 12th-rib fat thickness. When steers were harvested at similar BW during the stocker phase, both marbling score and 12th-rib fat thickness were linearly related with ADG and HCW. Although, the relationship between marbling score and ADG changed having a lesser slope compared with the relationship at a similar age, whereas, the relationship between marbling score and HCW was unchanged having a very similar slope compared with the relationship at a similar age. In contrast, the relationship of 12th-rib fat thickness with both ADG and HCW changed considerably having only a significant linear function. These data suggest that marbling score is more influenced by HCW than ADG, whereas 12th-rib fat thickness is influenced by both ADG and HCW.

DISCUSSION

Performance

In Experiments 1 and 2, rate of gain during the stocker phase was different among the four stocker production programs. Similarly to the current experiments, Hersom et al. (2004) reported rates of gains of 1.31, 0.54, and 0.16 kg/d in year 1, and 1.10, 0.68, and 0.15 kg/d in year 2 for high-rate of gain on wheat pasture, low-rate of gain on wheat pasture, and steers fed a protein supplement while grazing dormant native range, respectively. Phillips et al. (1991 and 2001) reported that steers grazing winter wheat pasture stocked at a rate of 1.0 to 2.5 steers/ha or grazing dormant native range plus CP supplementation resulted in similar rates of gain as the LGWP and CON treatments in the current experiments. Additionally, Choat et al. (2003) observed that steers grazing winter wheat pasture gained 1.03 kg/d compared with 0.29 kg/d for steers grazing dormant native range plus supplementation with a 38% CP supplement. Chapter III reported that from the same research station using similar treatments as the CON and CORN and showed similar rates of gain of 0.20 and 0.53 kg/d, respectively. Bodine and Purvis (2003) reported steers supplemented with a corn-based energy supplement with adequate DIP had increased ADG while grazing low quality forage compared with steers provided a soybean meal-based supplement or a corn-based supplement with no additional DIP. The supplement conversions (kg of as-fed supplement per kg of increased BW gain) of the CORN when compared with the CON were 8.30 and 7.57 for Experiment 1 and 2, respectively, which is similar to that reported by Chapter III of 8.09. Bodine and Purvis (2003) concluded that a corn supplement including adequate DIP can be fed to cattle grazing dormant native range without having detrimental impacts on forage intake; however, the current experiments and Chapter III indicate that the supplement conversions of 7.5 to 8.3 may not be economical with the current grain prices.

In the current experiments, there were little differences in finishing performance among the treatments. In Experiment 2, the CON steers had higher ADG and DMI compared with the WP treatments; however, in both experiments, the CON steers had a numerically higher G:F suggesting that compensatory gain was seen during finishing. Hersom et al. (2004) also reported no difference in feedlot performance among the winter grazing treatments implemented prior to finishing. White et al. (1987) showed no difference in finishing performance among steers previously grazing winter wheat pasture gaining 0.71 kg/d or restricted to one of three planes of nutrition to gain -0.23, -0.07, or 0.16 kg/d, respectively during the 98 d wintering phase. Similarly, Lewis et al. (1990) reported that steers supplemented with various levels of ruminal escape protein and alfalfa hay during winter grazing on crop residues to produce three different planes of nutrition (0.28, 0.38, 0.50 kg/d, respectively) had no effect on summer grazing or finishing performance. In contrast, Choat et al. (2003) observed that steers previously grazing dormant native range with a low rate of 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 lower DMI, ADG, and G:F during finishing compared with steers limit-fed a high-concentrate diet or fed an alfalfa hay-based diet during the growing phase. Similarly, Ridenour et al. (1982) showed that steers grown on winter wheat pasture or in a dry-lot setting with a 50% concentrate diet to 364 kg of BW prior to finishing had lower ADG during finishing compared with steers grown to 273 kg of BW prior to finishing. Therefore, the results are inconsistent on whether rate of gain during the previous stocker phase affects finishing performance indicating that further research is needed.

Carcass Characteristics

In Experiment 1 at the first intermediate harvest, the HGWP steers had heavier HCW compared with the DNR steers when harvested at a similar age; however, at the second intermediate harvest the CORN steers had similar HCW when grown additional days prior to finishing. In Experiment 2, the treatments grazed their respective treatments until reaching the targeted HCW of 200 kg, so there were no differences at intermediate harvest. For both experiments at intermediate harvest, the WP treatments had higher dressing percentages compared with the DNR treatments, with the HGWP steers having a larger LM area prior to entry into finishing, which suggests that there are some gut fill differences between these two production programs. At final harvest, there were no differences in HCW for both experiments. There were no differences in final dressing percentage in Experiment 1, but the CON steers had a lower dressing percentage compared with the other treatments in Experiment 2. Additionally, in Experiment 1 and 2, the LGWP steers and the HGWP steers had smaller LM area compared with the other treatments, respectively. It is unknown why there are these differences in dressing percentage and LM area at final harvest. Hersom et al. (2004) reported that when steers are harvested at the same age at the end of winter grazing, high-rate of gain on wheat pasture had greater HCW, dressing percent and LM area compared with low-rate of gain steers grazing wheat pasture and control steers supplemented while grazing dormant native range. In contrast, McCurdy et al. (2010) reported that when steers were harvested prior to finishing and following a growing program of similar rates of gain from feeding a silage based diet, programmed fed a high-concentrate diet, or steers grazing wheat pasture saw no difference in dressing percentage or LM area; however, the silage fed steers did have lower HCW compared with the other growing treatments. Additionally, Sainz et al. (1995) observed no differences in HCW or LM area following a growing program of providing a concentrate diet at ad libitum, or limit feeding the concentrate diet, or feeding a forage-based diet ad libitum. These researchers harvested at the same age point just prior to entering the finishing phase. At final harvest, Hersom et al. (2004) reported no differences in HCW, dressing percentage, of LM area in year 2, but in year 1 the steers grazing wheat pasture at a low-rate of gain had lower HCW compared with the steers grazing wheat pasture at a high-rate of gain and steers supplemented while grazing dormant native range, even though there were no differences in dressing percentage or LM area. McCurdy et al. (2010) showed no difference in HCW, dressing percentage, or LM area among the previously used growing treatments initiated prior to the finishing phase harvest. 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) showed steers that were fed a forage-based diet during the growing phase had lower 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 even when the treatments were harvested at similar carcass size or age of the animal. The researchers did suggest that LM area develops in a curvilinear manner as the animals matured showing that age of the animal and carcass weight are major factors. Therefore, the differences in dressing percentage and LM area may be attributable to the differences in HCW rather than differences in growth rates of the treatments during the growing phase.

The intent of the current experiments was to evaluate the amount of fat that was deposited and the partitioning among the fat depots during the stocker phase when compared at a similar BW and at a similar age of steers, and the influence on final carcass characteristics. The HGWP steers had the greatest 12th-rib fat, KPH, and marbling scores at the intermediate harvest in Experiment 1; however, in Experiment 2 the HGWP steers had the greatest 12th-rib fat and KPH, but the LGWP steers had the highest marbling score when harvested at a similar HCW. In year 1 Hersom et al. (2004), using treatments similar to those in the current experiments, reported that when harvested at a similar age following winter grazing, steers grazing wheat pasture for a high-rate of gain had greater 12th-rib fat and KPH at entry into the finishing phase compared with steers grazing wheat pasture for a low-rate of gain and steers supplemented with a protein supplement while grazing dormant native range, which were similar. However, in year 2, the low-gain wheat pasture steers had similar 12th-rib fat but higher KPH compared with the steers grazing dormant native range. Furthermore, for both years, the high-gain wheat pasture steers had greater marbling scores than low-gain wheat pasture steers, and the low-gain wheat pasture steers had greater marbling scores than the dormant native range steers. Additionally, Sainz et al. (1995) observed that steers consuming a concentrate diet ad libitum had greater 12th-rib fat, KPH, and marbling score compared with steers limit feeding the concentrate diet or fed a forage-based diet ad libitum. The concentrate limit fed steers had higher 12^{th} fat, KPH, and marbling scores when compared with the steers fed a forage-based diet. In contrast, McCurdy et al. (2010) reported that when steers were harvested prior to finishing following a growing program at similar rates of gain by feeding a silage based diet, programmed fed a high-concentrate diet, or grazing wheat pasture, no differences in 12th-rib fat, KPH, or marbling score were observed. The current experiments showed that the higher rates of gain deposits more 12th-rib fat, KPH, and marbling, which suggests that total energy intake has a huge role in the amount of fat deposition during the growing phase.

The previous studies (Sainz et al., 1995; Hersom et al., 2004; McCurdy et al., 2010) have reported that nutrition and management practices prior to finishing had minimal effects on final marbling score when harvested at similar 12th-rib fat thickness. Similarly, White et al. (1987) reported that steers grazing winter wheat pasture had lower 12th-rib fat compared with steers that were nutritionally restricted during winter grazing, but no differences in marbling score were seen between the production programs. Ridenour et al. (1982) observed no difference in carcass characteristics when steers were grown to either 273 or 364 kg prior to finishing on a 50% concentrate diet in a confinement setting or while grazing wheat pasture. Similarly, Lewis et al. (1990) reported no differences in carcass characteristics following differing rates of gain during winter grazing on crop residues. Henrickson et al. (1965) and Guenther et al. (1965)

showed that marbling scores increased with an increase in energy intake when steers were grown on a high or moderate plane of nutrition when harvested at a similar final BW. The researchers also concluded that 12th-rib fat may be smaller when previous plane of nutrition is restricted; however, Guenther et al. (1965) also reported that as the feeding period is extended, the rate 12th-rib fat is deposited is increased. Similarly, Choat et al. (2003) observed that steers previously grazing wheat pasture had greater final marbling scores compared with steers previously grazing dormant native range. Data has shown that when steers are harvested at a similar 12th-rib fat, 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.

Smith and Crouse (1984) have demonstrated that intramuscular adipocytes preferentially utilize glucose as the substrate for fatty acid synthesis, but the researchers concluded that marbling development is not as prone to changes in nutritional management or the age of the animal as compared with 12th-rib fat, which is more likely to change due to these factors. Therefore an increase in propionate concentrations can stimulate gluconeogenesis and result in higher glucose concentrations that could influence marbling development prior to finishing. In Experiment 1, the HGWP steers had the highest propionate concentration and the highest intermediate harvest marbling scores compared with the other treatments, which suggests that there may be an increase in gluconeogenesis. In contrast, the LGWP steers had the greatest marbling scores when harvested at similar HCW following the grazing phase in Experiment 2. However, the HGWP steers (for both Experiments) had greatest 12th-rib fat indicating that even though the HGWP steers had the lowest acetate:propionate ratio, subcutaneous fat deposition increased dramatically. Several studies have showed conflicting results when attempting to alter VFA patterns to increase marbling development. The current experiments and Chapter III reported no differences in intermediate and final marbling scores when supplementing CORN at 1% of BW compared with the CON. Bumpus (2006) observed that steers fed a corn-based supplement had similar ultrasound intramuscular fat compared to steers fed a soyhull-based supplement. McCurdy et al. (2010) reported that steers limit-fed a corn-based diet had similar marbling scores compared to those fed a corn-silage based diet or steers that were grazing WP. In contrast, Faulkner et al. (1994) reported that suckling calves provided a corn-based creep feed (0.93% of mean feeding BW) had increased marbling scores at the end of finishing compared to calves provided a soyhull-based creep feed suggesting that the increased glucose supply from corn supplementation improved marbling deposition. Sainz et al. (1995) reported that steers limit-fed a corn-based diet had greater marbling scores than those fed an alfalfa hay-based diet. However, in these studies, any improvement in marbling score coincided with an increase in 12th-rib fat indicating that any change in the VFA pattern did not improve intramuscular fat deposition at a greater rate compared with subcutaneous fat deposition. In the current study, LGWP had greater marbling scores but similar 12th-rib fat compared to CORN even though propionate concentrations were similar. These data in combination with the results from Experiment 1 that showed the LGWP had similar rumen propionate and acetate concentrations, acetate:propionate ratio, and 12th-rib fat, but greater marbling score compared with the CORN steers at intermediate harvest, suggests that by supplying additional starch in the diet prior to finishing may not influence marbling development. Moreover, the current data may suggest that overall energy intake has more of a role in marbling deposition.

