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ANABOLIC HORMONE EXPOSURE DURING VARIOUS STAGES OF GROWTH:
EFFECTS ON POST-WEANING PERFORMANCE, FRAME SIZE, AND CARCASS
CHARACTERISTICS OF CALF-FED STEERS

BY
WESLEY W. GENTRY

A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy

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2019

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EFFECTS ON POST-WEANING PERFORMANCE, FRAME SIZE, AND CARCASS
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WESLEY W. GENTRY

This dissertation is approved as a credible and independent investigation by a candidate for the Doctor of Philosophy in Animal Science degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CONTENTS

ABBREVIATIONS	viii
LIST OF TABLES.....	x
ABSTRACT.....	xii
CHAPTER I : REVIEW OF LITERATURE.....	1
INTRODUCTION	1
GROWTH.....	2
Concepts, Primary Tissues, and Composition	2
Frame Size	7
GROWTH PROMOTING IMPLANTS	11
Mechanisms of Action of Estrogens and Androgens.....	12
Combination Implants.....	15
Production Responses to Anabolic Implants	17
Extended-Release Implants.....	19
Implant Strategies	21
LITERATURE CITED.....	26
CHAPTER II: EFFECTS OF SUCKLING-PHASE IMPLANTS ON WEANING WEIGHT, POST-WEANING GROWTH PERFORMANCE, AND CARCASS CHARACTERISTICS OF STEER CALVES.....	43
ABSTRACT.....	43
INTRODUCTION	44
MATERIALS AND METHODS.....	45
Suckling-Phase.....	46

Receiving-Phase.....	46
Backgrounding and Finishing-Phase	49
Procedures Throughout All Phases.....	51
RESULTS AND DISCUSSION.....	52
Suckling-Phase.....	52
Receiving-Phase.....	53
Backgrounding and Finishing-Phase	56
LITERATURE CITED.....	61
CHAPTER III: EFFECT OF ANABOLIC HORMONE EXPOSURE DURING THE	
BACKGROUNDING-PHASE IN CALF-FED STEERS OF DIFFERENT FRAME	
SIZES	74
ABSTRACT.....	74
INTRODUCTION	75
MATERIALS AND METHODS.....	77
Exp. 1	77
Exp. 2	81
RESULTS	84
Exp. 1	84
Exp. 2	86
DISSCUSSION.....	89
Frame Size – Exp. 1 & 2.....	89
Backgrounding Implant – Exp. 1	97
Backgrounding Implant – Exp. 2	99

IMPLICATIONS 105

LITERATURE CITED 106

ABBREVIATIONS

ADG	average daily gain
AFBW	shrunk weight at 28% empty body fat
BF	back fat depth
BW	body weight
CH	conventional implant containing 14 mg estradiol benzoate and 100 mg trenbolone acetate
DM	dry matter
DMI	dry matter intake
E ₂	estradiol
EB	estradiol benzoate
EBF	empty body fat
FS	frame size
G:F	gain: feed
GED	estimated gain energy density
HCW	hot carcass weight
IGFBP	insulin like growth factor binding protein
IGF-I	insulin like growth factor-I
IMP	implant treatment
KPH	kidney pelvic and heart fat
LG	larger-framed
MBS	metabolic body size
NI	non-implanted (Chapter III)
NONE	non-implanted (Chapter II)
ONE-F	extended release implant containing 28 mg estradiol benzoate and 200 mg trenbolone acetate
ONE-G	extended release implant containing 21 mg estradiol benzoate and 150 mg trenbolone acetate
P	progesterone

REA	ribeye area
R-XS	extended release implant containing 40 mg estradiol and 200 mg trenbolone acetate
SEM	standard error of the mean
SM	smaller-framed
SS	conventional implant containing 20 mg estradiol benzoate and 200 mg progesterone
SYN-C	conventional implant containing 10 mg estradiol benzoate and 100 mg progesterone
TBA	trenbolone acetate
WW	weaning weight

LIST OF TABLES

Table 2.1. Chronology of significant events.....	67
Table 2.2. Actual ingredient and nutrient composition of diets.....	68
Table 2.3. Effect of suckling-phase implants on weaning weight of steers calves.....	69
Table 2.4. Effect of suckling-phase implants and subsequent receiving-phase performance of steer calves	70
Table 2.5. Effect of suckling-phase implants on circulating IGF-I concentrations in steer calves	71
Table 2.6. Effect of a suckling-phase implant containing estradiol benzoate and trenbolone acetate on backgrounding-phase, finishing-phase, live and carcass- adjusted performance of steer calves.....	72
Table 2.7. Effect of a suckling-phase implant containing estradiol benzoate and trenbolone acetate on carcass characteristics of steer calves	73
Table 3.1. Actual formulation and nutrient composition of diets fed in Exp. 1	114
Table 3.2. Actual formulation and nutrient composition of diets fed in Exp. 2	115
Table 3.3. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on interim performance corresponding to management in steer calves fed for 161 d in Exp. 1.....	116
Table 3.4. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on cumulative and carcass adjusted performance in steer calves fed for 161 d in Exp. 1	117

Table 3.5. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on carcass characteristics, empty body fat, and calculated frame score of steer calves fed for 161 d in Exp. 1	118
Table 3.6. Main effects of frame size and backgrounding estradiol benzoate and progesterone on interim performance corresponding to management in steer calves fed for 168 d in Exp. 2.....	119
Table 3.7. Main effects of frame size and backgrounding estradiol benzoate and progesterone on cumulative and carcass adjusted performance in steer calves fed for 168 d in Exp 2.....	120
Table 3.8. Main effects of frame size and backgrounding estradiol benzoate and progesterone on carcass characteristics, estimated empty body fat, and calculated frame score of steer calves fed for 168 d in Exp 2.....	121

ABSTRACT

ANABOLIC HORMONE EXPOSURE DURING VARIOUS STAGES OF GROWTH:
EFFECTS ON POST-WEANING PERFORMANCE, FRAME SIZE, AND CARCASS
CHARACTERISTICS OF CALF-FED STEERS

WESLEY W. GENTRY

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The growth promoting activity of implants have been documented. However, stage of growth in which the implant is administered may alter growth performance and carcass traits. An experiment was conducted to examine the effects of administering a conventional implant (Synovex C; **SYN-C**), or an extended-release combination implant (Synovex One Grass; **ONE-G**) to suckling steer calves on weaning weight, post-weaning growth performance, and carcass characteristics. Suckling steer calves were either not implanted (**NONE**) or were implanted with SYN-C or ONE-G. Steer calves were predominantly 30 to 60 d of age when implants were administered. Steers were weaned 176 d post-suckling implant administration. Weaning weight was greater for steers implanted with SYN-C compared to NONE (285 vs 291 \pm 1.1 kg; $P = 0.04$), and greater for steers implanted with ONE-G compared to SYN-C (291 vs 297 \pm 1.1 kg; $P = 0.02$). Steers were used in a 44-d receiving experiment, fed a common diet, and no implants were administered. No differences in receiving-phase growth performance were observed ($P \geq 0.57$). At the conclusion of the receiving experiment, NONE and ONE-G steers were used in a backgrounding and finishing experiment. All steers were implanted with 14 mg estradiol benzoate and 100 mg trenbolone acetate on d 49 and 28 mg estradiol benzoate and 200 mg trenbolone acetate on 129 and were fed for a total of 211 d. Steers implanted

with ONE-G during the suckling-phase were heavier than NONE steers at the onset of the backgrounding-phase (334 vs. 323 ± 0.9 kg; $P < 0.01$). By d 129 there were no differences in body weight ($P = 0.98$). No difference in cumulative dry matter intake (**DMI**) was observed ($P = 0.26$). On a cumulative carcass-adjusted basis NONE steers had greater gain-to-feed (G:F) than ONE-G steers (0.186 vs 0.174 ± 0.0035 ; $P = 0.04$). Steers implanted with ONE-G had a larger ribeye area than NONE steers, despite being implanted similarly in the feedlot (91.32 vs. 88.19 ± 0.893 cm²; $P = 0.05$). No differences were observed for other carcass characteristics or Quality Grade ($P \geq 0.24$). Percent empty body fat at harvest was not different for NONE and ONE-G steers ($P = 0.45$). The ONE-G implant is labeled for 200 d of implant coverage (FDA, 2014). To evaluate the potential anabolic effects of ONE-G in the feedlot, we chose not to re-implant steers until 226 d post-suckling implant administration. Therefore, steers implanted with ONE-G steers did not have continuous exposure to an active implant. Differences in early growth performance may be a consequence of discontinuous exposure to anabolic agents. Administering ONE-G during the suckling-phase did not diminish carcass quality. Future research should evaluate implant strategy options to follow ONE-G in suckling calves.

Two experiments were conducted to evaluate potential interaction of frame size (**FS**) and implant status in calf-fed steers. Steer calves from the same 2 sources were used in each experiment and were managed similarly from weaning to study initiation. Steers were the product of a 50-d calving season, so it was assumed differences in FS were reflected in weaning weight (**WW**). Smaller-framed (**SM**) and larger-framed (**LG**) steers were identified from tails of the WW distribution. Within each FS group, steers were implanted with 20 mg estradiol benzoate and 200 mg progesterone (**SS**) or 14 mg

estradiol benzoate and 100 mg trenbolone acetate (**CH**) on d 1 (Exp. 1), and non-implanted (**NI**) or implanted with SS on d 2 (Exp. 2). In both experiments, all steers were terminally implanted with 24 mg estradiol and 120 mg trenbolone acetate on d 84 and fed for 161 (Exp.1) and 168 d (Exp.2). No FS × implant interactions were observed in either experiment ($P \geq 0.08$). In both experiments LG steers had heavier body weights (**BW**), HCW, and BW adjusted to 28% empty body fat (**AFBW**), greater average daily gain (**ADG**), DMI, and feed:gain (**FG**) than SM steers ($P \leq 0.02$). No differences were evident in marbling score or Quality Grade distributions between SM and LG steers ($P \geq 0.13$). In Exp. 1, no differences in growth performance, carcass traits, AFBW, or calculated FS were observed for steers initially implanted with SS or CH ($P \geq 0.12$). In Exp. 2, steers implanted initially with SS had heavier final BW, greater ADG and DMI ($P \leq 0.01$), and no difference in FG ($P = 0.78$) than NI steers. Steers initially implanted with SS had heavier HCW ($P < 0.01$), but no other differences in carcass characteristics were observed ($P \geq 0.23$). Additionally, steers implanted with SS tended to have heavier AFBW ($P = 0.07$) and greater calculated FS ($P = 0.05$) than NI steers. Steers of different FS responded similarly to implants while in the feedlot. Previous exposure to implants did not alter the response to the terminal implant. Estradiol implants increase the FS of steers; however, when similar doses of estradiol are compared, trenbolone acetate does not further increase FS.

CHAPTER I : REVIEW OF LITERATURE

INTRODUCTION

Growth of domesticated livestock has fascinated humankind for centuries; likely since the domestication of sheep around 8,000 BC (Mignon-Grasteau et al., 2005). Information involving body composition of cattle prior to and following the fattening phase appears in the first edition of the classical Feeds and Feeding handbook by Henry (1898). Many publications on the subject of animal growth have appeared since, including those with an emphasis on primarily cattle (Berg and Butterfield, 1976). Early studies aimed to understand the phenomena of growth, while more recent studies have attempted to alter growth. Excluding effects of under or overnutrition, steroidal implants are unmatched in their ability to alter normal growth. Steroidal implants are compressed pellets that contain estrogens and androgens, alone or in combination, as well as various inert carrier compounds. The implant is placed subcutaneously in the back of the ear in cattle. After administration the implant will begin to dissolve slowly, and steroid hormones are carried by the blood stream to all tissues of the body. Use of a potent implant can increase slaughter weight of an animal by 70 kg (NASEM, 2016). Anabolic agents have been approved for use in the United States since 1954 in the form of oral diethylstilbestrol, and the first implant was approved in 1956 (estradiol benzoate and progesterone; Raun and Preston, 2002). Research has continued in the area of growth promotion with the most recent anabolic implant receiving approval in 2017 (FDA, 2017). Growth-promoting implants have the largest return on investment compared with any other technology available. Implants are approved for all stages of terminal

production including calf-hood, stocker, and feedlot. Approximately 90% of heifers and steers receive at least one implant while in the feedlot (APHIS, 2013). The efficacy and safety of implants have been demonstrated (Preston, 1999), and efforts to explore their optimal use in conjunction with the intrinsic growth of cattle is most warranted.

GROWTH

Growth can be defined as an increase in size and changes in functional capabilities of various organs and tissues from conception to birth (Grant and Helferich, 1991). While there are profound changes in size, shape and function of cells, tissues, and organs that occur in the fetus from conception to parturition, this review will focus on post-natal growth of ruminant animals. Post-natal growth is largely due to hypertrophy (increase in cell size), but one can argue that hyperplasia (increase in cell number) also occurs (Grant and Helferich, 1991). The latter is due to recruitment of satellite cells into muscle fibers in the post-natal phase. However, it should be noted that the primary unit of skeletal muscle is the muscle fiber, and number of muscle fibers are fixed at birth. Any observed growth in muscle fibers is because of increases in fiber size which by definition is hypertrophy (Forrest et al., 1975). The immediate post-natal phase of growth is regarded as a period of great differentiation in regard to relative amounts of skeletal muscle. This phase is accomplished in a period of about 8 weeks, in that time the animal has approximately doubled its birth weight (Berg and Butterfield, 1976).

Concepts, Primary Tissues, and Composition

Growth in animals is generally described as relative amounts of bone, muscle, and adipose because they are the primary tissues of the body excluding viscera. Haecker (1920), Moulton (1923), and Hammond (1932) were some of the first to characterize

growth of primary tissues. They concluded that bone and muscle were early developing tissues with a high impetus for growth early in life, and adipose was a latter developing tissue with a low impetus for growth initially, but a high impetus for growth as maturity was approached. Wilson and Osbourne (1960) list tissues achieving their maximum rate of growth in the following order from first to last; nervous tissue, skeletal tissue, muscular tissue, and finally adipose tissue. However, it should be noted that these tissue types do not develop or grow independently of one another, and that considerable overlap occurs (Berg and Butterfield, 1976). When one considers that a lesser average daily gain (ADG) causes a lesser weight of viscera (Ferrell et al., 1986), and that yearling cattle have typically experienced a slow rate of ADG while maintaining an ample skeletal size one might speculate that the skeleton has energetic priority over the viscera once maintenance energy requirements are met.

Compositional changes in growth can also be expressed in purely chemical terms by quantifying relative proportions of water, ash, crude protein (nitrogen), and fat (ether extract). It should be noted that while the tissue and chemical metric of explaining growth are both useful and ultimately have a similar objective, the two forms of measure are not synonymous. This becomes apparent when one analyzes the chemical composition of skeletal muscle, or the chemical fat in different adipose depots in cattle. Chemical composition of muscle from a steer is: 72.90% water, 20.33% protein, 5.64% fat, and 0.94% ash (Berg and Butterfield, 1976). The chemical fat content of adipose appears to be dependent upon depot site, in that the subcutaneous, intermuscular, kidney and mesenteric adipose depots contain 76.69, 70.94, 93.39, and 82.68% chemical fat, respectively (Berg and Butterfield, 1976). Each respective tissue type has a variable

chemical composition with obvious relationships for example; bone contains primarily ash, muscle contains primarily protein, and adipose contains primarily fat. While tissue composition and chemical composition are different measures, similarities are evident. For example, in steers the protein: ash ratio is relatively constant, especially from puberty to maturity (4.4 ± 0.05 ; Haecker, 1920), and the muscle: bone ratio yields a similar value (range 3.9-4.8; Berg and Butterfield, 1976).

Composition of the fat-free mass (water, bone, muscle) varies little with pigs and sheep regardless of previous plane of nutrition (Elsley et al., 1964). Authors concluded that variation in fat content is due to tissue function. Adipose tissue has a function very different than bone and skeletal muscle, in that it primarily serves as a means to store energy in excess of maintenance and lean growth potential. Similarly, the ratio of protein to ash is relatively constant when fat content is excluded (Murray, 1922). Reid et al. (1968) reports concentrations of water, protein, and ash in the fat-free empty bodies of cattle to be 72.91, 21.64, and 5.34%, respectively. On a dry matter basis, composition of protein and ash in the fat-free empty bodies of cattle are 80.26 and 19.74%, respectively. Similar proportions are found in pigs and sheep, perhaps with slightly greater protein and lesser ash (Reid et al., 1968).

Because empty body composition can be divided into fat-free and fat pools with little error, researchers have employed measure of specific gravity based on the principle of Archimedes to estimate water and fat content (Messinger and Steele, 1949; Kraybill et al., 1951). Density is a good estimator of body composition if groups of animals are used, special attention is paid to carcass and immersion water temperature, and amount of air trapped in the carcass is minimized (Garrett, 1968). This method was used in generating

retained energy in the California Net Energy System (Lofgreen and Garrett, 1968; Garrett, 1980) which serves as the cornerstone of predicting energy requirements of cattle (NASEM, 2016). The system has been updated with adjustment factors since its inception and accuracy is excellent for large groups of cattle if correct input parameters are chosen (Anderson, 2017). Carcass specific gravity has one large limitation, in that the animal can only be harvested once. This limitation has caused researchers to explore use of tracers, which become uniformly distributed throughout a compartment in the animal body. The most popular technique used in ruminants is the urea space dilution technique. After a blood sample is obtained a known amount of urea is administered intravenously, and several minutes later another blood sample is obtained. Urea space is calculated by dividing amount of injected urea by the increase in plasma urea concentration. Urea space can then be used to estimate the amount of body water and fat (Preston and Kock, 1973).