In addition to type of fermentation, differences in intermediate marbling score and 12th-rib fat among treatments could be due to differences in HCW or rate of gain. The current Experiments and raw data from Hersom et al. (2004) were combined to evaluate the relationship of marbling score and 12th-rib fat with ADG during the grazing phase and intermediate HCW. These data demonstrated that as ADG increases during grazing marbling score increases in a linear manner (R^2 = 0.723), whereas 12th-rib fat increases in a curvilinear manner (R^2 = 0.856). These data indicate that at greater rates of gain, 12th-rib fat increases at a greater rate than marbling deposition. These data also indicate that as intermediate HCW increases during the grazing phase marbling scores increase in a linear manner (R^2 = 0.783), whereas 12th-rib fat increases in a curvilinear manner (R^2 = 0.737). Similarly, Bruns et al. (2004) reported that marbling scores increased linearly and 12th-rib fat increased curve-linearly as HCW increased in steers fed in a confinement setting during finishing. Furthermore, Guenther et al. (1965) showed that differences in marbling scores between steers fed at different planes of nutrition were greater when harvested at a similar age than when harvested at similar HCW; similar results were observed for 12th-rib fat. In our meta-analysis, the relationship between rate of gain and marbling score (R^2 = 0.271) or 12th-rib fat (R^2 = 0.434) was not as good when steers were harvested at similar BW. Henrickson et al. (1965) reported that steers fed on a high plane of nutrition had greater marbling scores when harvested at a similar HCW compared to steers fed a lower plane of nutrition. Also, 12th-rib fat tended to decrease when plane of nutrition decreased during finishing (Henrickson et al., 1965). Moreover, Smith and Crouse (1984) observed that cattle fed a more energy dense diet had greater *in vitro* fatty acid synthesis rates in subcutaneous fat, but not in intramuscular fat compared with cattle fed a lower energy dense diet. These data suggest that energy density of the diet and rate of gain has a stronger influence on 12th-rib fat than marbling score. However, growing programs that affect growth rate have little influence on final marbling score when cattle are fed a high-energy diet during finishing and harvested at a similar 12th-rib fat.

In conclusion, body fat content when entering the feedyard may not negatively affect feedlot performance. In addition, changes in partitioning among fat depots during the stocker phase may not be reflected following finishing when cattle are harvested at a similar 12th-rib fat endpoint. Rate of gain and energy intake have a greater effect on subcutaneous fat deposition than intramuscular fat, whereas intramuscular fat deposition may be more related to the animal's body size.

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

Item	Treatment[1]			
	CON		CORN	
Ingredient composition, % As-fed				
Cottonseed meal	80.50		-	
Rolled corn	-		67.00	
Soybean meal, 47.5% CP	11.85		32.00	
Wheat middlings	7.65		-	
Limestone	-		1.00	
Chemical composition[2], % DM	Exp. 1	Exp. 2	Exp. 1	Exp. 2
DM, %	92.24	92.63	90.55	91.00
CP, % DM	44.70	44.40	23.90	25.60
NE_m, Mcal/kg	1.98	1.96	2.07	2.12
NE_g, Mcal/kg	1.34	1.32	1.41	1.43
ADF, % DM	14.40	13.60	4.80	3.10
NDF, % DM	21.70	24.80	12.40	9.70
TDN, % DM	80	79	83	84
Starch, % DM	23.00	22.59	63.57	65.00
Degradable intake protein, % of CP	68.90	70.87	59.33	59.50

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

[2] Chemical composition was performed at a commercial lab (Dairy One, Ithaca, NY), except for starch and degradable intake protein assays, which were conducted in-house.

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

	Experiment 1[1]		Experiment 2
Item	El Reno[2]	Stillwater[3]	Stillwater[3]
Ingredient composition, % DM			
Rolled corn	80.00	70.00	70.00
Dried distillers grains with solubles	-	12.00	12.00
Cottonseed meal	5.50	-	-
Prairie hay	-	6.00	6.00
Alfalfa hay	8.00	-	-
Supplement	2.50[4]	6.00[5]	6.00[5]
Molasses	4.00	-	-
Synergy 19-14[6]	-	6.00	6.00
Chemical composition, % DM			
DM, %	88.09	80.48	80.01
CP, % DM	15.58	13.90	13.73
NE_m, Mcal/kg	1.92	1.89	1.83
NE_g, Mcal/kg	1.28	1.25	1.19
ADF, % DM	6.18	7.10	9.14
NDF, % DM	13.28	16.85	17.99
TDN, % DM	78	77	75

[1] HGWP and LGWP treatments were fed at the El Reno location and the CON and CORN treatments were fed at the Stillwater location.

[2] El Reno feedlot was located at the USDA-ARS Grazinglands Research Laboratory in El Reno, OK.

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

[4] Supplement contained: 0.5% NH_4Cl, 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/metric ton.

[5] Supplement contained: 2.87% rolled corn, 1.04% wheat midds, 0.19% urea, 1.43% limestone, 0.23% NaCl, 0.001% MgO, 0.0001% $ZnSO_4$, 0.10% KCl, 0.00003% MnO, 0.00003% vitamin A, 0.00002% vitamin E, 0.0002% monensin, 0.0001% tylosin. Finishing diet was formulated to contain 33 g monensin/metric ton.

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

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

	Grazing Programs[1]		
Item	WP	DNR	SNR
		Experiment 1	
DM, %	32.80 ± 6.63	92.65 ± 2.39	39.72 ± 4.97
Ash, % DM	8.59 ± 1.44	4.48 ± 0.71	5.73 ± 0.31
CP, % DM	24.23 ± 3.18	4.73 ± 0.27	10.90 ± 1.93
NDF, % DM	47.35 ± 4.43	80.23 ± 1.11	70.44 ± 0.40
ADF, % DM	21.11 ± 3.25	47.89 ± 0.95	36.67 ± 1.19
		Experiment 2	
DM, %	32.13 ± 6.02	87.89 ± 3.21	41.57 ± 4.73
Ash, % DM	9.14 ± 2.14	5.66 ± 0.81	6.60 ± 0.56
CP, % DM	27.14 ± 2.35	5.05 ± 0.30	8.94 ± 0.36
NDF, % DM	45.64 ± 4.75	77.64 ± 1.77	68.78 ± 2.36
ADF, % DM	19.99 ± 3.07	47.98 ± 1.37	38.47 ± 2.13

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

Table 4. Fall/winter and summer grazing performance of steers from different grazing treatments for Experiment 1 and 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
			Experiment 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	7.41	0.52
Final BW[2], kg	281[a]	323[b]	341[c]	430[d]	3.53	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	-	-	8.50	0.01
Final BW, kg	358	399	-	-	9.88	0.01
ADG, kg/d	0.67	0.61	-	-	0.03	0.19
			Experiment 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	260	257	260	257	6.71	0.98
Final BW[2], kg	388[c]	372[ab]	377[bc]	363[a]	4.24	0.01
ADG, kg/d	0.49[a]	0.63[b]	0.84[c]	1.41[d]	0.02	0.01

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

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

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

Table 5. Ruminal volatile fatty acid and ammonia concentrations of cannulated steers grazing dormant native range or winter wheat pasture during Experiment 1

	Treatment[1]					*P*-value[2]	
Item	CON	CORN	LGWP	HGWP	SEM	Trt	Trt*Time
Ruminal pH	6.54	6.18	6.32	6.06	0.14	0.09	0.01
Ruminal ammonia, mM	6.70[b]	3.29[a]	16.79[d]	12.36[c]	1.39	0.01	0.01
Total VFA, mM	94.63[a]	99.07[a]	99.38[a]	118.14[b]	3.17	0.01	0.08
Acetate, mM/100mM	60.61[c]	57.72[b]	55.20[ab]	52.97[a]	1.07	0.01	0.01
Propionate, mM/100mM	16.24[a]	18.13[b]	17.90[b]	20.23[c]	0.57	0.01	0.03
Acetate:propionate	3.80[c]	3.24[b]	3.10[b]	2.61[a]	0.15	0.01	0.01

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Trt = treatment; Trt*Time = treatment x sampling time within sampling period.

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

Table 6. Carcass characteristics of steers at initial harvest for Experiment 1 and 2

	Experiment 1		Experiment 2	
Item	Mean	SD	Mean	SD
Steers, No.	4	-	4	-
HCW, kg	126	10.75	138	29.15
Dressing percentage, %	49.61	2.20	52.36	2.74
12th-rib fat, cm	0.03	0.05	0.27	0.17
KPH, %	0.88	0.25	0.55	0.06
LM area, cm^2	43.06	5.25	45.00	5.97
Yield grade	1.60	0.08	1.80	0.29
Marbling score[1]	220	34.64	148	48.56

[1] Marbling score grid: 100 = Practically Devoid^{00}; 200 = Traces^{00}; 300 = Slight^{00}.

Table 7. Intermediate carcass characteristics of steers following the winter and summer grazing phases for Experiment 1 and 2

	Treatment[1]							
	First Intermediate				Second Intermediate			
Item	CON	CORN	LGWP	HGWP	CON	CORN	SEM	*P*-value
	Experiment 1							
Steers, No.	3	3	3	3	3	3	-	-
Days of age	406	411	411	404	518	523	-	-
HCW, kg	150[a]	180[ab]	210[bc]	238[c]	188[b]	208[bc]	11.64	0.01
Dressing percent, %	52.68[a]	55.59[b]	59.25[c]	59.45[c]	51.86[a]	51.38[a]	0.67	0.01
12th-rib fat, 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	37.20[a]	50.96[b]	58.27[b]	60.64[b]	55.69[b]	55.48[b]	3.23	0.01
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]	18.36	0.01
	Experiment 2							
Steers, No.	4	4	4	4	-	-	-	-
Days of age	528	445	406	344	-	-	-	-
HCW, kg	207	201	226	204	-	-	6.90	0.09
Dressing percent, %	52.08[a]	52.29[a]	59.23[c]	54.98[b]	-	-	0.36	0.01
12th-rib fat, 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	53.06	57.74	60.64	55.16	-	-	2.52	0.22
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]	-	-	21.76	0.01

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Marbling grid: 100 = Practically Devoid[00]; 200 = Traces[00]; 300 = Slight[00]; 400 = Small[00].

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 8. Ultrasound measurements of steers at the end of the winter grazing period for Experiment 1 and stocker phase for Experiment 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
	———Experiment 1———					
Steers, No.	17	17	16	18	-	-
12th-rib fat, cm	0.16[a]	0.18[a]	0.29[b]	0.87[c]	0.03	0.01
LM area, cm^2	41.42[a]	50.20[b]	54.29[c]	67.87[d]	1.47	0.01
Intramuscular fat, %	3.42[ab]	3.24[a]	3.66[b]	4.83[c]	0.14	0.01
	———Experiment 2———					
Steers, No.	18	18	18	18	-	-
12th-rib fat, cm	0.30[b]	0.18[a]	0.35[b]	0.49[c]	0.02	0.01
LM area, cm^2	48.71[a]	49.39[a]	58.24[c]	54.19[b]	1.30	0.01
Intramuscular fat, %	2.62[a]	2.73[a]	2.91[a]	3.43[b]	0.12	0.01

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

Table 9. Finishing performance of steers from different stocker production programs for Experiments 1 and 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
	Experiment 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]	4.11	0.01
Final BW, kg	597[a]	632[b]	610[ab]	588[a]	8.18	0.04
ADG, kg/d	2.12	2.04	1.87	1.87	0.09	0.16
DMI, kg/d	12.14	12.53	11.84	11.17	0.43	0.16
Gain:feed	0.175	0.163	0.158	0.168	0.005	0.09
	Experiment 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]	0.52	0.01
Final BW, kg	617[b]	590[a]	575[a]	581[a]	7.86	0.02
ADG, kg/d	2.06[b]	1.53[a]	1.54[a]	1.70[a]	0.06	0.01
DMI, kg/d	11.93[b]	10.04[a]	10.02[a]	10.50[a]	0.25	0.01
Gain:feed	0.173	0.153	0.155	0.162	0.008	0.39

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 10. Final carcass characteristics of steers from different stocker production programs for Experiment 1

Item	Treatment[1]				SEM	*P*-value
	CON	CORN	LGWP	HGWP		
Steers, No.	11	11	13	15	-	-
Days of age	632	637	557	494	-	-
Unadjusted carcass characteristics						
HCW, kg	375	397	383	375	9.78	0.32
Dressing percent, %	62.70	63.07	62.84	63.13	0.56	0.80
12th-rib fat, 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	91.02[b]	93.66[b]	83.91[a]	95.79[b]	2.24	0.01
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	16.07	0.99
Quality grade distribution						
Upper 2/3 Choice, %	18.18	9.09	7.69	20.00	12.20	0.78
Low Choice, %	36.36	72.73	69.23	53.33	15.21	0.36
Select, %	45.45	18.18	23.08	26.67	15.75	0.58
Adjusted to 12th-rib fat						
KPH, %	2.18[b]	2.10[b]	1.70[a]	1.99[b]	0.10	0.01
LM area, cm^2	91.01[b]	93.63[b]	84.05[a]	95.69[b]	2.34	0.01
Yield grade[3]	3.16	3.19	3.43	3.00	0.11	0.07
Marbling score[2]	423	428	431	423	16.54	0.98

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Marbling grid: 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}.

[3] 12th-rib fat was a significant covariate ($P < 0.05$).

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 11. Final carcass characteristics of steers from different stocker production programs for Experiment 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
Steers, No.	14	14	14	14	-	-
Days of age	640	590	533	475	-	-
Unadjusted carcass characteristics						
HCW, kg	374	371	363	364	8.68	0.77
Dressing percent, %	60.81[a]	63.27[b]	62.89[b]	63.07[b]	0.60	0.02
12th-rib fat, cm	1.19[a]	1.53[b]	1.54[b]	1.65[b]	0.12	0.05
LM area, cm^2	85.14[b]	87.78[b]	85.77[b]	76.19[a]	2.10	0.01
Yield grade	3.10[a]	3.17[a]	3.18[a]	3.86[b]	0.15	0.01
Marbling score[2]	465	402	429	439	17.31	0.10
Quality grade distribution						
Upper 2/3 Choice, %	28.57	7.14	14.29	28.57	12.07	0.44
Low Choice, %	57.31	56.73	65.19	43.84	14.40	0.78
Select, %	14.29	35.71	21.43	28.57	12.81	0.61
Adjusted to 12th-rib fat						
LM area, cm^2	85.97[b]	87.68[b]	86.08[b]	75.91[a]	2.12	0.01
Yield grade[3]	3.24[a]	3.12[a]	3.18[a]	3.80[b]	0.14	0.01
Marbling score[2]	462	403	428	439	18.15	0.15

[1] CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Marbling grid: 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}.

[3] 12th-rib fat was a significant covariate ($P < 0.05$).

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

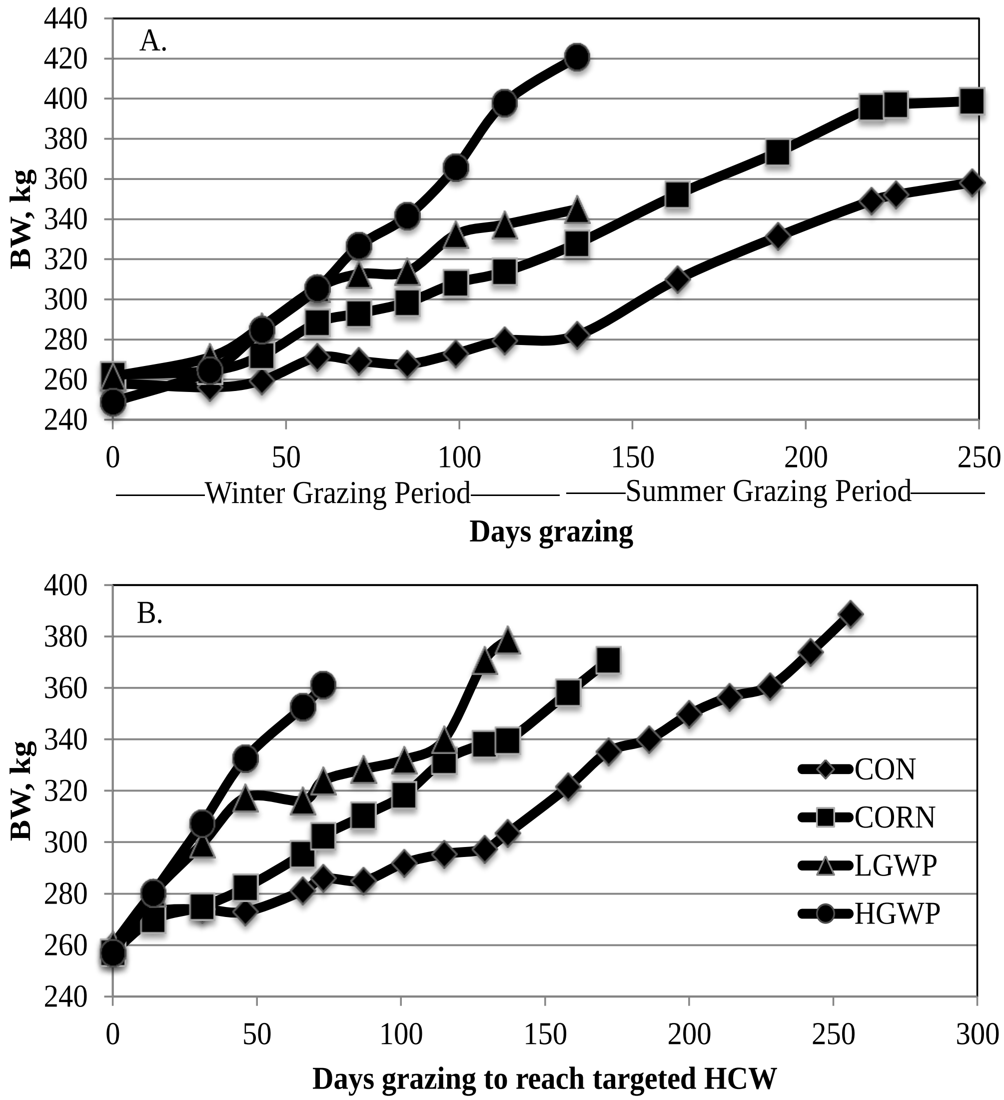

Figure 1. Change in live shrunk BW of steers during the winter and summer grazing period in Experiment 1 (A) and Experiment 2 (B). CON = 40% CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

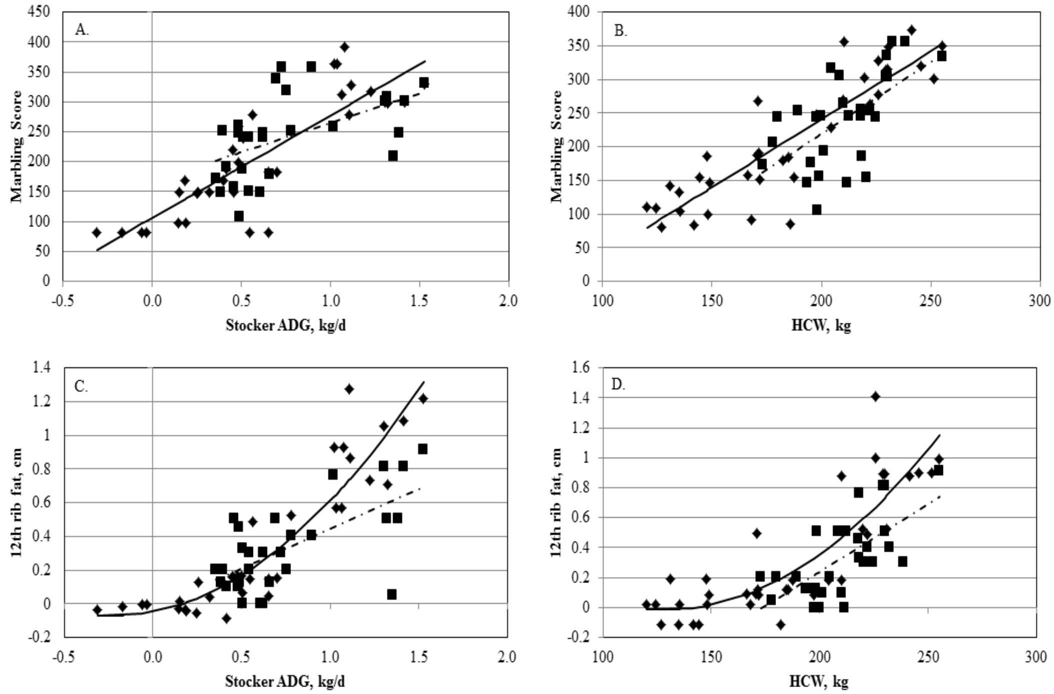

Figure 2. Relationship of marbling score with ADG during the grazing phase (A) and HCW at intermediate harvest (B) or the relationship of 12th-rib fat with ADG during the grazing phase (C) and HCW at intermediate harvest (D) when steers are harvested at similar age (♦) or BW (■) prior to finishing.

A) Marbling score at similar age (solid line) = 106.17 + 170.96*ADG; R^2 = 0.723; RMSE = 50.70. Marbling score at similar BW (dashed line) = 167.12 + 98.2041*ADG; R^2 = 0.271; RMSE = 60.07.