Another nondestructive means of estimating body composition which has widespread use is ultrasound technology. Greiner et al. (2003) concluded that 84 percent of the variation in total retail product weight, and 61 percent of the variation in retail product percentage could be explained measurements collected from ultrasound of the live animal 5 d prior to slaughter. Additionally, Ribeiro and Tedeschi (2012) demonstrated that internal fat can be accurately estimated ($r^2 = 0.84$) by using real-time ultrasound measurements. Baker et al. (2006) constructed a regression equation using ultrasound measurements and predicted carcass weight to estimate the percent empty body fat of bulls. The variables used in the equation accounted for 62% of the variation empty body fat. Ultrasound technology is also used to ensure that cattle used in research experiments are slaughtered at a similar compositional endpoint.

Direct measurement of body composition by dissection, or chemical analysis is very time consuming. For chemical analysis, an entire side of a carcass must be comminuted and accurately subsampled. The sheer size of a beef carcass leads to a tremendous amount of work. This obstacle lead researchers to evaluate whether portions of a carcass were suitable as a substitute for whole-carcass grinding. Hankins and Howe (1946) concluded that composition of the 9-10-11 rib section was highly correlated with composition of the whole carcass. The caveat to using the procedure is obtaining the exact rib portion; erroneous values may be realized if care is not taken in obtaining the correct sample. Nonetheless, the 9-10-11 rib section method has received great use in efforts to determine the body composition of cattle.

Some researchers have argued that the growth of adipose tissue should be considered separately from muscle or bone not only because composition of the fat-free body is relatively constant as discussed above, but also because adipose tissue has a different function than muscle or bone in that it largely serves as a means of surplus energy storage (Elsley et al., 1964). The idea that adipose tissue is a late-developing tissue, and that adipose seems to have the lowest priority of energy use for growth can be misleading if one considers distribution of adipose tissue in the body. Cianzio et al. (1982) investigated growth and distribution of adipose tissue in serially-slaughtered steers of two different frame sizes. The authors used the allometric equation of Huxley (1932) to determine relative growth rate of various adipose depots and concluded that the intramuscular adipose depot develops at a constant rate, while the subcutaneous, intermuscular, and kidney plus pelvic adipose depots are late developing. Bruns et al. (2004) harvested calf-fed steers (placed in the feedlot immediately after weaning) of

similar genetics at varying weights (352 to 587 kg shrunk weight) over two years. Marbling score increased linearly, and rib fat increased at an increasing rate as carcass weight increased. In other words, development of intramuscular adipose depots differs from development of subcutaneous adipose depots. Bruns et al. (2004) confirmed the work of Cianzio et al. (1982) in indicating intramuscular adipose tissue is not late-developing as is the subcutaneous adipose tissue but develops at a consistent rate. Similarly, McMeeken (1940) observed a larger difference in the amount of subcutaneous fat deposited than intramuscular fat deposited in pigs on differing planes of nutrition. The differences suggest that the subcutaneous and intramuscular fat depots develop at least somewhat independently of one another.

In early studies differences in the body composition of bulls, steers, and heifers were noted at similar body weights (Berg and Butterfield, 1976). Differences were also evident when comparing different breeds of a common sex and weight (Simpfendorfer, 1974). Differences in growth rate, and body composition at a given weight are even apparent within a breed. Although, the differences are usually of a lesser magnitude within breed than between breed. Variation of growth rate within a breed can be due to multiple factors but is largely correlated to frame size.

Frame Size

Frame size is correlated with growth rate, and furthermore weight at slaughter (1.27 cm rib fat) so much so that frame scores were implemented in 1979 and still serve as a classification variable (along with muscle scores) for marketing feeder cattle today (Tatum et al., 1986; USDA, 2000). The 1984 sixth-edition of the Nutrient Requirements of Beef Cattle adjusted the coefficient of the shrunk weight gain equation of Garrett

(1980) based upon sex and frame size (NRC, 1984). An important concept to recognize is that different frame-sized cattle are capable of achieving similar carcass characteristics, albeit at differing body weights. Crickenberger et al. (1978) fed small and average-framed Angus steers to a carcass fat of 31.14 and 31.04%, respectively. At a similar carcass fat content, average-framed steers yielded 34 kg of additional carcass weight over the small-framed steers. Similarly, Byers (1980) observed greater carcass weights in cattle of a large frame versus those of a smaller frame adjusted to a similar degree of fatness. Fox and Black (1984) calculated empty body weights at which different frame sizes of cattle reach a similar chemical composition and as would be expected weight increased as frame size increased.

Cattle of differing frame sizes are capable of achieving a similar body composition but at different body weights. A popular question is if a similar composition can be achieved in a similar amount of time. Williams et al. (1987) fed small and large-framed cattle for 175 d. As expected, large-framed cattle had heavier initial and final body weights, as well as, greater ADG and dry matter intake (**DMI**). Small and large-framed steers achieved a similar degree of fat-thickness after 175 d on feed (1.3 and 1.4 ± 0.17 cm, respectively). Solis et al. (1989) observed similar results in feeding large and very large-framed steers with only 2 d difference in days on feed. Very large-framed steers were heavier from initiation and throughout while gaining at an increased rate and consumed more feed than large-framed steers. Final empty body fat (**EBF**) was 21.9 and $23.2 \pm 1.3\%$ for large and very large framed steers, respectively.

Contrary to these results Cianzio et al. (1982) fed smaller and larger-framed steers to 465 and 468 ± 2.2 d of age and observed carcass fat to be 29.0 and $26.1 \pm 1\%$,

respectively. The authors report that carcass fat was not statistically different. However, the reported 3 percentage point difference is biologically relevant in that the difference could be an entire quality grade (NASEM, 2016). Cianzio et al. (1982) observed no difference in ADG between smaller and larger-frame sized steers which is likely the reason for the reduced fat content at a similar day of age. If larger-framed steers have an accelerated growth rate compared to smaller-framed steers they indeed may be able to achieve a similar degree of fatness in a similar amount of time. However, if ADG is similar for larger and smaller-framed steers, additional days on feed will likely be required to achieve a similar fat content. This is because at a similar ADG, composition of gain in a larger-framed steer is leaner compared with that of a smaller-framed steer. Therefore, a larger-framed steer must gain at an accelerated rate to achieve the same composition of gain as a smaller-framed steer.

Once it was demonstrated that cattle of different frame sizes were capable of reaching a similar body composition at similar days in the feedlot, researchers were able to simplify equations in growth models by scaling body weight to reference degree of maturity. This was accomplished by using the medium frame steer equation of Garrett (1980), and scaling weight at a specific amount of EBF using the equivalent body weight system of Fox and Black (1984) and Tylutki et al. (1994).

The concept of assessing growth in relation to a reference point was discussed by Berg and Butterfield (1976). Instead of using a specific degree of fatness as their reference, they compared the growth of certain body components in reference to the weight of bone plus muscle, ratio of muscle to bone, or ratio of protein to ash. Whether EBF or the ratio of muscle to bone is used, the objective is to reference degree of

maturity. The concept of mature weight is puzzling if one considers that different tissues have different growth rates, and maturity is defined as a tissue having attained the highest stage of complexity or mass (Forest et al., 1975; Owens et al., 1993). Even within one tissue type, bone for example, termination of growth does not occur simultaneously (Forest et al. 1975). Maturity alone is ambiguous and needs more context to be correctly understood (Owens et al., 1995). Owens et al. (1993) defined maturity as “the point of maximum protein mass, despite increased fat deposition that can occur beyond this point” and noted that maturity can occur when fat content of the empty body reaches 34-37%. It seems appropriate to define this point as physiological maturity of skeletal mass. The NASEM (2016) growth model uses chemical maturity instead of physiological maturity, which is generally 28% EBF (i.e. when low-Choice quality grade is achieved). If 30% EBF is a reasonable estimate of the chemical maturity in which cattle are marketed today, then cattle are marketed at approximately 81-88% of physiological maturity.

Previous plane of nutrition can alter the weight at which an animal reaches a certain chemical maturity. This is apparent in current beef cattle production practices such as calf-feeding and growing calves to become yearlings (Owens et al., 1995). To define the systems, a calf-fed steer is one that is weaned and placed immediately into the feedlot, whereas a yearling steer has grazed forage for a period of several months before entering the feedlot and is approximately one year of age. Griffin et al. (2007) compared animal performance data from the University of Nebraska from 1996-2004. Steers were received in the fall and heavier, large-framed steers were placed in the feedlot while lighter, small-framed steers were grazed on cornstalks during the winter, grass pasture during the summer, and subsequently finished in the feedlot. Initially the calf-fed steers

were on a higher plane of nutrition than the yearling steers. Calf-fed and yearling steers were harvested at a rib fat thickness of 1.35 and 1.19 ± 0.025 cm and yielded a carcass weight of 367 and 390 ± 2.3 kg, respectively. The higher plane of nutrition allowed the calf-fed steers to deposit more adipose tissue early, thus slaughter occurred at a lesser carcass weight than yearlings, but at a similar carcass composition. These data support the argument proposed by Owens et al. (1995) that “body composition when expressed as a percentage of mature weight or size may be fixed, but mature size, rather than being fixed, may be elastic.”

GROWTH PROMOTING IMPLANTS

Another practice that alters the weight at which an animal is compositionally fit for slaughter is the use of growth promoting implants. Steroidal implants effectively increase the frame size of the animal and allow for an increased weight at a defined chemical maturity. This phenomenon was first demonstrated by Preston (1978) who repeatedly administered diethylstilbestrol implants to Hereford-Angus and Charolais steers every 84 d for 486 d. Final body weight was 13-18% heavier for steers receiving implants, and hip height was increased by approximately 3 cm. Loy et al. (1998) demonstrated that an implant containing 36 mg zeranol or 20 mg estradiol benzoate (**EB**) and 200 mg progesterone (**P**) increased the frame size of steers fed for 189 d. Guiroy et al. (2002) conducted a meta-analysis involving 13 implant trials. Results indicated that steers implanted aggressively were 42 kg heavier at slaughter at a similar body composition as unimplanted steers.

Implants increase weight at slaughter, growth rate, feed efficiency, and in some cases carcass leanness (Preston, 1999). Combination implants, that contain an estrogen

and androgen are widely used today. However, it is important to note that implants are estrogen-based (Preston, 1999) because in steers estrogen alone elicits as much of a growth response (Bartle et al., 1992; Hutcheson et al., 1997) as an androgen alone, and in some cases a greater response is observed (Herschler et al., 1995). In heifers, an androgen may yield a more favorable response than an estrogen alone (Herschler et al., 1995; Pritchard and Rust, 1997); however, this can be explained when one considers the heifer has an endogenous source of estrogen. When heifers are ovariectomized the growth response from the implant is similar to that observed in steers (Pritchard and Rust, 1997).

Implants are regulated by law and must undergo rigorous multi-site testing before being approved by the U.S. Food and Drug Administration. The mechanisms of action will be subsequently reviewed, but it is worthwhile to note that arguably the most important aspect of implantation is correct placement. Implant site abnormalities may inhibit hormones from dissolving from the excipient into the blood stream and reaching tissues as intended. Indeed, the most costly implant abnormality in terms of feedlot profitability is a missing implant (Berry et al., 2000).

Mechanisms of Action of Estrogens and Androgens

Growth promoting implants can contain one compound alone or two in combination including: estradiol (**E₂**), EB, zeranol, P, testosterone propionate, and trenbolone acetate (**TBA**). These hormones are encapsulated in various carrier matrixes (lactose, cholesterol, polyethylene glycol) which theoretically may alter conventional implant payout, but this has yet to be demonstrated (Bartle et al., 1992). Zeranol is a synthetic macrolide that has estrogen-like activity, EB has approximately 72.4% the estrogenic activity as E₂, and TBA is a synthetic testosterone analog that has 10 to 50

times the anabolic activity compared to testosterone but does not cause behavioral changes (aggression) normally associated with androgens (Bouffault and Willemart, 1983). The most potent estrogen and androgen in terms of anabolic activity is $E_2-17\beta$ and TBA, respectively (Hossner, 2005). To date a definitive mechanism of action (discussed subsequently) of steroidal implants is not available. However, estrogens and androgens do not appear to have a common mechanism of action, and biological effects are additive.

The primary mechanism of action of estrogen is thought to occur via the somatotrophic axis. Trenkle (1970) demonstrated that feeding diethylstilbestrol increased plasma growth hormone (**GH**) and increased the weight of the pituitary gland. Rumsey et al. (1996a) demonstrated that steers implanted with 20 mg EB + 200 mg P had greater peak GH concentrations in response to intravenous injection of GH-releasing hormone and thyrotropin-releasing hormone. These data support that estrogen increases pituitary gland sensitivity to GH-releasing hormone, which explains why elevated levels of GH are found in steers implanted with estrogen. Estrogen increases the number of high and low-capacity GH receptors in the liver of cattle (Breier et al., 1988).

The primary effector of estrogens on growth in beef cattle is not GH, but insulin-like growth factor-I (**IGF-I**). Most of the IGF-I found in circulation is produced in the liver (Florini et al., 1996). Growth hormone also increases hepatic production of IGF binding protein-3, which is the major carrier of IGF-I in circulation (Hossner, 2005). The IGF-I produced in the liver acts upon peripheral cells in the body and increases lipogenesis, protein synthesis, and bone growth. Growth hormone elicits many of the same effects except that it increases lipolysis instead of lipogenesis. Insulin-like growth factor in part mediates the effect of GH by a negative feedback loop to the hypothalamus

(Hossner, 2005). The somatotrophic axis theory is not perfect, in that GH and estrogen effects are almost additive (Rumsey et al., 1996b), and estradiol implants increase IGF-I messenger ribonucleic acid in muscle of steers to a greater extent than exogenous GH alone (Hannon, 1990). The latter may be because skeletal muscle contains estrogen receptors at approximately 1% of those found in uterine tissue (Hossner, 2005) which may allow for a small but direct effect of estrogens on growth. Estrogen may influence growth of skeletal muscle by binding to several receptors: estrogen receptor- α and - β , and G protein-coupled receptor estrogen receptor-1 (Dayton and White, 2013). It should be noted however, that presence of receptors alone does not indicate estrogen activity; only that the possibility of estrogen activity exists.

Contrary to estrogens, androgens are believed to act directly on skeletal muscle. Compared to control steers, TBA alone does not increase GH concentrations in plasma (Hayden et al., 1992). Therefore, TBA does not seem to act directly on the hypothalamus or anterior pituitary and the somatotrophic axis theory would not encompass the action of TBA. Androgens are thought to act in a direct manner by directly binding to the androgen receptor on the nucleus of skeletal muscle tissue and increasing protein accretion.

The forequarters of an intact male are much larger than in a castrated male because of the androgen testosterone. Although it should be noted that an intact male produces many times more androgen than any implant would provide. If one considers that a 375-kg bull has a plasma testosterone concentration of 9.3 ng/ml (Martin et al., 1979) and that 4.5% of weight is comprised by plasma, we can estimate that a bull produces 157 mg of testosterone a day. The highest potency conventional implant available today contains 200 mg of TBA and is expected to payout over approximately

120 d (Preston, 1999). This translates to approximately 1.7 mg of TBA each day.

Although, not all androgens are equal. Testosterone and dihydrotestosterone increase muscle protein synthesis and degradation and TBA decreases protein synthesis and degradation. Both androgens elicit the net effect of protein accretion due to a disproportional effect on protein synthesis and degradation (Hossner, 2005).

Combination Implants

Both estrogens and androgens reduce plasma urea nitrogen, and the reduction compared with non-implanted can be used as a measure of response to an implant (Preston, 1999). Plasma E₂ or TBA concentrations follow a logarithmic decay when conventional implants are used (Brandt, 1997). Some implants contain P in combination with EB in the same pellet, which is thought primarily to extend the absorption time of E₂ (Brandt, 1997; Harrison et al., 1983). This is also the case when combining E₂ with TBA in the same pellet (Riis and Suresh, 1976; Harrison et al., 1983; Hayden et al., 1992). Hayden et al. (1992) speculated this was due to competition between E₂ and TBA for hepatic metabolism because TBA was maintained in circulation for a longer period of time when combined with E₂ in the same pellet. Heitzman et al. (1981) compared plasma concentrations of E₂ and TBA over a period of 100 d in steers implanted with E₂ pellets in one ear and TBA pellets in the other ear with steers implanted with combination E₂/TBA pellets. The steers implanted with the combination pellet maintained greater E₂ concentrations 40-100 d post implant administration than steers receiving the individual steroid pellets. No differences were observed for plasma TBA concentration.