B) Marbling score at similar age (solid line) = -163.14 + 2.0208*HCW; R^2 = 0.783; RMSE = 43.90. Marbling score at similar BW (dashed line) = -206.34 + 2.1283*HCW; R^2 = 0.352; RMSE = 56.79.

C) 12th-rib fat thickness at similar age (solid line) = -0.0472 + 0.2123*ADG + 0.4456*ADG^2; R^2 = 0.856; RMSE = 0.163. 12th-rib fat thickness at similar BW (dashed line) = -0.02499 + 0.4706*ADG; R^2 = 0.434; RMSE = 0.201.

D) 12th-rib fat thickness at similar age (solid line) = 1.2005 – 0.01883*HCW + 0.000073*HCW^2; R^2 = 0.737; RMSE = 0.219. 12th-rib fat thickness at similar BW (dashed line) = -1.5807 + 0.009096*HCW; R^2 = 0.450; RMSE = 0.197.

CHAPTER V

EFFECTS OF FORAGE ENERGY INTAKE AND SUPPLEMENTATION ON VISCERAL ORGAN MASS AND CARCASS COMPOSITION IN GROWING BEEF CATTLE

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ABSTRACT

Two experiments were conducted to examine the effect of forage energy intake and supplementation on visceral organ mass and carcass composition in stocker cattle grazing dormant native range (**DNR**) or winter wheat pasture (**WP**). In each experiment fall-weaned Angus steers were randomly allotted to one of the following stocker production programs: (1) control, 1.02 kg·hd^{-1}·d^{-1} of a 40% CP supplement while grazing DNR (**CON**); (2) corn-based supplement fed at 1% BW while grazing 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, 3 steers per treatment were harvested following winter grazing (138 d). The remaining WP steers were transitioned into the finishing phase, whereas the DNR steers were allowed to graze the same pastures for another 115 d prior to entering the feedyard. In Exp. 2, steers grazed 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 4 steers per treatment were selected for intermediate harvest prior to finishing. At the end of finishing, 4 additional steers from each treatment were selected for final carcass measurements. All steers were fed to a common 12th-rib fat thickness of 1.27 cm. Following winter grazing in Exp. 1, HGWP steers had the greatest ($P < 0.01$) mesenteric/omental fat, total viscera, and total splanchnic tissue mass compared with the other grazing treatments. Also, HGWP steers had the greater ($P < 0.01$) carcass and empty body fat compared with the other treatments. In Exp. 2 at

intermediate harvest, WP treatments had greater (*P* < 0.03) mesenteric/omental fat, total viscera, and total splanchnic tissue mass compared with CORN steers, with CON steers being intermediate. Also, the WP treatments had greater (*P* < 0.02) carcass and empty body fat compared with CORN steers, with CON steers being intermediate. At final harvest in Exp. 2, LGWP steers had the lowest total viscera and total splanchnic tissue mass compared with the other treatments. However, there were no differences among treatments for carcass or empty body fat. Stocker systems using winter wheat pasture or dormant native range result in cattle with differences in body fat and visceral organ mass prior to finishing, which may influence feedlot efficiency even though there were no differences in body fat and visceral organ mass at the end of finishing.

Key words: carcass density, growing beef cattle, adipose deposition, organ mass

INTRODUCTION

There are numerous growing programs for beef cattle in the Southern Great Plains, which can produce a wide range of ADG that can alter body fat content (i.e. fleshiness) going into the finishing phase (Hersom et al., 2004a; Chapter IV). Fox et al. (1972) reported nutritionally restricted steers have increased protein deposition during the first part of finishing, but at the end of finishing steers are depositing fat at a greater rate compared with steers that have never been restricted nutritionally. Hersom et al. (2004a) reported that steers wintered on wheat pasture at a high-rate of gain enter the finishing phase with greater body fat composition, but have similar finishing ADG and similar final marbling scores compared with steers wintered on dormant native range.

Hersom et al. (2004a) also demonstrated that maintenance requirement of growing beef cattle can be influenced by previous nutritional program. Ferrell and Jenkins (1985) reported that maintenance energy expenditures can mostly be attributed to energy use in the visceral organs. McLeod and Baldwin (2000) summarized that the gastrointestinal tract (**GIT**) and liver have a considerable impact on metabolizable energy use and account for 40 to 50% of the whole body heat production. Sainz and Bentley (1997) reported that the amount of absorbed nutrients seems to be the driving factor influencing liver mass, whereas the forestomach and intestines respond to dietary fiber content and amount of absorbed nutrients. Therefore, we hypothesized that different production programs, winter wheat pasture (**WP**) or dormant native range (**DNR**), affect visceral organ mass and the amount of carcass fat deposition during the stocker and finishing phases thereby impacting efficiency during finishing. The objective of the study was to examine the effect of stocker production programs on mass of visceral organs and differences in carcass composition of steers during the stocker and finishing phases.

MATERIALS AND METHODS

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

Animals, Treatments, and Management

Experiment 1 and 2. A detailed description of the stocker and finishing phases have been reported in a companion paper in Chapter IV and will be briefly summarized here. Fall-weaned steers from the same Oklahoma State University cow herd were used for two separate experiments; in Experiment 1, 72 Angus steers (258 ± 29 kg; 276 ± 18 d of age) and in Experiment 2, 76 Angus steers (258 ± 28 kg; 265 ± 20 d of age) were allotted to one of 4 treatments grazing either dormant native range (**DNR**) or winter wheat pasture (**WP**). Treatments included: (1) control, 1.02 $kg \cdot hd^{-1} \cdot d^{-1}$ of a 40% CP cottonseed meal-based supplement to meet their degradable intake protein (**DIP**) requirement while grazing DNR (**CON**); (2) corn/soybean meal-based supplement fed at 1% BW while grazing DNR (**CORN**); (3) grazing WP at a high stocking rate (3 steers/ha) to achieve a low rate of BW gain (**LGWP**); and (4) grazing WP at a low stocking rate (1 steers/ha) to achieve a high rate of BW gain (**HGWP**). Both experiments were initiated in early December when steers were allotted to treatments based upon initial BW and sire information if known. At this time 4 randomly selected steers were harvested at the Oklahoma State University Food and Agricultural Products Center (**FAPC**) abattoir in Stillwater, OK for collection of initial body composition. For each experiment and immediately upon hide removal and evisceration, the gastrointestinal tract was collected and separated into the reticulo-rumen, omasum, abomasum, and small and large intestine, emptied of contents, and weighed. Internal organs (heart, lungs, kidney, liver, spleen, and pancreas) and mesenteric/omental fat were also weighed. Empty BW was calculated as shrunk live BW and multiplied by 0.891 (NRC, 1996) because hide, head, feet, ears, and blood were not weighed. Total gastrointestinal tract was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine. Total viscera was calculated as the sum of the total gastrointestinal tract plus mesenteric/omental fat. Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas. Following a chill time of 48 h, the left side of each eviscerated carcass was quartered and carcass density measurements were made by the water-displacement method as described by Garrett and Hinman (1969). Each quarter was weighed in the air and then submerged in a tank (61 x 183 x 119 cm) containing 4° C water and was weighed using a triple-beam balance that was placed on a solid platform above the tank. The air temperature in the room was also 4°C to eliminate any variation in specific volume measurements. In Experiment 2, the KPH fat was removed from the carcass following evisceration and was weighed, placed in a bag, and chilled with the carcasses. Carcass density measurements were as described in Experiment 1, except the density of KPH fat was measured separately in a wire basket (20.3 x 20.3 x 20.3 cm). The weight of the KPH fat in air and in water was added to the weight of the whole carcass for calculation of carcass density. Carcass composition was calculated from carcass density using equations of Garrett and Hinman (1969). In addition, empty body composition was calculated from carcass fat measurements using equations reported by Sainz et al. (1995; Table 1).

Grazing and Finishing Phases

In Experiment 1, at the end of the 138 d winter grazing phase, 3 steers were selected from each treatment based upon known sires and final grazing BW for the first intermediate harvest. Steers were harvested as described for the initial harvest in Experiment 1. Additionally, the reticulo-rumen contents were collected, weighed, and three sub-samples were collected for DM analysis (oven drying at 115°C) to determine amount of rumen contents (g/kg of BW) at the end of winter grazing. At this time the remaining WP treatment steers were transitioned into the finishing phase, whereas the DNR treatments were transitioned into a season-long summer grazing program on the same pastures used during winter grazing. At the end of summer grazing, 3 steers from only the CON and CORN treatments were randomly selected based upon BW and were harvested as previously described. The remaining steers within each of these two treatments were transitioned into the finishing phase. All treatments were fed to an estimated 12th-rib fat thickness of 1.27 cm. At the end of finishing, 3 steers were randomly selected based upon BW from the LGWP and HGWP treatments and were harvested as previously described. No steers from the CON and CORN treatments were harvested for collection of visceral organ mass and carcass density measurements due to scheduling conflicts.

In Experiment 2, steers grazed their respective pastures until each treatment reached an estimated HCW of 200 kg. At this time point, 4 steers were selected from each treatment based upon known sire information and final grazing BW for intermediate harvest. Steers were harvested as described for the intermediate harvest in Experiment 1. The remaining steers from each treatment were transitioned into the finishing phase. Steers were fed to a predicted common fat endpoint of 1.27 cm of rib fat thickness based upon ultrasound measurements for 12th-rib fat approximately one month prior to harvest for determination of harvest date and selection of 4 steers for harvest at the FAPC abattoir. Steers were selected based upon their 12th-rib fat thickness and final finishing BW and were harvested as previously described.

Statistical Analysis

For each experiment, the mass of the organs from each harvest was expressed as grams per kilograms of empty BW. Mass of body components and carcass characteristics were analyzed as a completely randomized design with steer as the experimental unit (Proc MIXED; SAS Inst. Inc., Cary, NC). The statistical model included the fixed effect of winter grazing treatment and least square means were calculated and compared using a protected LSD ($P < 0.05$).

RESULTS

Growth performance and carcass data from the two experiments have been reported in Chapter IV.

Mass of Body Components

Initial Harvest.

Initial mass of body components for Experiments 1 and 2 are shown in Table 2. Due to using steers from the same herd two years in a row and initiating the experiments at a similar age of the animal, the data are very similar across years. The steers that were selected for initial harvest in Experiment 2 did have more mesenteric/omental fat as a proportion of empty BW compared with Experiment 1. This increase in fat deposition increased the total viscera and total splanchnic tissue as a proportion of empty BW compared with Experiment 1.

Intermediate Harvest

Experiment 1. When steers were harvested at a similar age following winter grazing, the HGWP had greater ($P < 0.03$) live BW and empty BW compared with the CON, and the CORN and LGWP treatments were intermediate (Table 3). When the CON and CORN steers were harvested following summer grazing for the second intermediate harvest, there was no difference in live BW or empty BW compared with the two WP treatments. At the end of winter grazing (first intermediate harvest), the DNR treatments had greater ($P < 0.01$) rumen content (g/kg of BW) compared with the WP treatments.

At first intermediate harvest, carcass mass (g/kg of empty BW) was greater ($P < 0.01$) for the two WP treatments compared with the CORN, and the CORN was greater than the CON steers. There were no differences ($P > 0.09$) among treatments for lungs-trachea, reticulo-rumen, small intestine, or spleen (g/kg of empty BW). The mass of the omasum (g/kg of empty BW) was greater ($P < 0.01$) for CON steers compared with HGWP steers, with CORN and LGWP steers being intermediate. The CON and CORN treatments tended ($P > 0.08$) to have greater large intestine and total GIT mass (g/kg of empty BW) compared with the two WP treatments. Additionally, the CON and CORN steers had less mesenteric/omental fat mass (g/kg of empty BW) and lower total viscera mass compared with the HGWP steers, with the LGWP being intermediate. At the second intermediate harvest, the CON and CORN steers had similar carcass mass as the CON steers at first intermediate harvest. However, at the second intermediate harvest, the CON and CORN steers had smaller ($P < 0.01$) proportion of lungs-trachea and small intestine compared with all of the treatments at the first intermediate harvest. At the second intermediate harvest, the CON and CORN steers had similar omasum mass as CON, CORN, and LGWP steers at the first intermediate harvest, but greater than the HGWP steers. The abomasum mass (g/kg of empty BW) was greatest for the CORN steers at the first intermediate harvest, and was greater than the CON and CORN steers at the second intermediate harvest. At the second intermediate harvest, the CON and CORN steers had similar large intestine and GIT mass as the WP treatments at the first intermediate harvest. Similarly, at the second intermediate harvest the CON and CORN steers were similar to LGWP steers at first intermediate harvest.

At first intermediate harvest, differences were seen in pancreas mass (g/kg of empty BW) where the HGWP steers were greater ($P < 0.01$) than the CON steers. Wheat pasture treatments had greater ($P < 0.01$) kidney mass (g/kg of empty BW) compared with the CON and CORN steers. At the second intermediate harvest, the CORN and LGWP steers had similar pancreas mass as CON, CORN, LGWP steers at first intermediate harvest, but lower pancreas mass than HGWP steers. Wheat pasture treatments had greater ($P < 0.01$) liver mass (g/kg of empty BW) compared with the CON and CORN steers at both the first and second intermediate harvests, which resulted in a similar trend for total splanchnic tissue. The CORN steers at the second intermediate harvest had lower kidney mass than all treatments at the first intermediate harvest.

Experiment 2. When steers were harvested at a similar HCW (200 kg), there were no differences ($P > 0.52$) in live or empty BW (Table 4). The CON steers had greater ($P < 0.03$) rumen content (g/kg of BW) compared with the LGWP steers, with the CORN and HGWP treatments being intermediate. There was a numerical increase for the DNR treatments to have greater rumen content compared with steers grazing WP, which agrees with the results observed in Experiment 1 at the end of winter grazing.

The LGWP steers had greater ($P < 0.01$) carcass mass (g/kg of empty BW) compared with the HGWP steers and the WP treatments had greater carcass mass compared with the CON and CORN steers that were grazing DNR. The HGWP steers had greater ($P < 0.01$) heart mass (g/kg of empty BW) compared with the other three treatments. The CON steers had greater ($P < 0.01$) omasum mass (g/kg of empty BW) compared with the CORN, LGWP, and HGWP steers. There was a tendency ($P = 0.09$) for the WP treatments to have greater small intestine mass (g/kg of empty BW) compared with the DNR treatments. However, there was no difference ($P > 0.36$) in lungs-trachea, reticulo-rumen, abomasum, large intestine, or total GIT mass (g/kg of empty BW) among treatments when harvested at a similar HCW. The CORN steers did have less ($P < 0.03$)

mesenteric/omental fat mass (g/kg of empty BW) compared with the other three treatments, which lead to smaller ($P < 0.02$) total viscera mass for the CORN steers. The DNR treatments had lower ($P < 0.02$) liver mass (g/kg of empty BW) compared with the WP treatments, which is similar to Experiment 1. The CORN steers had lower ($P < 0.01$) total splanchnic tissue content compared with the other three treatments when harvested at a similar HCW prior to entering the finishing phase. There was no difference ($P > 0.09$) for pancreas, spleen, or kidney mass (g/kg of empty BW) among treatments. The LGWP steers had greater ($P < 0.01$) KPH mass (g/kg of empty BW) compared with the CORN steers, with the CON and HGWP steers being intermediate.

Final Harvest.

Experiment 1. In Experiment 1, only the LGWP and HGWP treatments were harvested at the FAPC abattoir to collect mass of body components due to scheduling conflicts for the CON and CORN treatments (Table 5). There was no difference ($P > 0.87$) between treatments for live BW and empty BW. Also, there was no difference ($P > 0.32$) for carcass mass, heart, or lungs-trachea mass (g/kg of empty BW) between the WP treatments. There was a tendency ($P < 0.12$) for the HGWP steers to have greater reticulo-rumen and small intestine mass (g/kg of empty BW) compared with the LGWP steers. However, there were no differences ($P > 0.15$) for omasum, abomasum, large intestine, total GIT, or mesenteric/omental fat mass (g/kg of empty BW). There was a tendency ($P < 0.09$) for the HGWP steers to have greater total viscera and liver mass (g/kg of empty BW) compared with the LGWP steers. The HGWP steers did have greater ($P < 0.05$) total splanchnic tissue content and kidney mass (g/kg of empty BW) compared with the LGWP steers. However, there was no difference ($P > 0.35$) for pancreas or spleen mass (g/kg of empty BW) among WP treatments.

Experiment 2. There were no differences ($P > 0.58$) among the treatments for live BW or empty BW (Table 6). There was also no difference ($P > 0.27$) for carcass tissue content, heart, or lungs-trachea mass (g/kg of empty BW) among the treatments. The HGWP steers did have greater ($P < 0.01$) reticulo-rumen mass (g/kg of empty BW) compared with the LGWP steers, with the CON and CORN treatments being intermediate, which is similar to Experiment 1. The WP treatments had lower ($P < 0.01$) omasum mass (g/kg of empty BW) compared with the DNR treatments. There was a tendency ($P = 0.08$) for the CORN steers to have lower abomasum mass (g/kg of empty BW) compared with the other three treatments; however, there were no differences ($P > 0.13$) in small intestine, large intestine, or mesenteric/omental fat mass among the treatments. The LGWP steers had lower ($P < 0.04$) total GIT and total viscera mass (g/kg of empty BW) compared with the other treatments.

The CON steers had greater ($P < 0.02$) spleen and liver mass (g/kg of empty BW) compared with the other treatments. The CON steers had greater ($P < 0.01$) total splanchnic tissue mass content (g/kg of empty BW) compared with the CORN and LGWP steers, with the HGWP steers being intermediate. However, there were no differences ($P > 0.13$) among the treatments for pancreas, kidney, or KPH mass (g/kg of empty BW).

Carcass and Empty BW Chemical Composition

Initial Harvest. The carcass and empty BW chemical composition for steers at the initial harvests for Experiment 1 and 2 is shown in Table 7. The steers in Experiment

2 had considerably more 12th-rib fat thickness compared with Experiment 1. Additionally, the initial harvest steers in Experiment 2 had much lower carcass density values, which led to greater carcass fat when using the equations by Garrett and Hinman (1969) for chemical composition. The values derived using the Garrett and Hinman (1969) equations are still much higher than values derived using equations by Sainz et al. (1995). The values derived using equations published by Sainz et al. (1995) is similar to data reported by these researchers for their initial harvest steers.

Intermediate Harvest.

Experiment 1. As previously reported in Chapter IV, the HGWP steers had greater ($P < 0.01$) HCW, 12th-rib fat, KPH, mesenteric/omental fat, and marbling scores compared with the other grazing treatments at first intermediate harvest (Table 8). The LGWP steers had greater HCW, mesenteric/omental fat, and marbling scores compared with the CON steers, with the CORN steers being intermediate. At the second intermediate harvest, the CON and CORN steers have similar HCW, 12th-rib fat, and marbling scores as CORN and LGWP steers at the first intermediate harvest suggesting that as steers grow to similar BW while on summer pasture, accretion of individual fat depots compensated. There were no differences ($P > 0.61$) among the treatments at either intermediate harvest for carcass density or for chemical composition components when derived from the Garrett and Hinman (1969) equations. Based upon the Sainz et al. (1995) equations, the HGWP steers had greater ($P < 0.02$) carcass and empty body fat compared with the other treatments at both intermediate harvests. The CON and CORN steers at the first intermediate harvest had the lowest carcass and empty body fat, but at the second intermediate harvest (end of summer grazing) there were no differences in body fat content compared with the LGWP steers at first intermediate harvest.

Experiment 2. There was no difference in HCW ($P > 0.09$) among the treatments due to experimental design (Table 9), but the LGWP steers were slightly heavier at intermediate harvest due to an unexpected increase in rate of gain the last two-weeks of the grazing phase due to increased forage growth. There was a tendency ($P = 0.06$) for the HGWP steers to have greater 12th-rib fat thickness when compared with the CORN steers, with the CON and LGWP being intermediate. The WP treatments had greater ($P < 0.01$) KPH and tended ($P = 0.11$) to have greater mesenteric/omental fat compared with the DNR treatments. The LGWP steers had greater ($P < 0.01$) marbling scores compared with the HGWP steers, and HGWP steers had greater marbling scores than the CON and CORN steers. When values were derived from the Garrett and Hinman (1969) equations, there were no differences ($P > 0.21$) in carcass density or chemical composition among treatments when harvested at a similar HCW prior to entering the finishing phase. Although the HGWP steers did have a numerically higher percentage of fat and energy with lower water and nitrogen compared with the CON, CORN, and LGWP steers, which were similar. When using the Sainz et al. (1995) equations, the WP treatments had higher ($P < 0.02$) carcass and empty body fat compared with the CORN steers, with the CON steers being intermediate.

Final Harvest.

Experiment 1. Final carcass characteristics are reported in Chapter IV, which includes steers harvested the FAPC abattoir and at a commercial abattoir. Data reported here represents only those steers harvested at FAPC that were used for determination of carcass density measurements (Table 10). The HGWP steers tended (*P* = 0.10) to have higher KPH compared with the LGWP steers. However, there were no differences in carcass and empty BW chemical composition between the two WP treatments at the end of finishing.

Experiment 2. Final carcass characteristics are reported in Chapter IV, which includes steers harvested at the FAPC abattoir and at a commercial abattoir. Data reported here represents only those steers harvested at the FAPC abattoir that were used for determination of carcass density measurements (Table 11). The CON steers tended (*P* = 0.09) to have lower 12th-rib fat compared with the other treatments. However, there were no differences in HCW, KPH, or mesenteric fat among treatments. The HGWP steers that were harvested at the FAPC abattoir had lower (*P* < 0.04) marbling scores compared with the CON and CORN steers, with the LGWP steers being intermediate. The LGWP steers tended (*P* = 0.06) to have larger carcass density values, which resulted in lower carcass fat and energy content, and greater water and nitrogen content. However, there were no differences (*P* > 0.53) in carcass or empty body fat content among treatments using the equations developed by Sainz et al. (1995).

DISCUSSION

Growth performance and carcass characteristics for Experiments 1 and 2 are presented in Chapter IV. Only data pertaining to the steers harvested at the FAPC abattoir will be discussed in this manuscript.