Because estrogens and androgens have differing mechanisms of action, they act in an additive manner when given in combination. Johnson et al. (1996a) implanted steers

with 24 mg E₂ + 120 mg TBA and observed increased serum IGF-I and IGF-binding protein concentrations in implanted steers. The sera from implanted steers also stimulated the proliferation of cultured muscle satellite cells to a greater extent than sera from non-implanted steers. The elevated IGF-I levels in sera of implanted steers is likely the compound that caused increased proliferation of the cultured satellite cells, lending evidence to the importance of locally produced IGF-I (Johnson et al, 1998). Satellite cells are important in the growth of skeletal muscle in that they provide a source of DNA to support the increasing size of the muscle fiber (Moss and Leblond, 1971). Frey et al. (1995) demonstrated that satellite cell cultures from steers that were implanted with 24 mg E₂ + 120 mg TBA were more responsive to IGF-I and basic fibroblast growth factor than satellite cells from non-implanted steers. Therefore, implants seem increase the production of growth factors, and also the responsiveness of satellite cells to growth factors.

The effects of anabolic implants on energy requirements of cattle have been documented. Estrogen increased body weight and nitrogen losses below maintenance intake levels, but body weight gain and nitrogen retention increased more rapidly in implanted steers compared to non-implanted steers when intake approached near ad libitum (Rumsey and Hammond, 1990). Similarly, implanting steers once or twice with 36 mg zeranol or 20 mg EB + 200 mg P increased the efficiency of protein gain estimated by D₂O dilution, specific gravity, and energy intake (Loy et al., 1988). Generally speaking, estrogens increase the metabolic rate and thus maintenance requirements (Rumsey et al., 1980; Preston, 1975); however, 300 mg of TBA decreased the fasting metabolic rate in steers consuming low-quality roughage diets (Hunter and Vercoe,

1987). Lobley et al. (1985) determined that a combination of 20 mg E₂ + 140 mg TBA increased nitrogen retention in steers. Considering the energetic expense of protein turnover, any improvement in nitrogen retention increases the efficiency of metabolizable energy. In comparing the results of 13 published implant trials, in which most of the implants were a combination of E₂ and TBA, Guiroy et al. (2002) concluded that the anabolic implant response was due to reduced proportion of DMI required for maintenance, reduced energy content of gain, and increased efficiency of use of absorbed energy. The authors state implants reduce the energy content of gain by 5%, which makes logical sense if implants functionally shift the growth curve so greater weights are achieved at a similar EBF (Hutcheson et al., 1997).

Production Responses to Anabolic Implants

Combination implants are primarily used today because of the additive effects of estrogens and androgens. A single combination implant can increase ADG, DMI, gain: feed (**G:F**), hot carcass weight (**HCW**), ribeye area (**REA**), and lean yield, and decrease marbling score and percent of cattle grading Choice (Duckett et al., 1997). An implant containing 24 mg E₂ + 120 mg TBA increased ADG by 21% (d 0 to 115), the absolute weights of carcass bone, protein, and water in feedlot steers (Johnson et al., 1996b). It has been speculated that reduced marbling scores observed in implanted cattle may be because increased lean tissue dilutes intramuscular fat, without reducing lipogenesis (Hutcheson et al., 1997). Using serial slaughter techniques and 9-10-11 rib sections, Johnson et al. (1996b) calculated the protein and fat gain in the carcass. Implanted steers deposited more protein in the initial 40 d post-implant, and numerically more fat from d

41-115 post-implant. This response is likely because the implanted steers had 10% greater DMI than the non-implanted steers.

In terms of live performance, anabolic implants are mostly credited to increase ADG and feed efficiency (Preston, 1999; Guirouy et al, 2002), however, implants that contain estrogens also increase DMI (Duckett et al., 1997). An estrogen-based implant can increase DMI by 3-13% in feedlot steers and heifers (Duckett et al., 1997). Initially the increase in DMI may be thought to be a product of the increase in body weight, but Pritchard (1998) demonstrated that cattle implanted with 24 mg E₂ + 120 mg TBA or 28 mg EB + 200 mg TBA consumed more feed per unit metabolic body size (body weight^{3/4}) than non-implanted steers, especially late in the feeding period. The ADG and feed efficiency responses associated with implants are likely a combination of an increased anabolic demand, which increases DMI and in turn additional nutrients are introduced into the system which are used to achieve an accelerated rate of growth.

There has been some argument over the optimum ratio of estrogen to androgen. Bartle et al. (1992) observed that 1:5 ratio of E₂: TBA was better than similar doses of E₂ or TBA alone in terms of ADG, feed efficiency, and REA in steers. Herschler et al. (1995) concluded that steers and heifers implanted with a 1:10 ratio of E₂: TBA had increased ADG and feed efficiency, and more profitable carcasses compared to steers and heifers that were implanted with a 1:5 ratio of E₂: TBA. However, Pritchard (1998) was unable to detect a difference in steers receiving 24 mg E₂ + 120 mg TBA (1:5) or 28 mg EB + 200 mg TBA (1:10). Smith et al. (2018) corroborated these findings and stated that ADG, HCW, and sera concentrations of IGF-I were increased, and sera urea nitrogen

decreased in implanted steers compared to non-implanted steers, regardless of E₂: TBA ratio.

Extended-Release Implants

The value of using multiple implants within a production phase has been demonstrated primarily through increased HCW and feed efficiency (Duckett et al., 1997; Duckett and Andrae, 2001) and many feedlot operations choose to reimplant cattle (APHIS, 2013). Reimplanting is a useful practice when one implant does not provide anabolic stimulus for the entire production window. However, reworking cattle to administer another growth implant comes with a cost (Stanton, 1997; Wallace et al., 2008). The need to deliver additional days of anabolic stimulus without reimplanting led to the invention of extended-release implants.

The first extended-release implant became available in 2007 which contained two components: 1) pellets that were immediately available for payout (16 mg E₂ + 80 mg TBA), and 2) pellets that were protected from payout until approximately 70 d (24 mg E₂ + 120 mg TBA); with the entire product labeled for 200 d of growth promotion (FDA, 2007). The extended release implant contained a total of 40 mg E₂ and 200 mg TBA (**R-XS**) and yielded very similar results to a reimplant program that contained equal doses (quantities) of hormone (Parr et al., 2011). Although, it should be noted that an extended release implant will only yield superior results compared to a single implant if the production phase is long enough for the single implant to have paid out. In other words, 24 mg E₂ + 120 mg TBA in a conventional implant will yield similar results to R-XS in an extended release implant if the production phase is ~130 d (Parr et al., 2011).

Two additional extended-release implants became available in 2014, one containing 28 mg EB + 200 mg TBA (**ONE-F**) labeled for use during the feedlot phase, and the other containing 21 mg EB + 150 mg TBA (**ONE-G**) labeled for use in cattle grazing pasture (FDA, 2014). Both implants are labeled for 200 d of increased weight gain (Cleale et al., 2012; Cleale et al., 2015). Contrary to the first extended release implant approved, all pellets contained in these implants are coated to delay payout.

McLaughlin et al. (2013a) reported similar cumulative performance between steers implanted with 28 mg EB + 200 mg TBA either as a conventional implant or ONE-F, and R-XS fed for either 161 or 200 d. It is puzzling that the R-XS did not yield improved performance due to an increased hormone content, especially in the 200-d experiment. The cattle that received the conventional implant gained more in the initial 75 d, and less in the final 60 d compared to ONE-F so that final body weight was not different. Performance differences in interim periods are likely due to differences in implant payout when comparing extended release with conventional implants. According to explant data, ONE-F (Cleale et al., 2012) and R-XS (FDA, 2007; Smith et al., 2018) have different payout patterns vs conventional implants. Smith et al. (2018) observed that cattle implanted initially with 20 mg E₂ + 200 mg TBA weighed less on a carcass adjusted basis than cattle receiving the same implant but delayed until day 70 of a 213-d experiment. Regardless of implant timing, cattle implanted with 20 mg E₂ + 200 mg TBA exhibited a less carcass adjusted final weight than cattle implanted with R-XS. The results of McLaughlin et al. (2013a) agree with those of Prouty and Larson (2010) in that the equivalent dose of 28 mg EB and 200 mg TBA yielded similar performance to R-XS. However, McLaughlin et al. (2013b) observed a total of 42 mg EB and 300 mg TBA

yielded similar, or in some cases better live and carcass performance than R-XS across 5 locations. Due to the discrepancies in published literature, more work with ONE-F is needed.

The efficacy of ONE-G to increase ADG and thus bodyweight in steers and heifers over non-implanted contemporaries was demonstrated by Cleale et al. (2015). However, the results of ONE-G compared to other implants approved for pasture cattle have been mixed. No differences in ADG or final weight were observed for steers or heifers implanted with ONE-G, 36 mg zeranol, or 8 mg E₂ + 40 mg TBA in studies with a duration of 139-140 d (Zoetis, 2016). In another experiment lasting 139 d, ONE-G steers had increased ADG and thus increased final weights compared to steers implanted with 36 mg zeranol, or 8 mg E₂ + 40 mg TBA. However, in an experiment with a duration of 180 d, ONE-G steers had increased ADG and final weights compared to steers implanted with 36 mg zeranol, but no difference compared to steers implanted with 8 mg E₂ + 40 mg TBA (Zoetis, 2016). Furthermore, in a 200 d experiment steers implanted with ONE-G had greater ADG than steers implanted with 8 mg E₂ + 40 mg TBA, or 43.9 mg E₂ in a 400-d extended-release implant (Cleale et al., 2018). One would expect the niche of ONE-G to be in production scenarios that exceed the payout duration of conventional implants (>140 d). From the available data it seems that utilizing ONE-G may only be worthwhile when the production phase is near to 200 d.

Implant Strategies

Implants are useful in all phases of beef production and are not detrimental to subsequent phases of production if managed appropriately and label directions are followed (Duckett and Andrae, 2001). Selk (1997) reviewed the literature and reported

that preweaning ADG was improved by 5.15, 5.44, 3.92% for 36 mg zeranol, 10 mg EB and 100 mg P, and 24 mg E₂, respectively. Despite the proven efficacy of using implants during the suckling phase, only 33.7% of cow/calf operations in the US use implants in suckling calves (NAHMS, 2008).

One reason that producers may not implant calves is that the male calf comes with natural growth promotion in the form of testicles. However, the male calf will need to be castrated at some point and Beef Quality Assurance guidelines recommend that castration is done while the calf is young (< 3 mo.). Another reason a producer may not implant during the suckling phase is the perception that a castrated-implanted calf does not yield the same weaning weight as an intact male. However, Bruns and Pritchard (2004) demonstrated that calves implanted with 10 mg EB + 100 mg P had similar weaning weights as calves left intact over a preweaning period of approximately 120 d. Additionally, preweaning estrogenic implants are not detrimental to post-weaning performance, and calves receiving an estrogenic implant in the suckling-phase respond similarly to subsequent implants. (Mader et al., 1994; Pritchard et al., 2003; Pritchard et al., 2015).

Generally speaking, implants can be classified into four potency categories: low, moderate, intermediate, and high. Within category, implants yield similar results in terms of live performance and carcass characteristics. Low potency implants such as 36 mg zeranol and 10 mg + 100 mg P yield similar performance in suckling calves (Selk, 1997; Pritchard et al., 2003). As initial implants in a reimplant program, intermediate potency 16 mg E₂ + 80 mg TBA and 8 mg E₂ + 80 mg TBA are somewhat comparable to moderate potency 20 mg EB + 200 mg P and 20 mg EB + 200 mg testosterone

propionate, for steers and heifers, respectively (Folmer et al., 2009). Although, the implants that contained TBA tended to improve HCW in steers and marbling score in heifers, and significantly improved feed efficiency in heifers. The reason for increased performance in heifers may be because of the difference in anabolic activity of TBA and testosterone propionate previously discussed. In terms of live performance and HCW response to high-potency implants, 24 mg E₂ + 120 mg TBA yields similar results to 28 mg EB + 200 mg TBA (Pritchard, 1998; Kuhl et al., 1999; Trenkle, 1997; Roeber et al., 2000). In some instances, the percentage of Choice quality grade carcasses has differed (Trenkle, 1997), but this has not been observed in other studies (Pritchard, 1998; Kuhl et al., 1999; Roeber et al., 2000). However, Reinhardt and Wagner (2014) conducted a meta-analysis and concluded that implants containing 20 mg E₂ + 200 mg TBA have a slightly greater potency for growth promotion and reduced quality grade than implants containing 24 mg E₂ + 120 mg TBA.

The goal of an implant strategy is to maximize carcass value, and strategies are available that reduce the detriment to carcass quality sometimes associated with using implants (Montgomery et al., 2001). However, it should be noted that feeding cattle longer to achieve a greater rib fat thickness may have a larger impact on marbling score than implant status (Hermesmeier et al., 2000). Strategies should be designed around marketing and production goals (Platter et al., 2003). Perhaps if large-framed cattle are fed and severe discounts are incurred if carcasses are too heavy, then the appropriate strategy may involve fewer, or less potent implants than a strategy designed for smaller-framed cattle. If marketing cattle live or on a yield driven grid, aggressive strategies may be employed to maximize carcass weight. However, if marketing cattle on a grid that has

substantial premiums for quality grade perhaps a less aggressive implant strategy can be used so that quality grade is less likely to be impacted. Administering a high potency implant early in the feeding period when intake is low reduces marbling scores relative to non-implanted steers at a similar EBF (Bruns et al., 2005; Smith et al., 2018). By delaying an aggressive implant (Bruns et al., 2005), or using a low/high potency reimplant strategy instead of a high potency implant initially (Pritchard, 1998) marbling scores and quality grade are less likely to be reduced while still capturing added carcass weight.

In production scenarios that involve heavy-weight cattle placed on feed for a relatively short duration (~130 d) one implant may be sufficient to maximize performance (Parr et al., 2011). However, if the expected duration is longer (>140 d) multiple conventional implants, or an extended release implant may be required for optimal performance (Nichols et al., 2015). A typical practice in a reimplant program is to increase potency of successive implants (Johnson and Beckett, 2014). Total potency seems to be additive in terms of performance responses when administering an equal dose of hormone over 1, 2, or 3 implants (Parr et al., 2006), and when comparing extended release implants to conventional implants of identical hormone content (Parr et al., 2011; McLaughlin et al., 2013a). However, being too aggressive with an implant strategy may substantially reduce quality grade without any additional carcass weight or provides no benefit relative a more conservative implant strategy (Platter et al., 2003; Hilscher et al., 2016; Oney et al., 2018). An older theory that cattle can only respond to so much hormone and past that threshold not additional response is observed (Mader, 1997), seems to have gained additional merit.

When deciding to reimplant, it is commonly recommended to “count-backward” by starting with the terminal implant and ensuring that it will not payout by the time cattle are shipped. Once the terminal implant days have been accounted for one has to decide if an initial implant is needed, and how many days will expire between the initial and terminal implant. Depending on implant type and potency, the ideal reimplant window can range from 60 to 210 d (Nichols, et al., 2015). Terminal implant days deserve consideration as well. Cattle are depositing primarily adipose tissue late in the feeding period because lean growth potential has been maximized, and implants increase lean growth; the implant may be more valuable toward the end of the feeding period as opposed to the beginning (Smith et al., 2018).

It should be noted that there is likely more than one implant strategy that yields desirable outcomes in respect to production and marketing goals (Pritchard, 1994; Parr et al, 2006; Prouty and Larson, 2010; Nielson et al., 2016). The correct implant strategy involves considering production and marketing goals, the lean growth potential of the cattle, previous plane of nutrition and implant history, current and expected energy intake, days on feed, and additional factors succinctly outlined by Smith et al. (2017).

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**CHAPTER II: EFFECTS OF SUCKLING-PHASE IMPLANTS ON WEANING
WEIGHT, POST-WEANING GROWTH PERFORMANCE, AND CARCASS
CHARACTERISTICS OF STEER CALVES**

ABSTRACT

An experiment was conducted to examine the effects of administering a conventional implant (Synovex C; **SYN-C**), or an extended-release combination implant (Synovex One Grass; **ONE-G**) to suckling steer calves on weaning weight, post-weaning growth performance, and carcass characteristics. Suckling steer calves were either not implanted (**NONE**) or were implanted with SYN-C or ONE-G. Steer calves were predominantly 30 to 60 d of age when implants were administered. Steers were weaned 176 d post-suckling implant administration. Weaning weight was greater for steers implanted with SYN-C compared to NONE (285 vs 291 \pm 1.1 kg; $P = 0.04$), and greater for steers implanted with ONE-G compared to SYN-C (291 vs 297 \pm 1.1 kg; $P = 0.02$). Steers were used in a 44-d receiving experiment, fed a common diet, and no implants were administered. No differences in receiving-phase growth performance were observed ($P \geq 0.57$). At the conclusion of the receiving experiment, NONE and ONE-G steers were used in a backgrounding and finishing experiment. All steers were implanted with 14 mg estradiol benzoate and 100 mg trenbolone acetate on d 49 and 28 mg estradiol benzoate and 200 mg trenbolone acetate on 129 and were fed for a total of 211 d. Steers implanted with ONE-G during the suckling-phase were heavier than NONE steers at the onset of the backgrounding-phase (334 vs. 323 \pm 0.9 kg; $P < 0.01$). By d 129 there were no differences in body weight ($P = 0.98$). No difference in cumulative dry matter intake

(DMI) was observed ($P = 0.26$). On a cumulative carcass-adjusted basis NONE steers had greater gain-to-feed (G:F) than ONE-G steers (0.186 vs 0.174 ± 0.0035 ; $P = 0.04$). Steers implanted with ONE-G had a larger ribeye area than NONE steers, despite being implanted similarly in the feedlot (91.32 vs. 88.19 ± 0.893 cm²; $P = 0.05$). No differences were observed for other carcass characteristics or Quality Grade ($P \geq 0.24$). Percent empty body fat at harvest was not different for NONE and ONE-G steers ($P = 0.45$). The ONE-G implant is labeled for 200 d of implant coverage (FDA, 2014). To evaluate the potential anabolic effects of ONE-G in the feedlot, we chose not to re-implant steers until 226 d post-suckling implant administration. Therefore, the ONE-G steers did not have continuous exposure to an active implant. Differences in early growth performance may be a consequence of discontinuous exposure to anabolic agents. Administering ONE-G during the suckling-phase did not diminish carcass quality. Future research should evaluate implant strategy options to follow ONE-G in suckling calves.

INTRODUCTION

Growth promoting implants have been proven efficacious in all phases of beef production. In suckling steer calves on pasture, a conventional implant increased pre-weaning average daily gain (ADG) approximately 5% over non-implanted controls (Selk, 1997). The routine processes of branding in the spring is a convenient time to administer implants so that additional weaning weight can be realized in the fall. However, time elapsed between branding and weaning is generally longer than the payout duration of conventional suckling implants. A controlled-release implant with an extended payout would provide implant coverage during this period. Extended-release estrogenic implants for suckling calves have been examined previously. For example, 25.7 mg of estradiol in

a silicone rubber extended-release package (Compudose; Elanco Inc., Greenfield, IN) increased pre-weaning ADG of steer calves approximately 4% over non-implanted controls, which is slightly less than the response observed with conventional implants (Selk, 1997). However, no suckling-calf data are available regarding the effects of trenbolone acetate (**TBA**), which is commonly administered in combination with estradiol to pasture and feedlot cattle. A relatively new extended-release implant is available that contains 21 mg estradiol benzoate (**EB**) and 150 mg TBA (**ONE-G**; Synovex One Grass, Zoetis Inc., Parsippany, NJ) and contains a greater hormone concentration than any other pasture implant currently available (Cleale et al., 2015). Currently, data are not available examining the potential benefits or detriments associated with administering a high dose TBA containing implant, in the early stages of calf growth. The objective of this experiment was to examine the effects of administering a ONE-G implant to suckling steer calves on weaning weight, post-weaning growth performance, and carcass characteristics.

MATERIALS AND METHODS

The experiment was approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval #17-006E). The March-April born Angus and Angus × Simmental calves included in this experiment originated from a ranch located in western South Dakota where no creep feed was used. Suckling-calf implant treatments were applied at the ranch of origin. A list of significant dates throughout the experiment are reported in Table 2.1.

Suckling-Phase

On May 8th, 2016 bull calves were restrained for castration, vaccination, branding, and implanting. In the order that they were restrained bull calves were assigned to treatment in the sequence of: 1) no implant (**NONE**); 2) 10 mg EB and 100 mg progesterone (**SYN-C**; Synovex C, Zoetis Inc.); 3) SYN-C; and 4) ONE-G. Twice as many calves were implanted with SYN-C than the other implant groups so that an inference could be made about the validity of implant treatment allocation and minimize economic loss because of lesser body weight (**BW**) gain. Calves were allowed to graze in 2 separate pastures, and implant administration was stratified across pasture. Individual ear tag, pasture, and implant administered were recorded. Calves were predominantly 30 to 60 d old when suckling implants were administered and were reared by cows that were ≥ 3 yr of age.

Receiving-Phase

On October 31, 2016 (176 d post-implant) steers were weaned from their dams and shipped 588 km to the South Dakota State University Ruminant Nutrition Center Feedlot where all growth performance data were collected. After arrival at the feedlot the steers were temporarily placed in pens (10 steers/pen) with access to water and long-stem grass hay. Steers were processed the following morning (11 h post-arrival). Individual ranch identification and BW were recorded, and steers were tagged with a unique feedlot identification, vaccinated against viral antigens (Bovi-Shield Gold 5, Zoetis Inc.), and clostridial organisms (Ultrabac 7/Somubac, Zoetis Inc.), and treated for internal and external parasites (Cydectin, Bayer, Shawnee Mission, KS). Ranch identifications that could not be confirmed at feedlot processing (n = 3) were not included the experiment.

Body weight recorded at initial processing was considered calf weaning weight (**WW**). By design, the implant sequencing order at the cooperating ranch generated approximately twice as many steers implanted with SYN-C compared to the other treatments. When we evaluated the SYN-C calves on the basis of WW, the 2 groups were not different (288 and 294 ± 3.2 kg; $P = 0.42$). Thus, this verified that the implant treatments were applied randomly at the ranch.

Therefore, steers implanted with SYN-C were stratified by WW, and alternately assigned into 2 subsets of steers. Only 1 subset of steers ($n = 30$) was included in the receiving-phase experiment. A pasture effect ($n = 2$; $P = 0.01$) was observed for WW. Therefore, steers were sorted by pasture, then by implant, stratified by WW and assigned to a pen resulting in 3 pen replicates per implant (7 to 11 steers/pen), and 9 pens total. Removing one-half of the steers implanted with SYN-C resulted in a total of 88 steers that were included in the receiving experiment.

Steers were offered long-stem grass hay 3 d post-weaning and were offered a common receiving diet (Table 2.2) beginning on d 2 post-weaning. On d 18 feed batching was corrected for oatlage percent dry matter (**DM**) used in initial formulations, because oatlage DM was less than anticipated during diet formulation. Soybean meal was added to replace a portion of the soybean hulls in the diet (Table 2.2) on d 23, to correct for a decline in crude protein content of the oatlage during feedout. Steers were individually weighed in the morning prior to feed delivery on 21 and 44 d post-arrival at the feedlot. All BW excluding initial BW are shrunk (3%), to decrease the impact of fill on BW measures. Calf health was monitored daily.

Blood was collected on d 37 from a subset of steers, all originating from one pasture, (2 pens/treatment; n = 56 steers) via jugular venipuncture using 18-gauge needles and 10 mL vacuum sealed tubes (Becton Dickinson, Franklin Lakes, NJ). Blood was allowed to clot for 24 h at 4°C, then were centrifuged at $1,500 \times g$ for 20 min to obtain serum. Serum concentrations of Insulin Like Growth Factor-I (**IGF-I**) were determined in duplicate by radioimmunoassay (Echternkamp et al., 1990; Funston et al., 1995) for all blood samples. Insulin like growth factor binding proteins (**IGFBP**) were extracted from serum using a 1:17 ratio of sample to acidified ethanol (12.5% 2 N HCl: 87.5% absolute ethanol; Daughaday et al., 1980). Extracted samples were centrifuged ($12,000 \times g$ at 4°C) to separate IGFBP. A portion of the resulting supernatant was removed and neutralized with 0.855 M Tris base, incubated for an additional 4 h at 4°C, and then centrifuged at $12,000 \times g$ at 4°C to remove any additional IGFBP. When samples of this extract, equivalent to the original serum sample, were subjected to Western ligand blot analysis and subsequent phosphoimagery, no detected binding of ^{125}I -IGF-I to IGFBP was observed. Inhibition curves of the neutralized extracted serum ranging from 12.5 to 50 μL were parallel to the standard curve. Recombinant human IGF-I (GF-050; Austral Biological, San Ramon, CA, USA) was used as the standard and radioiodinated antigen. Antisera AFP 4892898 (National Hormone and Peptide Program, National Institutes of Diabetes, Digestive and Kidney Diseases, Bethesda, MD, USA) was used at a dilution of 1:62,500. Sensitivity of the assay was 15.5 pg/tube. Intra- and inter-assay CV were 4.9% and 8.5%, respectively.

Data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) as a complete randomized block design with implant as the main effect, pasture as the

blocking factor, and implant \times pasture was used as the error term. An allotment discrepancy in one replication of the ONE-G treatment compromised the DM intake (DMI) data for that treatment. Therefore, the effect of ONE-G on post-weaning steer growth performance was limited to BW and ADG. To accomplish this, animal served as the experimental unit for the analysis of WW, BW, and post-weaning ADG. For the analysis of post-weaning DMI and gain-to-feed (G:F) pen served as the experimental unit (and thus ONE-G was excluded). The IGF-I concentrations were analyzed as a completely randomized design (blood was only collected from steers in pasture 2) with implant as the main effect and animal as the experimental unit. Treatment effects were considered significant at $P \leq 0.05$, and statistical trends at $P \leq 0.10$. In the presence of a significant F -test, treatment least squares means were separated using the PDIFF option.

Backgrounding and Finishing-Phase

The BW collected on December 15, 2017 (d 44) was used to terminate the receiving-phase and the cattle were re-allotted and sorted to new pens based on this BW measure for the backgrounding/finishing-phase of the experiment. The primary reason for the re-allotment was to resolve the allotment discrepancy in the receiving-phase, but also to increase the number of replicate pens within implant treatment from 3 to 4. Only steers belonging to the NONE and ONE-G treatments were retained in the backgrounding and finishing-phases. To avoid treatment bias, the steers that were not retained for further use represented individuals nearest the mean BW on d 44 (± 0.5 standard deviations). For reallocation, steers were stratified by d 44 BW and assigned to replicates in a scrambled sequence of 1 through 4. Based on treatment and replicate combination, steers were assigned to pens so that each pen contained 7 steers.

Steers were weighed individually in the morning prior to feeding on d 44, 49, 72, 100, 129, 156, 184, and 211 post-arrival. Reported BW are shrunk (3%), to decrease the impact of fill on BW measures. All steers were implanted with 14 mg EB + 100 mg TBA (Synovex Choice; Zoetis Inc.) on d 50. All steers were re-implanted with 28 mg EB + 200 mg TBA (Synovex Plus; Zoetis Inc.) and were vaccinated with Clostridium Perfringens Type A Toxoid (Elanco Inc., Greenfield, IN) on d 130. Steers were treated for external parasites with CyLence (Bayer) on d 57 and 147. Steers were shipped for harvest on May 31, 2017 when the mean back fat depth (**BF**) for the overall population was estimated to be 1.27 cm. Steers were harvested at a commercial abattoir (Tyson Fresh Meats, Dakota City, NE) on June 1, 2017 after 211 d on feed. Individual identity was preserved throughout the harvest and grading process. Hot carcass weight (**HCW**) was measured on the day of harvest. Carcass data necessary to determine USDA Yield and Quality grade were obtained from the video image analysis system in the packing plant after a 36-h chill. Ribeye area (**REA**), BF, marbling score, and kidney pelvic heart fat (**KPH**) from each side of the carcass were averaged for each carcass. Yield grade was calculated by using the USDA regression equation (USDA, 2016). Empty body fat (**EBF**) and shrunk weight at 28 % EBF (**AFBW**) were estimated using equations from Guiroy et al. (2001). Carcass data were collected for all steers in the experiment.

One steer in the ONE-G treatment was removed on d 72 of the experiment (d 28 of backgrounding/finishing-phase) for reasons unrelated to the experiment. The steer was hospitalized individually prior to being removed, so BW and intake were corrected for the home pen back to the initiation of the backgrounding/finishing-phase.

Data were analyzed using the GLM procedure of SAS as a completely randomized design with implant as the main effect. Pen served as the experimental unit for the analysis of BW, ADG, DMI, G:F, and carcass data. Quality Grade distribution data were analyzed as binominal proportions using the GLIMMIX procedure of SAS using the ILINK option of LSMEANS. Treatment effects were considered significant at $P \leq 0.05$, and statistical trends at $P \leq 0.10$. Arithmetic means are reported for performance data and least squares means are reported for Quality Grade data.

Procedures Throughout All Phases

Outdoor pens were concrete surfaced and measured 7.6×7.6 m, with a 7.6 m fence-line feed bunk. Water tanks were located between adjacent pens and steers had *ad libitum* access to fresh water at all times. Pens were bedded with straw in an attempt to minimize animal discomfort during inclement weather, but never within 48 h of weighing steers. Feed deliveries were managed according to a clean bunk management system to approximate *ad libitum* intake and organized so that feed batch did not confound treatment. Steers were fed twice daily (0800, 1500 h) in equal amounts to the nearest 0.45 kg (as-is basis) at each delivery. Feed intake was dictated by management until d 14, after that point steers were fed to *ab libitum*. Briefly, steers were offered 0.6-times maintenance energy intake (NASEM, 2016) on d 2, and increases were limited so that intake did not exceed 2.3-times maintenance energy intake on d 14. Feed ingredients were conveyed to the nearest 0.454 kg into a 25.6 m³ mixer (Roto-Mix, Dodge City, KS) and mixed for 4 min.

Individual feed ingredients were sampled weekly throughout the experiment. Feed samples were dried in a forced air oven at 60°C until a constant weight was

maintained to determine DM content, then ground (Wiley mill, model 4, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen. Ground samples were analyzed for DM (105°C; AOAC, 1990), crude protein (Kjedahl method; AOAC, 1990), neutral and acid detergent fiber (Goering and Van Soest, 1970), and ash (AOAC, 1990). Distillers grains samples (dried and modified) were additionally analyzed for ether extract using an Ankom Fat Extractor (XT10; Ankom Technology, Macedon, NY). Tabular feed ingredient energy values (Preston, 2016) were used to estimate net energy concentration. If present, feed refusals were collected and dried at 60°C to calculate actual DMI. Dry matter intakes were calculated and summarized weekly using feed ingredient analyses and corresponding daily feed batching records. Ingredient and nutrient composition of the common diets (Table 2.2) were calculated using similar methods. Dietary changes on d 52 and 122 were to increase the NE_g content of the diet (Table 2.2). Other dietary modifications were a result of adapting to changing feed inventories, but never cofounded implant treatment.

RESULTS AND DISCUSSION

Throughout the results and discussion, d 1 to 44, d 45 to 129, and d 130 to 211 will be referred to as the receiving, backgrounding, and finishing-phases, respectively. These phases correspond to allotment as well as distinct dietary and implant management periods.

Suckling-Phase

Steers implanted with SYN-C had greater WW compared to NONE ($P = 0.04$), and steers implanted with ONE-G had greater WW compared to SYN-C ($P = 0.05$; Table 2.3). The additional WW observed for steers implanted with SYN-C compared to NONE

is consistent with past experiments (Mader et al., 1994; Pritchard et al., 2015). The 12 kg of added WW for steers implanted with ONE-G compared to NONE was twice the response relative to steers implanted with SYN-C compared to NONE. The response of steers implanted with ONE-G in the present experiment is in agreement with previous results. Hunter and Vercoe (1987) reported that when steers were implanted with TBA while grazing low-quality forage, a 9-12 % decrease in fasting heat production and a greater ADG relative to non-implanted steers was observed.

Receiving-Phase

No difference in receiving-phase ADG were observed in the present experiment (Table 2.4; $P = 0.98$). Mader et al. (1994) observed no difference in post-weaning ADG in Charolais and Simmental \times English that were non-implanted, or previously implanted with SYN-C (1.59 and 1.62 ± 0.040 kg, respectively). However, Pritchard et al. (2003) used Angus and Angus \times Limousine steers, which were similar to steers used in the present experiment and observed a 9% increase in ADG in steers implanted with SYN-C compared to non-implanted steers during the 40-d receiving-phase (1.45 and 1.33 ± 0.030 kg, respectively). This discrepancy is likely because of a difference in the duration of days between implanting and weaning, and thus a difference in when the initial implant was administered. In the experiment by Mader et al. (1994), 171 to 193 d had elapsed from implanting to weaning, whereas in the experiment by Pritchard et al. (2003) 133 to 159 d had elapsed.

The approximate payout of conventional implants ranges from 60-120 d (Mader, 1997). However, Ritchie et al. (1990) determined that 25% of the EB present in the original dose of a SYN-C implant remained 172 d after implant administration in

suckling calves. Although, given the results of the present experiment, payout after 172 d may be below the minimum threshold of circulating hormone needed to elicit a biological response (Brandt, 1997).

The ONE-G implant used in the present experiment was no longer eliciting a growth response during the receiving-phase, despite the labeled 200 d payout. Cleale et al. (2015) demonstrated that both steers and heifers implanted with ONE-G had increased ADG from d 0 to 202 compared to non-implanted contemporaries. However, the authors did not report interim ADG for the last period, which is of importance relative to the current experiment. Comparing the most recent interim and final BW reported by Cleale et al. (2015), it is unclear whether the ONE-G was eliciting a growth response at that time. The total BW gain during the last period reported was 10.2 and 12.4 kg for non-implanted heifers and heifers implanted with ONE-G, respectively. In steers, - 1.4 and 0.6 kg total BW gain was reported for non-implanted steers and steers implanted with ONE-G, respectively (Cleale et al., 2015). In the steer growth performance data, the observations concur with those of Hunter and Vercoe (1987); that TBA decreases maintenance energy requirement. Cleale et al. (2018) reported no difference in ADG in grazing steers implanted with ONE-G, 8 mg estradiol + 40 mg TBA (Revalor-G; Merck Animal Health, Madison, NJ), and 43.9 mg estradiol (Encore; Elanco Inc.) for the initial 70 d post-implant administration. However, increased ADG by steers implanted with ONE-G was observed from d 70 to 200 post-implant administration. At this point, it is unclear whether ONE-G elicits a growth response near 200 d. Perhaps, the response up to 200 d could be apparent because of increased ADG resulting from early payout of the implant. With no increase in post-weaning ADG during the receiving-phase for implanted

vs. non-implanted steers in the present experiment, it can be concluded that the growth promoting activity of both the SYN-C and ONE-G was depleted.