Mass of Body Components

Hersom et al. (2004b) reported that when treatments were harvested at a similar age just prior to finishing, steers previously grazing wheat pasture from a high-rate of gain had greater empty BW compared with steers grazing wheat pasture at a low-rate of gain and steers grazing dormant native range, which is similar to Experiment 1 first intermediate harvest. However, these researchers compared treatments at final harvest, there was no difference in empty BW, which is similar to the current experiments. McCurdy et al. (2010b) also showed no difference in empty BW percentage or change in empty BW from the end of the growing phase at intermediate harvest to the end of finishing among steers grazing wheat pasture, fed a silage-based diet ad libitum, or programmed fed a concentrate diet during the growing phase, which is similar to the results observed in Experiment 2.

The GIT and liver account for about 10 to 13% of the total body mass (Seal and Reynolds, 1993) but account for 40% of the oxygen consumption of the whole animal (McBride and Kelly, 1990). Protein synthesis in the GIT accounts for approximately 20 to 23% of the total energy expenditure of the GIT (McBride and Kelly, 1990). However, studies have shown that metabolic rate per unit of mass does not change, but organ mass changes in response to physiological demand. Therefore, differences in mass of these organs from previous nutritional programs can affect maintenance requirements and could possibly influence efficiency during finishing. Hersom et al. (2004b) reported that increased visceral organ mass results in greater maintenance energy requirement. These researchers reported an increased reticulo-rumen mass at intermediate harvest for steers grazing dormant native range and wheat pasture to produce a low-rate of gain compared with steers grazing wheat pasture to produce a high-rate of gain. These researchers concluded that this was caused by a reduced energy intake corresponding to higher intake of low-quality forage. Similarly, Sainz and Bentley (1997) showed that steers fed a forage-based diet during the growing phase had greater forestomach mass compared with steers grown on a concentrate diet. However, in the current experiments, there were no differences among the grazing treatments for reticulo-rumen mass (g/kg of empty BW). The current experiments weighed the contents (g/kg of BW) within the reticulo-rumen and observed that the WP treatments had less rumen content when harvested at a similar age and similar HCW compared with the DNR treatments. Even though we saw no differences in reticulo-rumen mass, the contents of the reticulo-rumen correlate with the results from Hersom et al. (2004b) and Sainz and Bentley (1997) when steers consuming a higher forage based diet had greater reticulo-rumen or forestomach mass, respectively. Steers at the first intermediate harvest in Experiment 1 and at the intermediate harvest in Experiment 2 were harvested with a full GIT, so the contents within the reticulo-rumen provides data indicating that the DNR steers had a greater rumen capacity compared with the WP steers due to trying to consume similar energy intake.

Hersom et al. (2004b) reported that the dormant native range steers had heavier omasum mass at entry into the feedlot compared with steers grazing winter wheat pasture, which is similar to the current experiments that omasum mass was greater for the CON compared with the other treatments. McCurdy et al. (2010b) observed no differences in omasum mass at the end of the growing phase when steers had similar rates of gain even though the fiber content of the diet differed (NDF = 45, 43, and 21% for the wheat pasture, silage-based diet, and programmed fed high concentrate diet, respectively). McLeod and Baldwin (2000) reported that steers fed a forage-based diet had greater omasum and reticulum mass (% of BW) compared with steers receiving a concentrate diet.

Hersom et al. (2004b) reported no difference in small intestine mass (g/kg of empty BW) at the end of winter grazing for year 1; however, in year 2 the researchers observed that steers that were nutritionally restricted had greater small intestine mass compared with steers grazing wheat pasture at a high-rate of gain. The current experiments are similar to year 1 in that there was no difference in small intestine mass among any of the treatments at any of the harvest times. In contrast, Drouillard et al. (1991) observed that the intestine mass of sheep that were nutritionally restricted for 14- or 42-d were lighter compared with the unrestricted sheep. McCurdy et al. (2010b) reported that steers in a confinement setting fed a silage-based diet ad libitum or programmed fed a concentrate diet had lighter small intestine mass at the end of the growing phase compared with steers grazing wheat pasture. There were no differences in small intestine mass at the end of finishing (McCurdy et al., 2010b). Sainz and Bentley (1997) reported that steers previously restricted nutritionally and then alimented to a high-concentrate finishing diet had greater small intestine mass at the end of finishing compared with steers that were never nutritionally restricted. For large intestine mass, there were no differences among grazing programs at any of the harvest times, which is similar to results of Hersom et al. (2004b) and McCurdy et al. (2010b).

Hersom et al. (2004b) reported that steers restricted nutritionally had greater total GIT mass (g/kg of empty BW) compared with steers grazing wheat pasture to produce a high-rate of gain. At the end of finishing, there were no differences among the treatments for total GIT mass (Hersom et al., 2004b). Similarly, the DNR steers tended to have greater total GIT mass compared with the WP steers at first intermediate harvest in Experiment 1, but no differences were seen at the intermediate harvest in Experiment 2.

At the end of finishing in Experiment 2, the LGWP steers had a lower total GIT mass than the other treatments, but not in Experiment 1.

At the first intermediate harvest in Experiment 1, the HGWP steers had greater mesenteric/omental fat compared with the LGWP steers, and the LGWP steers had greater mesenteric/omental fat compared with the DNR steers. However, the CON and CORN steers at the second intermediate harvest had similar mesenteric/omental fat compared with the LGWP steers prior to entering the finishing phase. In Experiment 2, the CORN steers had lower mesenteric/omental fat than compared with LGWP and HGWP steers when harvested at a similar HCW prior to entering the finishing phase, which could be due to the steers not having enough days during summer grazing to compensate for the nutritional restriction during winter grazing. Similarly, Hersom et al. (2004b) reported that at the end of winter grazing, steers grazing wheat pasture to produce a high-rate of gain had greater mesenteric/omental fat mass compared with steers grazing wheat pasture to produce a low-rate of gain, and steers grazing dormant native range having the least amount of mesenteric/omental fat. McCurdy et al. (2010b) observed that steers that were programmed fed a high-concentrate diet had greater mesenteric/omental fat at the end of the growing phase compared with steers grazing wheat pasture. Sainz et al. (1995) showed that steers either grown on a high-concentrate diet at ad libitum, programmed fed a high-concentrate diet, or fed a forage-based diet ad libitum mesenteric/omental fat increased as empty BW increased among treatments. The current experiments along with Hersom et al. (2004b) and McCurdy et al. (2010b) reported no difference at the end of finishing for mesenteric/omental fat deposition among the different growing programs. Primarily due to mesenteric/omental fat, the total viscera mass was also greatest for the HGWP steers in Experiment 1 compared with the other treatments at the first and second intermediate harvests. In Experiment 2, the CORN steers had lower total viscera mass at intermediate harvest compared with the other treatments when harvested at a similar HCW. In contrast, McCurdy et al. (2010b) reported no differences in total viscera mass prior to finishing or at the end of finishing.

Hersom et al. (2004b) reported that nutritionally restricted steers had lower liver mass compared with steers grazing wheat pasture to produce a high-rate of gain in year 1, but no differences were seen in year 2. McCurdy et al. (2010b) showed no difference in liver and total splanchnic tissue mass among growing programs at the end of the growing or finishing phases. In contrast, the current studies show that in Experiment 1, the WP treatments had greater liver and total splanchnic tissue mass compared with steers grazing DNR at both first and second intermediate harvests. In Experiment 2, the WP treatments had greater liver mass compared with the DNR treatments; however, only CORN steers had lower total splanchnic tissue mass compared with the WP treatments at intermediate harvest. At final harvest in Experiment 2, the CON steers had greater liver mass and total splanchnic tissue mass compared with the LGWP steers. These results agree with the concept that liver mass responds to increases in total energy intake and metabolic demand (Sainz and Bentley, 1997; Hersom et al., 2004b), but does not seem to respond to type of diet that was previously fed (McLeod and Baldwin, 2000).

Hersom et al. (2004b) reported that increases in maintenance energy requirement may be caused by increases in energy required for protein synthesis in visceral tissues. In the current experiments, Sharman et al. (2012) reported no differences in finishing G:F among treatments, but the CON steers had numerically greater efficiencies in both experiments. Therefore, since these steers had lower total viscera and total splanchnic tissue mass compared with the WP treatments, these results suggest that their maintenance energy requirement was lower and were more efficient in finishing.

Carcass and Empty BW Chemical Composition

Equations relating carcass density (Garrett and Hinman, 1969) and carcass fat characteristics (Sainz et al., 1995) to carcass and empty body chemical composition were used to compute carcass chemical composition. Hersom et al. (2004a) used grazing treatments very similar to those used in Experiment 1 (i.e. HGWP, LGWP, and CON harvested at similar age following winter grazing) and McCurdy et al. (2010a) had initial harvest values and used steers grazing wheat pasture to produce a high rate of gain similar to HGWP in Experiment 1. In these studies, chemical composition was determined by proximate analysis of the ground carcass. Hersom et al. (2004a) and McCurdy et al. (2010a) reported that steers grazing wheat pasture to produce a high rate of gain had carcass fat content of 20.7 and 15.1%, respectively. In Experiment 1, the equations of Garrett and Hinman (1969) seemed to over-estimate carcass fat for HGWP at the intermediate harvest giving a value of 27.58%, whereas, the equations developed by Sainz et al. (1995) gave a value of 20.97%. Hersom et al. (2004a) reported carcass fat values of 14.3 and 12.8%, and 7.4 and 4.7% for steers grazing wheat pasture to produce a low rate of gain and steers grazing dormant native range, respectively for two separate years. In Experiment 1, the equations of Garrett and Hinman (1969) predicted 21.69 and 21.54% carcass fat for LGWP and CON steers at the first intermediate harvest, which is considerably greater than the values reported by Hersom et al. (2004a) using proximate analysis. In contrast, the equations reported by Sainz et al. (1995) predicted carcass fat of

13.48 and 10.47% for LGWP and CON steers at first intermediate harvest. Interestingly, Gil et al. (1970) determined carcass density on 59 carcasses ranging from 10 to 42% fat and showed that carcass specific volume had a very poor relationship (R^2 = 0.03 to 0.25) with ether extract in lean carcasses (10 to 29% ether extract). Similarly, Carstens et al. (1991) reported that using carcass indicator cuts or carcass density to determine carcass components may be misleading due to the greater magnitude of composition change observed in the non-carcass tissue components. So, when evaluating carcass chemical composition at final harvest both the equations of Garrett and Hinman (1969) and those of Sainz et al. (1995), it appeared that Sainz et al. (1995) gave results similar to the values reported by Hersom et al. (2004a). Therefore, the equations developed by Sainz et al. (1995), which estimate carcass fat from 10 to 21% for intermediate harvest and from 28 to 34% for final harvest, provide values more similar to the chemical composition values reported by Hersom et al. (2004a) and McCurdy et al. (2010a) than equations of Garrett and Hinman (1969).