As a result of the discrepancy in the receiving-phase allotment, DMI and G:F are presented for only the NONE and SYN-C steers, not the steers that received ONE-G (Table 2.4). Dry matter intake and G:F were not different for NONE and SYN-C throughout the receiving-phase ($P \geq 0.57$). Pritchard et al. (2003) did not administer an implant during the receiving-phase and did not report a difference in DMI between non-implanted steers and steers that received a SYN-C during the suckling-phase (6.01 and 6.09 ± 0.050 kg, respectively). However, because an increased receiving-phase ADG was observed by Pritchard et al. (2003), steers that received the SYN-C had 7% greater G:F than non-implanted steers (0.236 and 0.221, respectively). Mader et al. (1994) and Pritchard et al. (2015) implanted steers with 20 mg EB + 200 mg progesterone (Synovex S; Zoetis Inc) soon after feedlot arrival and observed no difference in DMI or G:F in steers that had previously been implanted with SYN-C compared to non-implanted controls.

Levels of circulating IGF-I tended ($P = 0.06$; Table 2.5) to be greater for ONE-G steers compared to NONE, or SYN-C steers. With a labeled pay out duration of 200 d, it is logical that the ONE-G implant still had some transient effect on IGF-I levels 213 d post-implant. However, data are not available that quantify circulating IGF-I in calves. Nonetheless, data that are available (Johnson et al., 1996a; Bryant et al., 2010; Parr et al., 2014; Smith et al., 2018) were collected using heavier BW cattle (> 425 kg) and higher potency implants than used in the current experiment. In those studies, implants increased circulating IGF-I from 13 to 96% over non-implanted controls. Johnson et al. (1996a,

1996b) observed a 31% increase in IGF-I that accompanied a 17.5% increase in ADG in implanted steers 40 d after the implant was administered. Similarly, Smith et al. (2018) observed an 18% increase in ADG and a 37% increase in IGF-I of implanted steers 70 d post implant. However, a 17% increase in IGF-I in the present experiment may not be biologically relevant because no differences in ADG were observed.

Backgrounding and Finishing-Phase

Interim and cumulative growth performance corresponding to management are reported in Table 2.6. All steers were re-implanted with 14 mg EB + 100 mg TBA (Synovex Choice) on d 50, and this was the first implant administered after the initial suckling implant was administered (227 d later). Dry matter intake was not different for NONE and ONE-G steers during d 50-72 (7.56 and 7.36 ± 0.090 kg, respectively). However, comparing DMI from d 50-72 with the subsequent period (d 73-100) it was likely inadvertently limited early in the backgrounding-phase (8.74 and 8.99 ± 0.221 kg for NONE and steers implanted with ONE-G, respectively). To adapt steers to the backgrounding diet (Table 2.2), the amount of DM offered was decreased, to allow for dietary adaptation of a diet containing more starch. The subsequent increases in DM offered may not have occurred at the appropriate rate. Despite a potentially reduced DMI early in the backgrounding-phase, the cattle had an ADG over 1.4 kg (Table 2.6).

The NONE steers had an increased G:F ($P = 0.05$) compared to steers implanted with ONE-G during the backgrounding-phase. Steers implanted with ONE-G began to lose the initial WW advantage over NONE steers during this phase of production. The BW eventually converged at 129 d post-weaning. An important distinction must be made. The ONE-G implant is labeled for 200 d of growth promotion and steers in the present

experiment were implanted 227 d post ONE-G implantation. Because an interruption in anabolic stimulus occurred, one cannot reach the conclusion that steers implanted with ONE-G do not respond to subsequent implants. Some evidence exists that when a steer is no longer under the stimulus of a previous implant ADG is lesser than non-implanted controls. For example, Smith et al. (2018) implanted steers with 20 mg estradiol + 200 mg of TBA (Revalor-200; Merck Animal Health) on d 1. From d 141 to 213 the previously implanted steers gained 6% less than non-implanted steers. In the present experiment, steers previously implanted with ONE-G had a lesser ($P = 0.04$) ADG than NONE steers after being implanted on d 50 during the interim period from d 50 to 72 (0.97 and 0.75 ± 0.061 kg ADG for NONE and ONE-G, respectively).

All steers were implanted with 28 mg EB + 200 mg TBA (Synovex Plus) on d 129. Response to the terminal implant was not different for steers initially implanted with ONE-G or NONE ($P \geq 0.22$). This is interesting because of the previously discussed response to the backgrounding implant. Sequential implant research from Mader et al. (1994) and Pritchard et al. (2003) observed that an estrogenic implant administered to a suckling-calf was not a detriment to subsequent performance in the feedlot. However, the ONE-G implant contained TBA; therefore, the results may not be comparable to those of Mader et al. (1994) and Pritchard et al. (2003).

In large pens, Folmer et al. (2009) compared initial implants (at feedlot arrival) consisting of 20 mg EB + 200 mg progesterone (Synovex S) to 16 mg estradiol + 80 mg TBA (Revalor-IS; Merck Animal Health), followed by a terminal implant containing 24 mg estradiol + 120 mg TBA (Revalor-S; Merck Animal Health) 78 d later. Steers implanted initially with TBA tended to have greater final BW and HCW compared to

steers not receiving TBA initially. According to Folmer et al. (2009), initial implantation with TBA does not alter the response to subsequent TBA exposure, at least in situations where an appropriately designed implant strategy is used. This may not be the case if the anabolic activity of the initial implant has expired prior to re-implantation, as in the current experiment. Generally, it is recommended that re-implantation take place 60 to 120 d after the initial implant is administered when using conventional implants (Nichols et al., 2015).

The ONE-G steers did not exhibit decreased performance relative to the NONE steers during the finishing-phase ($P \geq 0.22$). Although, because of increased ADG by the NONE steers early in the backgrounding-phase, G:F for the NONE steers were greater ($P = 0.05$) than steers previously implanted with ONE-G during the backgrounding-phase.

There was no difference in final BW, final carcass-adjusted BW, cumulative d 45 to 211 DMI or ADG ($P \geq 0.16$; Table 2.6). The NONE steers had greater G:F than the ONE-G steers from d 45 to 211 on a live and carcass-adjusted basis ($P \leq 0.02$). The performance differences observed during the backgrounding-phase carried over into cumulative G:F. Suckling implant strategy did not impact degree of finish as denoted by BF or estimated percent EBF ($P \geq 0.45$; Table 2.7). Also, FSBW was not different for steers implanted with ONE-G or NONE during the suckling-phase ($P = 0.36$). Hot carcass weight and Yield Grade were also not different ($P \geq 0.24$) for the 2 implant treatments. Ribeye area was larger for ONE-G steers ($P = 0.05$). It is possible that even though the steers implanted with ONE-G lost the initial WW advantage over NONE steers, the effect of TBA on muscle growth early in life may have persisted to harvest. When comparing finishing-phase implant studies, implanted steers have a larger ribeye

than non-implanted controls, but this is primarily a function of increased carcass weight. The REA/HCW ratio in those studies are usually not different (Bryant et al., 2010; Pritchard, 1998; Parr et al., 2011), but in contrast the HCW was not different between the two implant treatments ($P = 0.85$), and REA/HCW tended to favor the ONE-G treatment ($P = 0.07$).

The potential consequences of administering a potent implant during early stages of growth, and subsequent effects on quality attributes of the carcass were of particular interest because implanted cattle have decreased marbling score, shifted quality grade distribution, and advanced skeletal maturity in some instances (Morgan, 1997; Guiroy et al., 2002; Bruns et al., 2005). In the present experiment, no carcass defects were noted, and marbling scores were not different ($P = 0.25$) for NONE and steers previously implanted with ONE-G. This is interesting because intramuscular fat is an early developing tissue (Cianzio et al., 1982; Bruns et al., 2004), and one would surmise that if marbling can be impacted by timing of implantation in the feedlot phase (Bruns et al., 2005) one could impact marbling in an earlier stage of growth. Perhaps the controlled-release coating (Lee et al., 2000) did not allow hormone to leave the excipient at a rate which would impede intramuscular fat development. However, marbling score has been decreased relative to non-implanted controls when a more potent implant with the same controlled-release coating was used in a feedlot setting (Cleale et al., 2012). Additionally, there was no difference in Quality Grade distribution in the current experiment.

In conclusion, both the ONE-G and the SYN-C implant improved weaning weight. However, there was no evidence that the ONE-G implant was still positively affecting ADG post-weaning (177 d post-implantation). Steers implanted with ONE-G

eventually lost the initial weaning weight advantage over NONE steers, most likely because of non-continuous anabolic stimulation. This experiment did not evaluate re-implant strategies for calves that had been implanted with ONE-G during the suckling-phase. However, because no carcass defects were evident, re-implant strategies must be explored in order to potentially realize the increased weaning weight at slaughter.

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Table 2.1. Chronology of significant events

Event	Date	Day of Exp. ¹	Elapsed days since suckling implant
Administered suckling implant ²	5/8/16	-	-
Weaning ²	10/31/16	0	176
Begin receiving-phase	11/1/16	1	177
Collect sera ³	12/7/16	37	213
Begin backgrounding-phase	12/15/16	44	221
Administered backgrounding implant	12/20/16	49	226
Begin finishing-phase & administered terminal implant	3/10/17	129	306
Ship to abattoir	5/31/17	211	388
Harvest steers	6/1/17	-	389

¹Experiment days correspond to days in the feedlot

²Took place on cooperating ranch

³Sera analyzed for circulating insulin like growth factor-I

Table 2.2. Actual ingredient and nutrient composition of diets^{1,2}

Item	Days of experiment						
	2-22	23-48	49-51	52-86	87-121	122-142	143-211
n, samples	3	4	1	5	5	3	10
Dry-rolled corn, %						49.67	68.04
High moisture ear corn, %				51.85	54.70	24.55	
Soybean hulls, %	58.97	46.86	46.87				
Modified distillers grains, %							19.50
Dried distillers grains, %				16.50	14.59	11.91	
Soybean meal, %		4.40	7.23				
Oatlage, %	35.31	43.77	43.88				
Corn silage, %				24.67	25.68	8.90	
Sorghum silage, %							7.58
Liquid supplement 1 ³ , %				5.00			
Liquid supplement 2 ⁴ , %					5.03	4.97	4.88
Pelleted supplement 1 ⁵ , %	5.72	4.97					
Pelleted supplement 2 ⁶ , %			2.02	1.98			
Dry matter, %	48.30	44.82	44.89	60.59	60.21	73.57	68.80
Crude protein, %	11.36	13.11	14.82	13.68	12.57	12.23	14.21
Neutral detergent fiber, %	64.06	61.28	59.98	21.48	21.06	15.35	14.86
Acid detergent fiber, %	48.70	44.21	40.68	9.64	9.92	6.34	5.80
Ash, %	7.89	7.97	7.41	5.39	5.36	4.55	5.16
Ether extract, %	2.30	2.31	2.33	4.21	4.18	4.29	4.83
NEm ⁷ , Mcal/kg	1.86	1.78	1.78	1.89	1.87	2.04	2.08
NEg ⁷ , Mcal/kg	1.15	1.08	1.08	1.24	1.23	1.37	1.40

¹Dry matter basis²Calculated from weekly ingredient assays and batching records³Contained 39% crude protein from nonprotein nitrogen on a dry matter basis and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)⁴Contained 39% crude protein from nonprotein nitrogen and 648 mg/kg monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN) on a dry matter basis and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)⁵Contained 545 mg/kg monensin (Rumensin 90; Elanco Animal Health) and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)⁶Contained 1665 mg/kg monensin (Rumensin 90; Elanco Animal Health)⁷NEm = Net energy for maintenance; NEg = Net energy for gain; calculated from tabular net energy values (Preston, 2016)

Table 2.3. Effect of suckling-phase implants on weaning weight of steers calves¹

Item	Suckling-phase implant ²			SEM	<i>P</i> -value
	NONE	SYN-C	ONE-G		
n, steers	31	60	29	-	-
Weaning body weight, kg	285 ^c	291 ^b	297 ^a	1.1	0.03

¹Calculated using unshrunk live body weight; Least squares means are reported

²NONE = no suckling-phase-implant; SYN-C = 10 mg estradiol benzoate + 100 mg progesterone (Synovex C; Zoetis Inc., Kalamazoo, MI) suckling-phase conventional implant; ONE-G = 21 mg estradiol benzoate + 150 mg trenbolone acetate (Synovex One Grass; Zoetis Inc.) suckling-phase extended-release implant

^{a-c}Means within a row without a common superscript differ ($P \leq 0.05$)

Table 2.4. Effect of suckling-phase implants and subsequent receiving-phase performance of steer calves¹

Item	Suckling-phase implant ²			SEM	P-value
	NONE	SYN-C	ONE-G		
n, steers	30	30	28	-	-
n, pens	3	3	3	-	-
	Receiving phase				
Initial body weight, kg	284 ^b	290 ^{a,b}	297 ^a	1.7	0.06
d 1 to 21					
d 21 body weight, kg	300 ^b	306 ^{a,b}	313 ^a	1.9	0.07
Average daily gain, kg	0.76	0.73	0.75	0.038	0.89
Dry matter intake, kg	4.15	4.12	-	0.054	0.69
Gain:feed	0.181	0.182	-	0.0225	0.97
d 22 to 44					
d 44 body weight, kg	320	328	334	3.2	0.16
Average daily gain, kg	0.89	0.95	0.92	0.093	0.92
Dry matter intake, kg	7.34	7.44	-	0.117	0.60
Gain:feed	0.115	0.128	-	0.0129	0.57
d 1 to 44					
Average daily gain, kg	0.83	0.85	0.84	0.066	0.98
Dry matter intake, kg	5.82	5.86	-	0.060	0.71
Gain:feed	0.138	0.146	-	0.0099	0.61

¹Shrink (3%) was applied to body weights, excluding initial body weight; Least squares means are reported

²NONE = no suckling-phase-implant; SYN-C = 10 mg estradiol benzoate + 100 mg progesterone (Synovex C; Zoetis Inc.) suckling-phase conventional implant; ONE-G = 21 mg estradiol benzoate + 150 mg trenbolone acetate (Synovex One Grass; Zoetis Inc.) suckling-phase extended-release implant

^{a-b}Means within a row without a common superscript differ ($P \leq 0.05$)

Table 2.5. Effect of suckling-phase implants on circulating IGF-I concentrations in steer calves¹

Item	Suckling-phase implant ²			SEM	<i>P</i> -value
	NONE	SYN-C	ONE-G		
n, steers	20	20	16	-	-
IGF-I ³ , ng/ml	150 ^b	146 ^b	176 ^a	9.9	0.06

¹Sera samples were collected on d 37 of the receiving-phase, 213 d post administration of the suckling-phase implant; Least squares means are reported

²NONE = no suckling-phase-implant; SYN-C = 10 mg estradiol benzoate and 100 mg progesterone (Synovex C; Zoetis Inc., Kalamazoo, MI) suckling-phase conventional implant; ONE-G = 21 mg estradiol benzoate and 150 mg trenbolone acetate (Synovex One Grass; Zoetis Inc.) suckling-phase extended-release implant

³IGF-I = Insulin like growth factor-I

^{a-b}Means within a row without a common superscript differ ($P \leq 0.05$)

Table 2.6. Effect of a suckling-phase implant containing estradiol benzoate and trenbolone acetate on backgrounding-phase, finishing-phase, live and carcass-adjusted performance of steer calves¹

Item	Suckling-phase implant ²		SEM	P-value
	NONE	ONE-G		
n, steers	28	27	-	-
n, pens	4	4	-	-
d 44 body weight, kg	323	334	0.9	<0.01
----- Backgrounding-phase -----				
d 45 to 129				
d 129 body weight, kg	454	455	5.2	0.98
Average daily gain, kg	1.55	1.42	0.063	0.18
Dry matter intake, kg	8.53	8.67	0.145	0.51
Gain:feed	0.181	0.163	0.0051	0.05
----- Finishing-phase -----				
d 130 to 211				
Final body weight, kg	622	622	4.3	0.90
Average daily gain, kg	2.04	2.05	0.032	0.89
Dry matter intake, kg	11.41	11.81	0.205	0.22
Gain:feed	0.179	0.174	0.0041	0.36
----- Cumulative background and finishing-phases -----				
d 45 to 211				
Live weight basis				
Average daily gain, kg	1.79	1.73	0.026	0.12
Dry matter intake, kg	9.94	10.21	0.154	0.26
Gain:feed	0.180	0.169	0.0024	0.02
Carcass-adjusted basis ³				
Final body weight, kg	631	630	5.9	0.89
Average daily gain, kg	1.85	1.77	0.037	0.19
Gain:feed	0.186	0.174	0.0035	0.04

¹Shrink (3%) was applied to body weights

²NONE = no suckling-phase-implant; ONE-G = 21 mg estradiol benzoate + 150 mg trenbolone acetate (Synovex One Grass; Zoetis Inc., Kalamazoo, MI) suckling-phase extended-release implant; All steers were implanted with 14 mg estradiol benzoate + 100 mg trenbolone acetate (Synovex Choice; Zoetis Inc.) on d 49, and 28 mg estradiol benzoate + 200 mg trenbolone acetate (Synovex Plus; Zoetis Inc.) on d 129

³Calculated as hot carcass weight divided by 0.625

Table 2.7. Effect of a suckling-phase implant containing estradiol benzoate and trenbolone acetate on carcass characteristics of steer calves