Hersom et al. (2004a) reported that steers grazing wheat pasture at high-rate of gain had greater carcass and empty body fat at the end of grazing compared with the steers grazing wheat pasture at a low-rate of gain, with the steers grazing dormant native range having the lowest carcass and empty body fat (averaging 20.14, 13.33, 5.80%, respectively). Similarly, in Experiment 1, the HGWP steers had the greatest amount of carcass fat at both intermediate harvests compared with the other three treatments; however, in Experiment 2, there was no difference between HGWP, LGWP, and CORN steers for carcass or empty body fat when harvested at similar HCW at the end of grazing. Hersom et al. (2004a) reported no differences for carcass or empty body fat composition at the end of finishing in year 1, but in year 2, the restricted steers had greater carcass and empty body fat compared with steers grazing wheat pasture at a high-rate of gain suggesting a compensatory gain effect. In contrast, Carstens et al. (1991) reported that steers exhibiting compensatory gain had approximately 18% lower NE_g requirements during finishing. At the end of finishing, the compensatory steers had less empty body fat and more empty body protein compared with steers that were continuously grown. Similarly, Drouillard et al. (1991) observed that lambs that were nutritionally restricted had lower empty body fat and greater empty body protein compared with lambs that were not restricted. Fox et al. (1972) reported that steers exhibiting compensatory gain and grown to 341 kg had greater empty body protein and less empty body fat compared with steers that were full-fed (not restricted). However, when the treatments were grown to 454 kg, the compensatory steers deposited more fat and less protein compared with the first period of finishing, but changes in body composition during the second period were not different from the non-restricted steers.

Owens et al. (1995) reported that as the animal matures, more energy is directed towards fat deposition and that fat accretion is 1.6 times more energetically efficient as compared with protein accretion, due to greater protein turnover compared with lipid synthesis. However, on a live weight basis, protein accretion is more efficient due to water content of the muscle. In the current experiments, Chapter IV reported no differences in finishing G:F among the treatments, but the CON steers had numerically greater efficiencies in both experiments. In Experiment 2, the CON steers had greater ADG and DMI compared with the other treatments, but this could be attributed to differences in the time of year the steers were finished. The CON steers were finished during the early fall winter months, whereas the other treatments endured periods of hot humid weather that is expected in Stillwater, OK during the summer months. Even though each treatment entered finishing at different carcass and empty body fat compositions, there were no effects on finishing performance.

In conclusion, stocker systems using winter wheat pasture or dormant native range result in cattle with differences in body fat and visceral organ mass prior to finishing. Visceral organ mass at entry into the finishing phase may have a greater influence on finishing efficiency compared with carcass composition, even though when steers are harvested at a similar 12th-rib fat thickness at the end of finishing, there are minimal differences body fat and visceral organ mass. Thus previous grazing management may influence visceral organ mass and maintenance energy requirements during the early part of finishing. Further research is needed to better determine the effects of visceral organ mass on efficiency throughout finishing.

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Table 1. Equations used to calculate carcass and empty BW chemical composition using carcass density or carcass characteristics

Garrett and Hinman, (1969)	
Carcass ether extract, %	Y = 587.86 – (530.45 * carcass density)
Carcass water, %	Y = (375.20 * carcass density) – 343.80
Carcass nitrogen, %	Y = (20.00 * carcass density) – 18.57
Carcass energy, kcal/gm	Y = 49.54 – (43.63 * carcass density)
Sainz et al., (1995)	
Carcass fat[1], %	Y = 8.68 + (0.541 * mesenteric fat) + (0.510 * 12th-rib fat) + (1.58 * KPH)
Empty body fat[1], %	Y = 7.09 + (0.513 * mesenteric fat) + (0.470 * 12th-rib fat) + (1.48 * KPH)

[1] Units for calculation: Mesenteric/omental fat = kg; 12th-rib fat = mm; KPH = %.

Table 2. Mass of body components for the initial harvest steers in Experiments 1 and 2

	Experiment 1		Experiment 2	
Item	Mean	SD	Mean	SD
Steer, No.	4	-	4	-
Live BW[1], kg	254	15	262	49
Empty BW, kg	227	13	233	44
	g/kg of empty BW			
Carcass	557	25	588	31
Heart	4.12	1.03	6.21	0.65
Lungs-trachea	7.91	1.78	9.15	1.62
Reticulo-rumen	21.88	3.02	22.57	2.47
Omasum	8.13	1.54	8.50	1.52
Abomasum	2.90	1.06	3.42	0.36
Small intestine	13.65	1.58	15.88	1.16
Large intestine	9.72	3.39	9.57	0.81
Total GIT[2]	56.28	2.48	59.94	4.00
Mesenteric/omental fat	14.13	2.57	20.31	4.02
Total viscera[3]	70.41	2.85	80.25	1.97
Pancreas	0.96	0.09	0.87	0.14
Spleen	1.87	0.30	1.65	0.06
Liver	10.49	1.37	12.09	1.81
Total splanchnic tissue[4]	83.73	3.19	94.86	2.33
Kidney	-	-	2.51	0.19
KPH	-	-	7.30	2.52

[1] Live BW = 5-h shrunk live BW when steers were withheld from feed and water.

[2] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[3] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[4] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

Table 3. Mass of body components for steers from different stocker production programs at the first and second intermediate harvest in Experiment 1

	Treatment[1]							
	First Intermediate[2]				Second Intermediate[2]			
Item	CON	CORN	LGWP	HGWP	CON	CORN	SEM	*P*-value
Steers, No.	3	3	3	3	3	3	-	-
Live BW[3], kg	286[a]	324[ab]	354[abc]	401[c]	362[bc]	405[c]	23.38	0.03
Rumen content, g/kg BW	9.64[b]	8.27[b]	4.51[a]	5.43[a]	-	-	0.66	0.01
Empty BW, kg	255[a]	288[ab]	316[bc]	357[c]	322[c]	361[c]	20.84	0.03
	g/kg of empty BW							
Carcass	591[a]	624[b]	665[c]	667[c]	582[a]	577[a]	7.44	0.01
Heart	6.10[a]	6.60[ab]	9.11[c]	8.05[bc]	5.53[a]	5.38[a]	0.61	0.01
Lungs-trachea	11.47[c]	10.25[bc]	11.47[c]	12.53[c]	8.10[a]	8.44[ab]	0.89	0.02
Reticulo-rumen	23.43	23.01	23.66	23.73	23.38	21.87	0.81	0.62
Omasum	10.52[c]	8.46[ab]	8.34[ab]	7.22[a]	9.50[bc]	9.31[bc]	0.51	0.01
Abomasum	4.81[bc]	5.44[c]	4.35[b]	4.34[b]	3.09[a]	3.06[a]	0.34	0.01
Small intestine	17.20[b]	16.71[b]	16.61[b]	16.55[b]	12.80[a]	13.63[a]	0.95	0.02
Large intestine	10.41	10.87	9.28	8.35	8.75	9.25	0.60	0.08
Total GIT[4]	66.38	64.50	62.23	60.20	57.51	57.12	2.41	0.10
Mesenteric/omental fat	6.09[a]	8.94[a]	16.72[b]	30.56[c]	14.80[b]	16.59[b]	2.01	0.01
Total viscera[5]	72.46[ab]	73.43[ab]	78.95[b]	90.75[c]	72.32[a]	73.70[ab]	2.18	0.01
Pancreas	0.93[a]	1.21[b]	1.04[ab]	1.52[c]	0.97[ab]	1.20[b]	0.09	0.01
Spleen	1.77	1.97	2.86	2.16	1.93	1.92	0.25	0.09
Liver	13.94[a]	13.18[a]	17.64[b]	17.38[b]	12.53[a]	12.29[a]	0.65	0.01
Total splanchnic tissue[6]	89.11[a]	89.80[a]	100.49[b]	111.82[c]	87.75[a]	89.12[a]	2.27	0.01
Kidney	3.18[bc]	3.76[c]	5.06[d]	5.29[d]	2.32[ab]	2.14[a]	0.33	0.01

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] First Intermediate harvest was conducted at the end of winter grazing; Second Intermediate harvest was conducted at the end of summer grazing.

[3] Live BW = 5-h shrunk live BW when steers were withheld from feed and water.

[4] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[5] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[6] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4. Mass of body components for steers from different stocker production programs at the intermediate harvest in Experiment 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
Steers, No.	4	4	4	4	-	-
Live BW[2], kg	398	385	381	371	12.27	0.52
Rumen content, g/kg BW	9.19[b]	8.59[b]	5.44[a]	7.49[ab]	0.81	0.03
Empty BW, kg	354	343	340	331	10.94	0.52
	g/kg of empty BW					
Carcass	584[a]	587[a]	665[c]	617[b]	3.86	0.01
Heart	5.49[a]	5.41[a]	5.06[a]	6.07[b]	0.16	0.01
Lungs-trachea	8.50	9.29	8.82	9.81	0.53	0.36
Reticulo-rumen	23.70	22.28	23.47	23.41	0.78	0.60
Omasum	11.18[b]	8.24[a]	7.55[a]	6.78[a]	0.54	0.01
Abomasum	3.79	3.81	4.06	3.95	0.16	0.60
Small intestine	12.59	13.97	15.68	16.53	1.07	0.09
Large intestine	9.82	8.41	8.67	10.18	1.20	0.68
Total GIT[3]	61.07	56.71	59.42	60.86	2.31	0.54
Mesenteric/omental fat	18.22[ab]	13.70[a]	21.78[b]	22.91[b]	2.04	0.03
Total viscera[4]	79.30[b]	70.41[a]	81.21[b]	83.77[b]	2.56	0.02
Pancreas	1.09	1.01	1.37	1.12	0.09	0.09
Spleen	2.07	2.03	2.14	2.00	0.17	0.95
Liver	13.43[a]	13.31[a]	15.90[b]	15.84[b]	0.62	0.02
Total splanchnic tissue[5]	95.89[b]	86.77[a]	100.62[b]	102.73[b]	2.74	0.01
Kidney	2.59	2.63	2.78	2.84	0.12	0.44
KPH	5.30[ab]	4.13[a]	9.14[c]	7.26[bc]	0.68	0.01

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Live BW = 5-h shrunk live BW when steers were withheld from feed and water.

[3] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[4] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[5] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 5. Mass of body components for steers from different wheat pasture stocker programs at final harvest in Experiment 1

Item	Treatment[1] LGWP	HGWP	SEM	*P*-value
Steers, No.	3	3	-	-
Live BW[2], kg	599	591	30.68	0.88
Empty BW, kg	533	527	27.38	0.87
	———g/kg of empty BW———			
Carcass	720	696	21.89	0.48
Heart	5.71	5.38	0.23	0.37
Lungs-trachea	6.59	7.06	0.29	0.32
Reticulo-rumen	20.70	26.88	1.93	0.09
Omasum	4.95	4.65	0.30	0.52
Abomasum	2.92	3.10	0.43	0.78
Small intestine	10.16	11.89	0.62	0.12
Large intestine	6.79	5.86	0.62	0.35
Total GIT[3]	45.51	52.38	2.76	0.15
Mesenteric/omental fat	39.67	46.81	2.91	0.16
Total viscera[4]	85.18	99.18	4.17	0.08
Pancreas	0.83	1.09	0.17	0.35
Spleen	1.92	1.92	0.15	0.99
Liver	13.72	15.12	0.45	0.09
Total splanchnic tissue[5]	101.65	117.32	3.92	0.05
Kidney	2.28	3.79	0.35	0.04

[1] LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Live BW = 5-h shrunk live BW when steers were withheld from feed and water.