Item	Suckling-phase implant ¹		SEM	<i>P</i> -value
	NONE	ONE-G		
n, steers	28	27	-	-
n, pens	4	4	-	-
Hot carcass weight (HCW), kg	395	394	3.7	0.85
Dressing percentage ²	63.42	63.26	0.261	0.69
Back fat, cm	1.33	1.31	0.081	0.87
Ribeye area (REA), cm ²	88.19	91.32	0.893	0.05
REA/HCW, 6.45cm ² /45.4 kg	1.58	1.64	0.019	0.07
Marbling score ³	595	567	15.9	0.25
Calculated Yield Grade ⁴	3.10	2.91	0.098	0.24
Kidney pelvic and heart fat, %	1.80	1.82	0.032	0.75
Quality Grade				
Prime, %	3.57	0.00	2.596	0.33
Premium Choice, %	7.14	7.41	5.091	0.97
Avg. Choice, %	28.57	25.93	8.727	0.83
Low Choice, %	42.86	44.44	9.721	0.91
Select, %	17.86	22.22	7.830	0.69
Empty body fat ⁵ , %	30.58	30.01	0.504	0.45
AFBW ^{5,6} , kg	578	586	5.9	0.36

¹NONE = no suckling-phase-implant; ONE-G = 21 mg estradiol benzoate + 150 mg trenbolone acetate (Synovex One Grass; Zoetis Inc., Kalamazoo, MI) suckling-phase extended-release implant; All steers were implanted with 14 mg estradiol benzoate + 100 mg trenbolone acetate (Synovex Choice; Zoetis Inc.) on d 49, and 28 mg estradiol benzoate + 200 mg trenbolone acetate (Synovex Plus; Zoetis Inc.) on d 129

²Calculated as hot carcass weight divided by shrunk (3%) final body weight

³Small⁰ = 500, Modest⁰ = 600

⁴Calculated using USDA (2016) regression equation

⁵Estimated using equations from Guiroy et al. (2001)

⁶AFBW = Final shrunk body weight at 28% empty body fat

**CHAPTER III: EFFECT OF ANABOLIC HORMONE EXPOSURE DURING
THE BACKGROUNDING-PHASE IN CALF-FED STEERS OF DIFFERENT
FRAME SIZES**

ABSTRACT

The frame size (**FS**) of the U.S. cowherd is diverse, which leads to diversity in feeder cattle frame size and fed cattle hot carcass weights (**HCW**). Feedlots must manage inherent variation in the frame size of feeder cattle. Given that implants alter FS, they may be an effective tool to manage variation in HCW across groups of cattle. Two experiments were conducted to evaluate the potential interaction of FS and implant status in calf-fed steers. Steer calves from the same 2 sources were used in each experiment and were managed similarly from weaning to study initiation. Steers were the product of a 50-d calving season, so it was assumed FS differences were reflected in weaning weight (**WW**). Smaller-framed (**SM**) and larger-framed (**LG**) steers were identified from the tails of the WW distribution. Within each FS group, steers were implanted with 20 mg estradiol benzoate and 200 mg progesterone (**SS**) or 14 mg estradiol benzoate and 100 mg trenbolone acetate (**CH**) on d 1 (Exp. 1), and non-implanted (**NI**) or implanted with SS on d 2 (Exp. 2). In both experiments, all steers were terminally implanted with 24 mg estradiol and 120 mg trenbolone acetate and fed for 161 (Exp.1) and 168 d (Exp.2). No FS × implant interactions were observed in either experiment ($P \geq 0.08$). In both experiments LG steers had heavier body weights (**BW**), HCW, and BW adjusted to 28% empty body fat (**AFBW**), greater average daily gain (**ADG**), dry matter intake (**DMI**), and feed:gain (**FG**) than SM steers ($P \leq 0.02$). No differences were evident in marbling

score or Quality Grade distributions between SM and LG steers ($P \geq 0.13$). In Exp. 1, no differences in growth performance, carcass traits, AFBW, or calculated FS were observed for steers initially implanted with SS or CH ($P \geq 0.12$). In Exp. 2, steers implanted initially with SS had heavier final BW, greater ADG and DMI ($P \leq 0.01$), and no difference in FG ($P = 0.78$) than NI steers. Steers initially implanted with SS had heavier HCW ($P < 0.01$), but no other differences in carcass characteristics were observed ($P \geq 0.23$). Additionally, steers implanted with SS tended to have heavier AFBW ($P = 0.07$) and greater calculated FS ($P = 0.05$) than NI steers. Steers of different FS responded similarly to implants. Previous exposure to implants did not alter the response to the terminal implant. Estradiol increases the FS of steers; however, when similar doses of estradiol are compared, trenbolone acetate does not further increase FS.

INTRODUCTION

Growth rate and carcass weight are primary determinants of feedlot profitability, along with feed efficiency. In some instances, 85% of the variation in cost of gain can be explained by average daily gain (ADG), dry matter intake (DMI), hot carcass weight (HCW) and year (Retallick et al., 2013). In 1979 frame size (FS) and muscle thickness scores were assigned as a method to value feeder cattle, and were later updated in 2000 (USDA, 2000; Grona et al., 2002). The implementation of FS and muscle thickness scores was largely based on results from Tatum et al. (1986a, 1986b, 1986c). Indeed, FS was positively correlated to ADG and harvest weight at a constant carcass fat percentage (Tatum et al., 1986b).

Feedlots are forced to manage variation in age, weight, and FS, and can be accomplished by sorting (Armbruster et al., 2013). Sorting is accomplished on the basis

of weight and/or some measure of frame size; feedlots do not usually have the privilege of knowing the exact age of feeder cattle. The FS of the U.S. cowherd is diverse, which leads to diversity in feeder cattle frame size and fed cattle HCW. However, FS can be altered by implants containing anabolic hormones (Preston, 1978; Loy et al., 1988). In fact, a meta-analysis concluded that aggressively implanted steers were 42 kg heavier at harvest than non-implanted steers of similar body composition (Guiroy et al., 2002). Implants have been available since 1956 (Preston, 1999), and approximately 90% of steers and heifers placed on feed in the United States are implanted at least once (APHIS, 2013). Additionally, the growth response from use of multiple implants within a production system has been demonstrated (Duckett et al., 1997; Duckett and Andrae, 2001).

Implications of FS and implant status on growth of beef cattle have been documented; however, their potential interaction has only briefly been explored. Experiments designed to explore the potential interaction of FS and implant status used steers that were non-implanted or implanted for the entire duration of the experiment (Williams et al., 1987; Soils et al., 1989). Using a negative control is necessary to quantify implant response in a research setting. However, given the return on investment that an implant provides (Griffin and Mader, 1997), it may be economically unwise to forego implanting for the entire production phase. Smith et al. (2018) demonstrated that a terminal implant yields superior growth performance compared to an initial implant, when only 1 conventional implant was administered in cattle fed for 213 d. Furthermore, Byers (1980) examined the interaction of growing and finishing-phase implant exposure, but the interaction with FS was not explored.

Because return on investment of from implants is high, we propose that most cattle should receive at least one implant, unless enrolled in non-hormone treated program or where heavy carcasses are a concern. Additionally, our hypothesis was that to reduce variation in HCW, perhaps a smaller-framed steer requires a more potent implant strategy than a larger-framed contemporary. The objectives of these experiments were to 1) examine the effects of backgrounding implant exposure and potency on animal growth performance, and carcass characteristics of steers of different FS, and 2) determine if variation in HCW between smaller and larger-framed steers could be mitigated with backgrounding implant strategy.

MATERIALS AND METHODS

Experiments were approved by the South Dakota State University Institutional Animal Care and Use Committee (Approval 17-004E and 17-077E, Exp. 1 and 2, respectively) and were conducted at the South Dakota State University Ruminant Nutrition Center. Experiment 1 was initiated on December 22, 2016 and terminated on June 1, 2017. Experiment 2 was initiated on December 7, 2017 and terminated on May 24, 2018. Angus and Angus × Simmental steers used in both experiments originated from the same 2 ranches in Western South Dakota and were a product of a 50-d calving season.

Exp. 1

Steer calves were weaned and immediately shipped 588 km to the South Dakota State University Ruminant Nutrition Center. Steers were vaccinated for clostridial (Ultrabac 7/Somubac, Zoetis Inc.) and viral pathogens (Bovi-Shield Gold 5, Zoetis Inc.),

treated with an anthelmintic for external parasites (Cydectin, Bayer, Shawnee Mission, KS), and were equipped with a unique feedlot identification tag.

Because calves were from 2 sources and age was assumed to be relatively uniform, body weight (**BW**) was used as a proxy for FS. Arrival BW was used to segregate steers into smaller-framed (**SM**) and larger-framed (**LG**) contemporary groups. Each FS group consisted of 64 steers from an overall population of 212 steers. Arrival BW were 245 ± 1.9 kg and 321 ± 2.4 kg for SM and LG steers, respectively. Steers were allowed a 51-d acclimation period prior to initiation of the experiment. During the last 9 d of the acclimation period, steers were fed approximately 2-times estimated maintenance energy intake (NASEM, 2016) of a common diet (13.4% CP, 1.79 Mcal/kg NEm) to equalize gastrointestinal tract fill across FS groups. No implants were used during the acclimation period.

Factorialized within SM and LG, steers were implanted with either 20 mg estradiol benzoate + 200 mg progesterone (**SS**; Synovex S, Zoetis Inc., Parsippany, NJ) or 14 mg estradiol benzoate + 100 mg trenbolone acetate (**CH**; Synovex Choice, Zoetis Inc.) on d 1 of the present experiment. This resulted in 4 treatments: **SM-SS**, **SM-CH**, **LG-SS**, and **LG-CH**. During implanting steers were vaccinated with *Clostridium Perfringens* Type A Toxoid (Elanco Inc., Greenfield, IN). Steers were placed in pens (8 steers/pen) based on FS and implant treatment (**IMP**). This factorial treatment structure resulted in 8 replicates per main effect of FS or IMP, and 4 replicates per simple effect of FS \times IMP.

Outdoor pens were concrete surfaced and measured 7.6×7.6 m, with a 7.6 m fence-line feed bunk. Water tanks were located between adjacent pens and steers had *ad*

libitum access to fresh water at all times. Pens were bedded with straw in an attempt to minimize animal discomfort during inclement weather, but never within 48 h of weighing steers. Diets fed during this experiment are reported in Table 3.1. The diet changed on d 36 because of evolving supplement inventory. Changes on d 70 and 91 were to increase dietary energy concentration. Feed deliveries were managed according to a clean bunk management system to approximate *ad libitum* intake and organized so that feed delivery sequence did not confound treatment. Steers were fed twice daily (0800, 1500 h) in equal amounts to the nearest 0.45 kg (as-is basis) at each delivery. Feed ingredients were conveyed to the nearest 0.454 kg into a 25.6 m³ mixer (Roto-Mix, Dodge City, KS) and mixed for 4 min.

Individual feed ingredients were sampled weekly throughout the experiment. Feed samples were dried in a forced air oven at 60°C until a constant weight was maintained to determine dry matter (**DM**) content, then ground (Wiley mill, model 4, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen. Ground samples were analyzed for DM (105°C; AOAC, 1990), crude protein (Kjedahl method; AOAC, 1990), neutral and acid detergent fiber (Goering and Van Soest, 1970), and ash (AOAC, 1990). Distillers grains samples (dried and modified) were additionally analyzed for ether extract content using an Ankom Fat Extractor (XT10; Ankom Technology, Macedon, NY). Tabular feed ingredient energy values (Preston, 2016) were used to estimate dietary net energy concentration. Dry matter intakes, ingredient and nutrient composition were calculated and summarized weekly using feed ingredient analyses and corresponding daily feed batching records.

Steers were weighed individually in the morning prior to feed delivery approximately every 28 d. Reported BW are shrunk (3%), to decrease the impact of fill on BW measures. Steers were treated for external parasites with CyLence (Bayer, Shawnee Mission, KS) on d 56 and 105, and implanted with 24 mg estradiol + 120 mg trenbolone acetate (Revalor-S, Merck Animal Health, Madison, NJ) on d 84. Steers were shipped on June 1, 2017 after 161 d on feed when mean back fat depth (**BF**) for the overall population was estimated to be 1.27 cm.

Steers were harvested at a commercial abattoir (Tyson Fresh Meats, Dakota City, NE) on June 2, 2017. Individual identity was preserved throughout the harvest and grading process. Hot carcass weight was measured on the day of harvest. Dressing percent was calculated using shrunk (3%) final BW. Carcass data necessary to determine USDA Yield and Quality Grade were obtained from the video image analysis system in the packing plant the following day. Ribeye area (**REA**), BF, marbling score, and kidney pelvic heart fat (**KPH**) from each side of the carcass were averaged for each carcass. Yield grade was calculated by using the USDA regression equation (USDA, 2016). Empty body fat (**EBF**) and shrunk weight at 28 % EBF (**AFBW**) were estimated using equations from Guiroy et al. (2001) and compared with AFBW and FS reported by Fox et al. (1992).

A necropsy was conducted on all steers that died during the experiment. One steer belonging to the SM-CH treatment died on d 15 from causes unrelated to treatment, and corresponding data were removed from the experiment. One steer belonging to the LG-SS treatment was found dead in the home pen on d 115, from causes unrelated to treatment. Differences in implant administration occurred prior to d 84, therefore, the

data corresponding to the steer were included until d 84 and excluded from performance post d 84.

Frame size is defined as hip height at a given age, or by AFBW. We used AFBW distribution within FS as a metric to identify steers that were outliers or misclassified at the onset of the experiment. Two LG-NI, and 1 LG-SS steer were identified. Steers were removed from carcass data but remained in pen performance data so gain: feed (**G:F**) was not biased because individual contribution to pen DMI was not known.

Animal growth performance and carcass data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) as a completely randomized block design with a factorial arrangement of treatments. Main effects were 1) FS, and 2) IMP. Replicate was considered a fixed blocking factor, which accounted for feed delivery sequence and feedlot location. The interaction of FS \times IMP was included in the model and residual error was used as the error term. With a significant F-test, means were separated using the LSMEANS statement with the PDIFF option. Pen served as the experimental unit for all analyses, excluding quality grade distribution. Quality grade distributions were analyzed as binomial proportions using the GLIMMIX procedure of SAS with the ILINK option where carcass was the experimental unit. For all analyses, effects were considered significant at $P \leq 0.05$, and statistical trends at $P \leq 0.10$.

Exp. 2

Methods were similar to those described in Exp. 1 in terms of acclimation to facilities, feeding to equalize gastrointestinal tract fill, and segregation into SM and LG contemporary groups. Visual appraisal of hip height relative to FS contemporaries was used to detect outliers within each FS group. Four and 9 steers were identified in the SM

and LG groups, respectively, by two independent unbiased individuals. Suitable replacements were found that fell within the BW distribution and visual hip height estimates for each FS group. Each FS group consisted of 80 steers from an overall population of 371 steers. Arrival BW were 253 ± 0.8 kg and 313 ± 1.6 kg for SM and LG steers, respectively.

Factorialized within SM and LG, steers were either non-implanted (**NI**) or implanted with SS on d 2 of the experiment. This resulted in 4 simple effect treatments: **SM-NI**, **SM-SS**, **LG-NI**, and **LG-SS**. During implanting steers were vaccinated with Clostridium Perfringens Type A Toxoid. Steers were placed in pens (8 steers/pen) based upon FS and IMP. This factorial arrangement of treatments supplied the experiment with 10 replicates per main effect of FS or IMP, and 5 replicates per simple effect of FS \times IMP.

Diets fed during this experiment are reported in Table 3.2. On d 1 steers were fed the common diet used to equalize fill. The diet was changed on d 2, 71, 78 to increase the energy density. On d 111 high-moisture corn and oat hay were used to replace high-moisture ear corn. Weighing schedule, laboratory assays, feed delivery and bunk management were similar to those described in Exp. 1.

Steers were revaccinated with Clostridium Perfringens Type A Toxoid and treated for external parasites with CyLence on d 56. On d 84 steers were retreated with CyLence and implanted with 24 mg estradiol + 120 mg trenbolone acetate (Revalor-S). Implant sites were appraised via ear palpation 28 d after each implant was administered by an individual who did not administer the previous implant. Abscess rate was 1.3% for steers receiving the SS implant and 1.9% for the terminal implant. Data were not excluded on

the basis of implant abnormality. Steers were shipped on May 24, 2018 after 168 d on feed when mean BF depth for the overall population was estimated to be 1.27 cm. Steers were shipped to the same commercial abattoir, and procedures were similar to those described in Exp. 1. Carcass data were collected for all steers enrolled in the experiment.

One steer belonging to the LG-SS treatment was found dead in the pen on d 10, from causes unrelated to treatment. Data unique to that steer were removed. One steer belonging to the SM-SS treatment was found dead in the pen on d 128, for reasons unrelated to treatment. Once again, differences in implant administration occurred prior to d 84, therefore, the data corresponding to the steer were included until d 84 and excluded from performance post d 84. Based on AFBW distribution within FS group, 1 steer from SM-NI, SM-SS, and LG-SS, and 3 steers from LG-NI were classified as outliers and data were handled as in Exp 1.

Animal performance and carcass data were analyzed using the GLM procedure of SAS as a completely randomized block design with a factorial arrangement of treatments. Main effects were 1) FS, and 2) IMP. Replicate was considered a fixed blocking factor, which accounted for feed delivery sequence. The interaction of FS \times IMP was included in the model and residual error was used as the error term. With a significant F-test, means were separated using the LSMEANS statement with the PDIFF option. Pen served as the experimental unit for all analyses, excluding quality grade distribution. Quality grade distributions were analyzed as binomial proportions using the GLIMMIX procedure of SAS with the ILINK option where carcass was the experimental unit. For all analyses, effects were considered significant at $P \leq 0.05$, and statistical trends at $P \leq 0.10$.

RESULTS

Significant ($P \leq 0.05$) interactions were not observed; therefore, main effect means of FS and IMP are reported in the tables.

The backgrounding-phase corresponds to d 1 to 84 in each experiment. The finishing-phase corresponds to d 85 to 161 in Exp. 1 and d 85 to 168 in Exp. 2. These phases represent distinct differences in diet energy density and anabolic hormone exposure. All steers in both experiments were terminally implanted on d 85. Thus, the backgrounding-phase represents when the main effect of IMP was applied.

Exp. 1

By design, initial BW was greater ($P < 0.01$) for LG than SM steers (Table 3.3). This difference persisted throughout the experiment, as observed in interim (d 84) and final BW ($P < 0.01$). Larger-framed steers had 8% greater ($P = 0.03$) ADG, 14% greater ($P < 0.01$) DMI, and tended ($P = 0.06$) to have 6% lesser G:F than SM steers during the backgrounding-phase. Grams of DMI per kg of metabolic body size (**MBS**; Kleiber, 1961) and estimated gain energy density (**GED**) were not different for SM and LG steers during the backgrounding-phase ($P \geq 0.21$). Briefly, DMI was scaled to MBS to make inferences about intake relative to body size and energy requirements, and GED was calculated by dividing estimated retained energy by observed ADG. No differences ($P \geq 0.22$) were observed for BW, ADG, DMI, G:F, or GED between steers implanted with SS or CH during the backgrounding-phase.

During the finishing-phase, LG steers had a 12% greater ($P < 0.01$) DMI, tended to exhibit a 4% greater ($P = 0.09$) ADG, and had a 7% lesser ($P < 0.01$) G:F than SM steers. However, DMI within context of MBS was not different between SM and LG

steers ($P = 0.54$). Despite no differences in the backgrounding-phase, estimated GED was 6% greater ($P = 0.01$) for LG steers than SM steers during the finishing-phase. Effects of IMP during the finishing-phase resembles that during the backgrounding-phase with no differences observed between SS and CH for any of the variables ($P \geq 0.63$).

Cumulative differences observed in the backgrounding and finishing-phases on a live and carcass-weight basis are presented in Table 3.4. Compared to SM steers, LG steers had 6, 13, and 6% greater ($P \leq 0.02$) ADG, DMI, and GED, respectively and 7% lesser ($P < 0.01$) G:F on a live-weight basis. Relative to MBS, DMI was not different between SM and LG steers ($P = 0.34$). Examining performance on a carcass-adjusted basis also resulted with LG steers exhibiting heavier final BW ($P < 0.01$), a 7% greater ADG ($P = 0.01$), and a 5% lesser G:F ($P = 0.03$) than SM steers. No differences were apparent in either the backgrounding or finishing-phases for the main effect of IMP, thus no differences ($P \geq 0.12$) were observed on a cumulative live or carcass-adjusted basis.

A FS \times IMP tendency ($P = 0.08$) was observed for yield grade in that LG-CH steers had a greater yield grade than SM-CH steers (3.42 vs. 2.96, respectively), and neither were different than SM-SS or LG-SS (3.14 vs. 3.23, respectively). A FS \times IMP tendency ($P = 0.08$) was also observed for KPH with SM-SS steers having a greater KPH than LG-SS (2.19 and 1.88, respectively), and neither being different from SM-CH or LG-CH (2.09 and 2.13, respectively).

Larger-framed steers had greater HCW, REA, and yield grade than SM steers ($P \leq 0.02$). However, SM steers had a greater ($P < 0.01$) ratio of REA to HCW. Back fat thickness tended ($P = 0.10$) to be greater for LG steers compared to SM steers. No

differences were observed for dressing percent, marbling score, KPH, or individual quality grades ($P \geq 0.13$) for SM and LG steers.

Estimated EBF, AFBW, and calculated FS were greater ($P \leq 0.01$) for LG compared to SM steers (Table 3.5). Larger-framed cattle had a greater ($P < 0.01$) proportion of EBF and final shrunk BW at 28% EBF ($P < 0.01$) than SM cattle. Smaller-framed and LG differed ($P < 0.01$) by approximately 2 frame scores based on final shrunk BW at 28% EBF and data from Fox et al. (1992). The percentage of carcasses grading Premium Choice tended ($P = 0.08$) to be greater for steers implanted with CH compared to SS. No other differences in carcass traits attributable to IMP were noted ($P \geq 0.12$). Implanting steers with SS or CH yielded EBF, AFBW, and calculated FS that were not different ($P \geq 0.18$).

Exp. 2

Initial BW was greater ($P < 0.01$) for LG than SM steers by design (Table 3.6). Average daily gain was not different ($P = 0.14$) between SM and LG steers during the backgrounding-phase. Thus, the difference in initial BW persisted and LG steers were heavier ($P < 0.01$) than SM steers when the interim BW (d 84) was collected. Dry matter intake was 6% greater, G:F was 9% lesser, and GED was 11% greater ($P < 0.01$) for LG than SM steers during the backgrounding-phase. Similar to Exp. 1, DMI per kg of MBS was not different ($P = 0.49$) between SM and LG steers.

Initial BW was different ($P = 0.04$) between NI and steers implanted with SS; however, the magnitude of difference was only 1 kg (Table 3.6). Therefore, a meaningful biological difference is unlikely. Average daily gain, DMI, and DMI per kg MBS were 6, 3, and 2% greater for steers implanted with SS compared to NI during the

backgrounding-phase ($P \leq 0.03$). Also, G:F tended to be 3% greater ($P = 0.08$) for steers implanted with SS compared to NI steers. As a result, interim BW was 8 kg greater ($P = 0.01$) for steers implanted with SS. Moreover, GED was not altered by implanting steers with SS ($P = 0.31$).

A FS \times IMP tendency ($P = 0.08$) was observed for G:F in the finishing-phase, with SM-NI steers exhibiting a greater G:F than all other treatments that did not differ from each other. As opposed to the backgrounding-phase, ADG was 4% greater ($P < 0.01$) for LG than SM steers during the finishing-phase. Final BW was also greater ($P < 0.01$) for LG compared to SM steers. Larger-framed steers had 11% greater ($P < 0.01$) DMI, and a 7% lesser ($P < 0.01$) G:F than SM steers. Dry matter intake relative to MBS was greater ($P = 0.04$) for LG compared to SM steers; however, this difference was only 1 g/kg of MBS. Gain energy density was also 7% greater ($P < 0.01$) for LG compared to SM steers during the finishing-phase.

Interim BW was greater for steers implanted with SS compared to NI steers ($P < 0.01$). Steers implanted with SS had ADG that did not differ ($P = 0.24$) from NI steers during the finishing-phase, and interim BW differences persisted in final BW ($P < 0.01$). As a reminder, all steers were implanted similarly on d 85. Dry matter intake and DMI per kg of MBS of steers implanted with SS was 4 and 2% greater ($P < 0.01$), respectively, than NI steers. However, no difference ($P = 0.15$) was detected in G:F during the finishing-phase. Gain energy density was 3% greater ($P = 0.05$) for steers implanted with SS as an initial implant than NI steers during the finishing-phase.

A FS \times IMP tendency ($P = 0.10$) was observed for cumulative DMI per kg of MBS with SM-SS and LG-SS (104.9 and 104.9, respectively) being greater than LG-NI,

and LG-NI greater than SM-NI (103.3 and 101.6, respectively). A FS × IMP tendency ($P = 0.08$) was also observed for cumulative GED with LG-NI and LG-SS (5.49 and 5.46, respectively) being greater than SM-SS, and SM-SS greater than SM-NI (5.11 and 4.97, respectively).

Cumulative ADG, DMI and GED were greater ($P < 0.01$; Table 3.7) both on a live and carcass-adjusted basis, and DMI per kg MBS tended to be greater ($P = 0.10$) for LG compared to SM steers. Smaller-framed steers had greater ($P < 0.01$) cumulative and carcass-adjusted G:F than LG steers. Carcass adjusted final BW was greater ($P < 0.01$) for LG than SM steers.

On a cumulative basis implanting steers with SS as an initial implant increased ($P < 0.01$) carcass adjusted final BW, DMI, DMI per kg MBS, and ADG on a live and carcass-adjusted basis (Table 3.7). No differences between NI and SS were evident for GED, or G:F on a live or carcass-adjusted basis ($P \geq 0.24$).

Hot carcass weight, dressing percent, BF, REA, and yield grade were greater ($P < 0.01$) for LG compared to SM steers. Smaller-framed steers had greater ($P < 0.01$) ratio of REA to HCW and KPH compared to LG steers. Marbling score between the two FS groups were not different ($P = 0.77$). No differences ($P \geq 0.27$) were observed for the distribution of Prime, Premium Choice, Average Choice, Low Choice, or Select Quality Grade between SM and LG steers.

Implanting steers with SS increased HCW compared to NI during the backgrounding-phase ($P < 0.01$). Non-implanted steers tended ($P = 0.07$) to have a larger REA to HCW ratio compared to steers implanted with SS. No other differences ($P \geq 0.22$) were observed attributable to IMP for any carcass characteristics other than HCW.

Empty body fat, AFBW, and calculated FS were greater ($P < 0.01$) for LG steers than SM steers. No difference in estimated EBF ($P = 0.69$) was observed between NI and SS. However, AFBW tended ($P = 0.07$) to be greater, and calculated FS was greater ($P = 0.05$) for steers implanted with SS compared to NI steers.

DISCUSSION

The absence of a significant FS \times IMP interaction in the present experiments concur with results from previous experiments. Williams et al. (1987) fed small and large FS steers, and within FS compared NI to implantation with zeranol, which is a synthetic macrolide with estrogenic activity. Steers receiving zeranol implants were implanted on d 0 and 97, and all steers were fed for 175 d. Small and large FS steers responded similarly to zeranol in terms of growth performance and carcass characteristics. Solis et al. (1989) fed large and very-large FS steers for average of 182 d, and within FS steers were either NI or implanted twice with 36 mg zeranol, 72 mg zeranol, SS, or 36 mg zeranol + SS on d 0 and 90. The response by small and large FS steers was not different within each implant strategy. The present experiments, Williams et al. (1987), and Solis et al. (1989) all conclude that cattle of varying FS respond in a similar manner to growth promoting implants.

Frame Size – Exp. 1 & 2

Differences in initial BW between the two FS groups were 73 and 63 kg in Exp. 1 and 2, respectively. A difference of 29 to 58 kg in initial BW is reported in the literature where at least two FS groups are compared (Crickenberger et al., 1978; Byers, 1980; Cianzio et al., 1982; Tatum et al., 1986a; Williams et al., 1987; Solis et al., 1989; Trenkle, 2001). Trenkle (2001) observed a 29 kg difference in initial BW, 4.8 cm

difference in hip height, and a 0.9-unit frame score difference in steers classified as small and large frame size. Tatum et al. (1986a) reported a difference of 30 and 46 kg difference in initial BW between small and medium, and medium and large framed feeder steers, respectively. This equates to a 76 kg difference between small and large framed steers. Differences in initial BW between SM and LG steers in the present experiment, is in agreement with observations from Tatum et al. (1986a).

It should be acknowledged that some experiments (Cianzio et al., 1982; Williams et al., 1987; Solis et al., 1989) have used different breeds of cattle to acquire different FS, while few (Crickenberger et al., 1978; Byers 1980) including the present experiment have evaluated performance and carcass differences attributable to FS within a breed or similar parent population. Indeed, 20 different breeds (as purebreds or crossbreds) were represented in the experiment by Tatum et al. (1986a). Therefore, some of the FS responses reported in the literature may be attributable to breed and not FS alone.

During the backgrounding-phase, ADG was 8% greater for LG steers in Exp. 1, while no difference was observed in Exp. 2 (Tables 3.3 and 3.6). Dietary energy differences between experiments during the backgrounding-phase were minimal (1.26 and 1.21 Mcal/kg NEg, in Exp. 1 and 2, respectively). Given that, if physical fill was limiting DMI it should have occurred similarly across frame sizes and experiments. In fact, DMI response was similar across both experiments during the backgrounding-phase in that LG steers consumed 13 to 14% more DM than SM steers. Also, SM and LG steers did not differ in DMI when scaled to MBS. This infers that DMI was similar between the SM and LG steers in relation to their respective maintenance energy requirements.

The DMI response attributable to FS was of greater magnitude than the ADG response across both experiments. The discrepancy during the backgrounding-phase can be partially explained by differing GED. In Exp. 1, GED did not differ between SM and LG steers. However, in Exp. 2 LG steers had greater GED than SM steers. A GED of 1.2 Mcal/kg ADG implies that composition of gain is 100% lean and fat free; conversely, a GED of 8.0 Mcal/kg ADG implies that composition of gain is 100% adipose (Reid et al., 1955; Garrett and Hinman, 1969; Berg and Butterfield, 1976; Owens et al. 1995). Therefore, in LG steers the additional retained energy over that of SM steers was predominantly in the form of adipose, which is less efficient on a G:F-basis than lean accretion (Owens et al. 1995).

Solis et al. (1989) measured body composition of very-large, and large FS steers using D₂O and specific gravity techniques. The authors reported greater empty body ADG for very-large compared to large FS steers during an 84-d growing phase, as well as a 98-d finishing-phase. During the growing phase grams deposited as protein were not different between FS groups; however, very-large FS steers deposited more grams of fat per day than large FS steers (Solis et al., 1989). Fat expressed as a percentage of gain was greater, and protein expressed as a percentage of gain was lesser for very-large vs large FS steers. During the 98-d finishing-phase very-large FS steers deposited more grams of fat and protein than large FS steers, with no differences in composition of gain expressed as percent fat or protein. For the combined growing and finishing-phases, very-large FS steers deposited more grams of fat and protein, and composition of gain was greater in fat and lesser in protein compared to large FS steers (Solis et al., 1989). The authors also

reported that very-large FS steers had a greater GED than large FS steers, which is in agreement with the present experiments (Tables 3.3 and 3.6).

Williams et al. (1987) fed small and large FS steers for 175 d. Average daily gain was not different through d 97; however, from d 97 to 175 and from d 0 to 175 ADG was greater for large FS compared to small FS steers. In that experiment DMI was greater for large FS steers with no difference in G:F between small or large FS steers. The authors report that rate of protein deposition was not different between the two FS groups; however, large FS steers deposited more grams of fat per day than did small FS steers. This is in contrast to work reported by Byers (1980), that observed that rates of protein deposition are greater for cattle of larger FS. Byers (1980) additionally reported that when fed moderate-energy diets are fed, small and large FS have similar ADG, with small FS cattle having a 6.8% greater G:F despite being approximately 11% fatter. The ability for small FS cattle to utilize moderate energy diets well in relation to large FS contemporaries lends evidence to the common practice of increasing frame size or growing cattle of smaller FS prior to feedlot entry (Byers, 1980; Owens et al., 1995). Additionally, when the two FS groups were fed high-energy whole shelled-corn diets, large FS cattle had 8.3% greater ADG and 6.3% greater G:F compared to small FS cattle (Byers, 1980). Perhaps in Exp. 2 the energy density of the diet fed during the backgrounding-phase was not great enough for the LG steers to express their full ADG potential. When the energy density of the diet was increased during the finishing-phase, LG steers had greater ADG than SM steers (Table 3.6).

Excluding moderate energy diets (Byers, 1980) and isolated instances where ADG was not different through 180 d of age (Cianzio et al., 1982), it is generally

accepted that cattle of greater FS will have greater ADG, DMI, and G:F (Tatum et al., 1986b). The expected response in ADG, carcass-adjusted ADG, and DMI in relation to FS were observed in the current experiments; however, SM steers had greater G:F, and carcass-adjusted G:F than LG steers (Tables 3.4 and 3.7). Trenkle (2001) reported that small FS cattle tend to be more efficient than large FS cattle that were not different in BF or yield grade. Several factors can influence G:F such as: maintenance energy requirements, DMI in excess of maintenance energy requirements, and composition of BW gain. Data were not collected in the present experiment that could infer any differences in maintenance energy requirements between SM and LG steers; however, one can conclude from GED that composition of gain for LG steers contained more adipose than SM steers.

Final BW was greater and thus, LG steers had 57 and 51 kg heavier HCW than SM steers (Tables 3.5 and 3.8). Final BW and carcass adjusted final BW were greater for LG than SM steers, as would be expected (Crickenberger et al., 1978; Byers, 1980; Cianzio et al., 1982; Tatum et al., 1986a; Williams et al., 1987; Solis et al., 1989; Trenkle, 2001). When harvested at a similar body composition, steers of a greater FS will have a heavier HCW (Cianzio et al., 1982; Crickenberger et al., 1978; Byers, 1980; Trenkle, 2001). In Exp. 2, dressing percentage was greater for LG steers compared to SM; yet no difference was observed in Exp. 1. Greater dressing percentage observed in LG steers in Exp 2. is likely because of a greater degree of fatness, as indicated by estimated EBF. As an animal becomes more chemically mature and ADG becomes more adipose in composition there is a disproportionate increase in the fat component of the carcass (Haecker, 1920; Berg and Butterfield, 1976; Tatum et al., 1986b).