[3] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[4] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[5] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

Table 6. Mass of body components for steers from different stocker production programs at final harvest in Experiment 2

Item	Treatment[1]				SEM	*P*-value
	CON	CORN	LGWP	HGWP		
Steers, No.	4	4	4	4	-	-
Live BW[2], kg	625	599	592	577	24.32	0.59
Empty BW, kg	557	534	528	514	21.68	0.58
	g/kg of empty BW					
Carcass	668	693	678	681	11.59	0.52
Heart	5.55	5.71	5.51	6.13	0.23	0.27
Lungs-trachea	7.17	7.32	7.21	6.47	0.37	0.40
Reticulo-rumen	25.03[bc]	23.44[ab]	21.62[a]	25.86[c]	0.78	0.01
Omasum	7.09[b]	6.71[b]	5.66[a]	5.37[a]	0.26	0.01
Abomasum	3.38	2.76	3.41	3.51	0.20	0.08
Small intestine	11.40	12.12	10.48	10.87	0.60	0.29
Large intestine	6.54	7.11	6.16	6.38	0.52	0.62
Total GIT[3]	53.44[b]	52.15[b]	47.32[a]	51.99[b]	1.38	0.04
Mesenteric/omental fat	47.19	41.87	39.33	47.79	2.70	0.13
Total viscera[4]	100.63[b]	94.02[b]	86.65[a]	99.78[b]	2.26	0.01
Pancreas	1.06	1.01	0.88	1.18	0.08	0.13
Spleen	2.19[b]	1.77[a]	1.84[a]	1.66[a]	0.09	0.01
Liver	17.51[b]	14.63[a]	15.04[a]	15.45[a]	0.56	0.02
Total splanchnic tissue[5]	121.39[c]	111.42[ab]	104.42[a]	118.08[bc]	2.59	0.01
Kidney	1.99	2.05	2.08	2.25	0.08	0.21
KPH	13.28	14.15	11.22	13.87	0.97	0.19

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] Live BW = 5-h shrunk live BW when steers were withheld from feed and water.

[3] Total GIT (gastrointestinal tract) was calculated as the sum of the reticulo-rumen, omasum, abomasum, small intestine, and large intestine.

[4] Total viscera was calculated as total GIT plus the mesenteric/omental fat.

[5] Total splanchnic tissue was calculated as total viscera plus liver, spleen, and pancreas.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 7. Carcass and empty BW chemical composition for the initial harvest steers in Experiments 1 and 2

	Experiment 1		Experiment 2	
Item	Mean	SD	Mean	SD
Steer, No.	4	-	4	-
HCW, kg	126	10.75	138	29.15
12th-rib fat, mm	0.25	0.51	2.67	1.73
KPH, %	0.88	0.25	0.55	0.06
Mesenteric/omental fat, kg	3.22	0.72	4.86	1.65
Marbling score	220	34.64	148	48.56
Carcass density	1.076	0.004	1.049	0.007
Garrett and Hinman, (1969)				
Carcass ether extract, %	17.23	2.31	31.26	3.68
Carcass water, %	59.82	1.63	49.90	2.60
Carcass nitrogen, %	2.95	0.09	2.42	0.14
Carcass energy, kcal/gm	2.61	0.19	3.76	0.30
Sainz et al., (1995)				
Carcass fat, %	11.93	0.84	13.54	1.61
Empty body fat, %	10.16	0.79	11.65	1.50

Table 8. Carcass and empty BW chemical composition for steers from different stocker production programs at the first and second intermediate harvest in Experiment 1

	Treatment[1]							
	First Intermediate[2]				Second Intermediate[2]			
Item	CON	CORN	LGWP	HGWP	CON	CORN	SEM	*P*-value
Steers, No.	3	3	3	3	3	3	-	-
HCW, kg	150[a]	180[ab]	210[b]	238[c]	188[b]	208[bc]	11.64	0.01
12th-rib fat, mm	0.34[a]	1.02[ab]	1.69[ab]	8.47[c]	1.69[ab]	2.71[b]	0.57	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
Mesenteric/omental fat, kg	1.53[a]	2.64[a]	5.34[b]	10.84[c]	4.74[b]	5.99[b]	0.69	0.01
Marbling score	180[a]	217[ab]	280[c]	340[d]	233[ab]	240[bc]	18.36	0.01
Carcass density	1.068	1.066	1.067	1.056	1.063	1.068	0.005	0.61
Garrett and Hinman, (1969)								
Carcass ether extract, %	21.54	22.29	21.69	27.58	23.96	21.57	2.75	0.61
Carcass water, %	56.77	56.24	56.66	52.50	55.06	56.75	1.95	0.61
Carcass nitrogen, %	2.78	2.75	2.78	2.55	2.69	2.78	0.10	0.61
Carcass energy, kcal/gm	2.96	3.02	2.97	3.46	3.16	2.96	0.23	0.61
Sainz et al., (1995)								
Carcass fat, %	10.47[a]	11.41[ab]	13.48[bc]	20.97[d]	13.16[bc]	14.62[c]	0.69	0.01
Empty body fat, %	8.78[a]	9.66[ab]	11.61[c]	18.60[d]	11.30[bc]	12.67[c]	0.65	0.01

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[2] First Intermediate harvest was conducted at the end of winter grazing; Second Intermediate harvest was conducted at the end of summer grazing.

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

Table 9. Carcass and empty BW chemical composition for steers from different stocker production programs at intermediate harvest in Experiment 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
Steers, No.	4	4	4	4	-	-
HCW, kg	207	201	226	204	6.90	0.09
12th-rib fat, mm	3.56	0.64	3.56	4.57	0.93	0.06
KPH, %	0.63[a]	0.50[a]	1.13[b]	1.38[b]	0.11	0.01
Mesenteric/omental fat, kg	6.50	4.70	7.44	7.65	0.85	0.11
Marbling score	158[a]	143[a]	315[c]	228[b]	21.76	0.01
Carcass density	1.069	1.066	1.065	1.051	0.006	0.21
Garrett and Hinman, (1969)						
Carcass ether extract, %	20.94	22.24	22.95	30.31	3.19	0.21
Carcass water, %	57.20	56.28	55.77	50.57	2.25	0.21
Carcass nitrogen, %	2.81	2.76	2.73	2.45	0.12	0.21
Carcass energy, kcal/gm	2.91	3.02	3.08	3.86	0.26	0.21
Sainz et al., (1995)						
Carcass fat, %	15.00[ab]	12.34[a]	16.29[b]	17.32[b]	0.94	0.02
Empty body fat, %	13.02[ab]	10.54[a]	14.24[b]	15.20[b]	0.88	0.02

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 10. Carcass and empty BW chemical composition for steers from wheat pasture stocker programs at final harvest in Experiment 1

	Treatment[1]			
Item	LGWP	HGWP	SEM	*P*-value
Steers, No.	3	3	-	-
HCW, kg	384	366	20.21	0.55
12th-rib fat, mm	16.93	16.51	2.90	0.92
KPH, %	1.33	1.83	0.17	0.10
Mesenteric/omental fat, kg	21.18	24.60	1.89	0.27
Marbling score	383	343	19.44	0.22
Carcass density	1.052	1.052	0.002	0.82
Garrett and Hinman, (1969)				
Carcass ether extract, %	29.73	30.09	1.07	0.82
Carcass water, %	50.98	50.72	0.76	0.82
Carcass nitrogen, %	2.47	2.46	0.04	0.82
Carcass energy, kcal/gm	3.63	3.66	0.09	0.82
Sainz et al., (1995)				
Carcass fat, %	30.88	33.31	1.70	0.37
Empty body fat, %	27.89	30.18	1.58	0.36

[1] LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

Table 11. Carcass and empty BW chemical composition for steers from different stocker production programs at final harvest in Experiment 2

	Treatment[1]					
Item	CON	CORN	LGWP	HGWP	SEM	*P*-value
Steers, No.	4	4	4	4	-	-
HCW, kg	371	370	358	350	15.28	0.74
12th-rib fat, mm	11.81	15.24	16.83	17.78	1.59	0.09
KPH, %	1.75	1.50	1.63	1.75	0.16	0.64
Mesenteric/omental fat, kg	26.33	22.41	20.95	24.63	1.99	0.28
Marbling score	395[bc]	418[c]	363[ab]	340[a]	17.71	0.04
Carcass density	1.057	1.056	1.064	1.054	0.002	0.06
Garrett and Hinman, (1969)						
Carcass ether extract, %	27.36	29.03	24.91	30.20	1.25	0.06
Carcass water, %	52.66	51.48	54.39	50.65	0.89	0.06
Carcass nitrogen, %	2.56	2.50	2.66	2.46	0.05	0.06
Carcass energy, kcal/gm	3.44	3.58	3.24	3.67	0.10	0.06
Sainz et al., (1995)						
Carcass fat, %	31.71	30.95	31.16	33.84	1.50	0.53
Empty body fat, %	28.74	27.97	28.15	30.67	1.41	0.53

[1] CON = 40 % CP supplement; CORN = corn-based supplement; LGWP = low rate of gain on wheat pasture; HGWP = high rate of gain on wheat pasture.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

VITA

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Doctor of Philosophy

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Three experiments were conducted to determine the effects of energy supplementation, rate of gain, and type of fermentation from different grazing programs on subsequent finishing performance, carcass characteristics, body composition, and visceral organ mass in growing beef cattle. The first experiment examined the effects of starch- vs. fiber-based energy supplements in steers grazing dormant native range (**DNR**). Energy supplementation increased grazing ADG compared with the control steers, and the starch supplemented steers had greater ADG compared with the two fiber-based supplemented treatments. At intermediate harvest, energy supplementation increased mesenteric fat deposition compared with the control steers, but there were no differences in 12th-rib fat or marbling score. At the end of finishing, there were no differences in final carcass quality suggesting that total energy intake was too low in this production system to influence marbling deposition. The second and third experiment examined the effects of forage energy intake and type of fermentation on fat deposition in stocker cattle grazing DNR or winter wheat pasture (**WP**). The control and starch-based energy supplement were the same as in the first experiment, but 2 different stocking rates were used on WP to produce differing rates of gain. The experiments were designed to determine differences in fat deposition at a similar age and similar HCW prior to finishing and the subsequent effects on finishing performance and final carcass quality. Grazing ADG was 0.19, 0.52, 0.68, and 1.37 kg/d in the second experiment and 0.49, 0.63, 0.84, and 1.41 kg/d in the third experiment for the control, starch-supplemented, and low and high rate of gain wheat pasture steers, respectively. At intermediate harvest, the WP treatments had greater 12th-rib fat, marbling score, and carcass body fat compared with the DNR treatments. At the end of finishing, there were no differences in final carcass quality or carcass body fat among the treatments for either experiment. These results show that stocker cattle grazing programs that result in higher rates of gain and (or) higher ruminal propionate concentrations increase intramuscular fat and 12th-rib fat at the end of grazing. Intramuscular fat increased linearly with rate of gain and energy intake during the stocker phase, whereas 12th-rib fat increased quadratically. However, final marbling score was not influenced by the different grazing programs when steers were fed to a similar 12th-rib fat endpoint.

ADVISER'S APPROVAL: Dr. Gerald W. Horn