Larger-framed steers generally had greater BF in both Exp 1 and 2 (Tables 3.5 and 3.8). This is contrary to our hypothesis. Tatum et al. (1986b) reported that the subcutaneous adipose depot represented a greater percent of all adipose depots in small FS compared to medium or large FS steers. Cianzio et al. (1982) reported similar findings between small and large FS steers. However, one must consider the accretion rate of subcutaneous adipose relative to other adipose depots. Late in the feeding period accretion is rapid (Cianzio et al. 1982; Bruns et al. 2004). Williams et al. (1987) reported no difference in grams of protein deposition, but greater adipose deposition in large FS compared to small FS steers fed for 175 d. Individual birthdates of the steers used in this experiment are not available to verify age of the two FS groups, but days in the feedlot on a high plane of nutrition was constant. Creep feed was not provided to the calves prior to shipping to the Ruminant Nutrition Center; therefore, it is unlikely the calves were supplied enough energy for substantial adipose deposition before these experiments began. Additionally, Cianzio et al. (1982) reported that the allometric growth coefficient for subcutaneous fat of large FS steers was different than one, while this was not the case for small FS steers. In other words, the difference in BF in the present experiments may have manifested late in the feeding period, but without some estimation of body composition at several intervals throughout the experiment no conclusion can be made. Regardless, the LG steers had greater BF and a lesser G:F than SM steers. This observation concurs with Hermesmeier et al. (2000), who reported that steers fed to a targeted 1.4 cm BF had a 2.9% lesser G:F than steers targeted to achieve 1.0 cm BF.

As would be expected from greater HCW, LG steers had approximately 7% greater REA than SM steers (Tables 3.5 and 3.8). However, SM steers had a greater REA

in relation to their respective HCW. Reinhardt et al. (2009) reported that medium FS steers and heifers exhibited a greater REA per unit HCW than did large FS steers and heifers. This may be a result of the nonlinear relationship of REA to HCW (Lawrence et al. 2008). Yield grade was greater for LG than SM steers. The difference in the present experiments is likely because LG steers had greater BF, and also may partially be a result of the nonlinear relationship of REA to HCW (Lawrence et al. 2008). Williams et al. (1987) and Trenkle (2001) report no difference in yield grade between small and large FS steers, but HCW in those studies were 20 to 100 kg lighter than those in the present experiments. Larger-framed steers had heavier HCW, but REA was not proportionally large enough to offset the increase in HCW relative to SM steers. Ribeye area is the only variable in the USDA equation that is associated with a reduction in yield grade (USDA, 2016); therefore, the LG steers may be at a disadvantage to SM steers in terms of yield grade because of the observed REA/HCW ratio.

Marbling score was not different between the 2 FS groups for either experiment. This is in agreement with the published literature (Cianzio et al., 1982; Williams et al., 1987; Trenkle, 2001). Marbling is an early in life developing adipose depot (Cianzio et al., 1982; Bruns et al., 2004), and DMI did not differ between FS groups when scaled to MBS during the backgrounding-phase, we did not anticipate any differences in marbling score. Furthermore, backgrounding-phase ADG relative to each FS must have been sufficient to support intramuscular adipose accretion.

No difference in KPH was observed in Exp. 1; however, in Exp 2. KPH was 4% greater for SM than LG steers. Cianzio et al. (1982) reported a greater KPH allometric growth coefficient for smaller FS compared to larger FS steers. The coefficient was 1.02

and 0.81 for smaller and larger FS steers, respectively. The coefficient for the smaller FS steers did not differ from one ($P < 0.05$), while the coefficient for larger FS steers was lesser than one ($P < 0.05$). In other words, KPH depot in larger FS steers had a slower accretion rate relative to total adipose accretion rate across all depots. Perhaps this has some energetic implications. The KPH depot is greater in chemical fat content compared to subcutaneous, intermuscular, and mesenteric adipose depots (Berg and Butterfield, 1976). Because SM steers had greater KPH and less BF than LG steers in Exp 2, it may be that retained energy was stored in more energy dense form in SM steers. It is unclear why this may have occurred, given the two FS groups were managed similarly, fed a common diet, and existed in a common environment from birth to harvest. Similar to marbling score, no differences were evident in quality grade distribution attributable to FS, which was expected.

Estimated EBF was greater for LG than SM steers (Tables 3.5 and 3.8). In the equation used to estimate EBF, the largest coefficient is associated with BF (Guiroy et al., 2001). Therefore, differences in BF are likely being magnified in estimated EBF. Nonetheless, this was not anticipated, and it was expected that EBF would be similar on a common harvest day for steers that were different in FS. Solis et al. (1989) reported no difference in measured EBF between large and very-large FS steers at harvest. However, EBF estimated via D₂O dilution was lesser for very-large FS steers at the initiation of the experiment. In that experiment actual EBF was 21.9 and 23.2% at harvest for large and very-large steers respectively. However, those steers were harvested at a much lesser chemical maturity than the steers were harvested in the present experiments. Given the rate of adipose accretion discussed previously, perhaps if the steers used in Solis et al.

(1989) were fed for a longer duration, EBF may have been greater for the very-large FS steers.

Adjusting final BW to a common EBF yielded expected results; AFBW was greater for LG than SM steers in both experiments (Tables 3.5 and 3.8). This observation is a cornerstone in discussing cattle of various FS. Cattle of all FS are capable of reaching a similar body composition in a similar timeframe; however, large FS cattle have heavier BW than small FS at a similar compositional endpoint. Furthermore, using AFBW and data from Fox et al. (1992), LG steers were of greater calculated FS than SM steers. This observation validates that the experiment was initiated with steers of differing FS.

Backgrounding Implant – Exp. 1

Estradiol benzoate is 71.4% estradiol on a molecular weight basis. The SS and CH implants are similar in EB content, with the SS implant containing slightly more EB. The implant comparison in this experiment essentially evaluates whether or not the backgrounding implant formulation should contain TBA. No differences in backgrounding-phase growth performance or DMI were observed whether steers were implanted with SS or CH (Table 3.3). In this experiment, both the SS and CH were equally effective during the backgrounding-phase.

All steers received a common terminal implant (Revalor-S) and responded similarly during the finishing-phase regardless of the initial implant (Table 3.3). There is a misconception that once cattle are implanted, they do not respond as well to subsequent implants. This is not the case when estrogenic implants are used (Mader et al., 1994; Pritchard et al., 2003), and in the current experiment the TBA in the CH implant did not decrease performance relative to SS implanted steers. No differences occurred in either

production phase, and there was no difference in cumulative live, or carcass-adjusted animal growth performance (Table 3.4). Herschler et al. (1995) compared steers implanted with SS, or CH to NI steers fed for 140 d. Steers implanted with SS and CH had 15 and 18 % greater ADG, and 6 and 8% greater G:F than NI steers.

Neilson et al. (2016) implanted steers with CH followed by 28 mg EB + 200 mg TBA (Synovex Plus; Zoetis Inc), or SS followed by 24 mg estradiol + 120 mg TBA (Revalor-S). No differences in growth performance were observed in that experiment, which is in agreement with the present experiment. In large pens, Folmer et al. (2009) implanted steers with SS, or 16 mg estradiol + 80 mg TBA (Revalor-IS; Merck) as an initial implant, with both groups implanted with Revalor-S as a terminal implant. Steers implanted with Revalor-IS tended to have a greater carcass-adjusted final BW and HCW. Only cumulative performance is reported in that experiment, so it is unclear whether the difference in BW started to accumulate early because of the initial implant, or if steers implanted with Revalor-IS responded more favorably to the terminal implant.

No differences were evident in carcass characteristics for steers implanted initially with SS or CH other than more SS steers tended to grade Premium Choice (Table 3.5). However, this is likely a type I error because of the limited number of observations (Galyean and Wester, 2010) and was a difference of only 3 carcasses. In this experiment one steer represents approximately 1.6% of the main effect population, which is almost as great as the SEM for that variable. Herschler et al. (1995) observed no differences in carcass characteristics between steers implanted with SS or CH for the duration of a 140-d feeding period, which is in agreement with the present experiment.

Steers implanted with SS or CH had similar estimated EBF (Table 3.5). Similarly, Folmer et al. (2009) observed no difference in estimated EBF between steers implanted initially with SS or Revalor-IS. Loy et al. (1988) found that NI steers, steers implanted once or twice with SS, or steers implanted once or twice with 36 mg zeranol (Ralgro; Merck) had EBF that were not different after 189 d on feed. In the present experiment, implanting steers with SS or CH during the backgrounding-phase did not yield differences in AFBW or calculated FS. It seems that both implants were equally effective in promoting growth during the backgrounding-phase and did not alter the response to the terminal implant. More than one implant strategy likely yields desirable outcomes in respect to production and marketing goals (Pritchard, 1994; Parr et al, 2006; Prouty and Larson, 2010; Nielson et al., 2016).

Backgrounding Implant – Exp. 2

Initial BW was 1 kg greater for steers implanted with SS compared to NI. This is not biologically relevant and is a product of the low SEM at the onset of the experiment. During the background phase, ADG was increased 6% in steers implanted with SS relative to NI steers. An increase of greater magnitude was expected. According to data compiled by Duckett et al. (1997), the use of a single SS implant compared to nonimplant steers should yield a 15% ADG response. A query conducted on the Merck and Texas Tech University North American TBA Implant Database yields a 12% ADG response comparing steers implanted with SS compared to NI (Merck and TTU, 2019). In these experiments a single SS implant was administered for the duration of the trial; whereas, in the present experiment the SS was administered on d 2 and the terminal implant was administered on d 84. Pritchard (1994) compared various implant strategies in steers fed

for 140 d, all implanted steers received an initial and d 70 implant. Steers implanted with SS had 12% greater ADG through the initial 70 d compared to NI steers. Loy et al. (1988) observed an 8% increase in ADG in cattle implanted with SS over NI steers during the initial 84 d of a 189-d experiment. The latter two experiments discussed represent a similar implant evaluation timeframe as the current experiment, and those studies (Loy et al. 1988; Pritchard, 1994) noted a greater ADG response from the SS implant.

Implants increase DMI as well as ADG, so when a desired ADG response is not observed one has to evaluate whether a DMI response was evident. Implanting steers with a SS can increase DMI by 6% (Anderson and Botts, 1995). In the current experiment, steers implanted with SS had 3% greater DMI than NI steers. Duckett et al. (1997) reported a 4% increase, Pritchard (1994) reported a 5% increase, and Loy et al. (1988) reported no increase in DMI of steers implanted with SS relative to NI steers. In the present experiment, steers implanted with SS had 2% greater DMI when scaled MBS, which has also been demonstrated by Loy et al. (1988) using SS, and by Pritchard (1998) using other implants. In other words, DMI is increased because of reasons other than increased BW, perhaps by the anabolic profile supplied by the implant. Given these data, it is likely that DMI was not limiting the ADG response in steers implanted with SS. Estrogenic implants slightly increase maintenance energy requirements (Rumsey et al., 1980; Rumsey and Hammond, 1990), but body weight gain and nitrogen retention increases more rapidly in steers implanted with an estrogenic growth promotant compared to NI steers, when DMI approached ad libitum (Rumsey and Hammond, 1990). It is unclear why only a 6% increase in ADG was observed in the current experiment.

Steers implanted with SS tended to have 3% greater G:F than NI steers, which was expected. Implanting steers with SS have resulted in a 5 to 10% increase in G:F (Loy et al., 1988; Pritchard, 1994; Duckett et al., 1997). The G:F response in the present experiment was likely lesser in magnitude because of the lesser ADG response. In the present experiment, GED was not different during the backgrounding-phase. Pritchard (1998) demonstrated a decreased GED when estradiol/TBA combination implants were used. Implants effectively increase the FS of cattle (Preston 1978; Loy et al. 1998), which means that implanted steers are in a leaner stage of growth relative to NI steers at a similar point in time.

Interim BW was greater for steers implanted with SS compared to NI steers because of the increased ADG during the backgrounding-phase (Table 3.6). No difference was observed in finishing-phase ADG after steers had received the terminal implant. As discussed previously there is a misconception that once implanted, steers do not respond as well to subsequent implants. Dry matter intake and DMI per MBS was greater for steers implanted with SS. The payout of a SS implant is approximately 120 d (Mader, 1997). Given that all steers were reimplemented 83 d after implantation of the SS, it is likely at least at the beginning of the finishing-phase steers implanted with SS were exposed to more anabolic than NI steers. This may be why the DMI response persisted into the finishing-phase. No difference in G:F were observed during the finishing-phase, again lending evidence that previous implantation does not hamper the effect of subsequent implants in a well-designed strategy (Table 3.6). During the finishing-phase, steers implanted with SS had a greater GED than NI steers. This is the energetic result of a greater DMI and a similar ADG. It seems that both implant groups had maximized their

lean growth potential, and because steers implanted with SS had greater DMI the additional retained energy was deposited as adipose tissue. Daily fat deposition was increased in steers implanted twice with 36 mg zeranol compared with NI steers in a 175-d feeding period reported by Williams et al. (1987).

Steers implanted with SS maintained the interim BW advantage over NI steers, as illustrated by final BW and carcass adjusted final BW being greater (Table 3.7). Byers (1980) observed that steers implanted with diethylstilbestrol during the growing and finishing-phase had more kg of protein in the empty body than steers NI during the growing-phase but implanted with diethylstilbestrol during finishing. No difference in empty body protein was evident if steers were implanted with diethylstilbestrol once, either in the growing or finishing-phase (Byers, 1980). On a cumulative-basis steers implanted with SS during the backgrounding-phase had greater ADG, DMI, DMI/MBS, and carcass adjusted ADG than NI steers, in the current experiment. No differences were observed in G:F, carcass adjusted or live, or GED between NI and SS steers. The additivity of sequential implantation has been demonstrated by Mader et al. (1994) and Pritchard et al. (2003). Duckett and Andrea (2001) reported that weight gain from implanting is additive throughout all phases of beef production, which is supported by the results of the present experiment.

Steers implanted with SS during the backgrounding-phase had heavier HCW than NI steers, despite receiving a common terminal implant (Table 3.8). Duckett and Andrea (2001) report a 4.75% increase in HCW over NI steers when one estrogen + androgen combination implant is used. Additionally, they report a 6.61% increase in HCW over NI steers when a reimplant strategy is used involving an initial estrogenic implant followed

by an estrogen + androgen combination implant. The difference relative to NI controls between these two implant strategies is approximately 2%, which is similar to the response in the current experiment.

The tendency observed for NI steers to have a greater REA/HCW ratio is biologically irrelevant given that the difference was only 0.2 cm²/kg of HCW. Delaying or lowering the potency of the initial implant has lessened the decrease in marbling score attributable to implanting (Pritchard, 1998; Bruns et al., 2005; Smith et al., 2018). Therefore, we were particularly interested in marbling score responses attributable to altering implant exposure during the backgrounding-phase. While all implant dosages have decreased marbling score to some extent, evidence exists that implies TBA may be more detrimental to marbling score or percentage of carcass grading choice (Reinhardt and Wagner, 2014). Although, according to the data of Herschler et al. (1995) an implant containing 60 mg of estradiol or a SS implant depressed marbling relative to NI steers, while steers implanted with 300 mg TBA had marbling scores not different than NI steers. However, no difference in marbling score in the present experiment was observed (Table 3.8). Perhaps DMI was sufficient to meet the additional growth demand resulting from the implant, without impeding development of intramuscular fat depots. Depression in marbling scores associated with implanting may be related to energy intake at the time of implanting (Bruns et al. 2005). Implants increase lean growth potential, and if DMI is not sufficient to meet that increased growth potential while maintaining intramuscular adipose accretion, marbling scores may be decreased.

No difference in estimated EBF was observed for NI steers or steers implanted with SS during the backgrounding-phase (Table 3.8). It has been well documented that

steers are capable of achieving a similar degree of EBF despite various implant strategies (Loy et al., 1988; Hutcheson et al., 1997; Bruns et al., 2005). Implanting steers with SS initially tended to increase AFBW compared to NI steers and is in agreement with published literature (Loy et al., 1988; Hutcheson et al., 1997; Bruns et al., 2005; Smith et al., 2018). Furthermore, calculated FS was increased by implanting steers initially with SS. The FS response is the hallmark of utilizing growth promoting implants. Whether the quantitative measure of FS is AFBW (Loy et al., 1988; Hutcheson et al., 1997; Bruns et al., 2005; Smith et al., 2018), or hip height (Preston, 1978; Loy et al., 1988) it is well documented that implants increase both units of measure.

Improving carcass uniformity should allow feedlot operators to market cattle more precisely. With low variation in a pen of cattle, the mean HCW can approach the heavyweight discount without having a high percentage of carcass that receive the discount. Variation in FS exists in all groups of cattle, and we hypothesized that variation in HCW could be reduced by implanting SM cattle twice, and LG only once. The following data consider each carcass as an individual. As a baseline, NI steers that only received a terminal implant had HCW of 385 ± 3.8 kg, and steers implanted with SS during the backgrounding-phase and received a terminal implant had HCW of 392 ± 3.7 kg. Remember that the NI and SS groups were composed of SM and LG steers. A hypothetical population was formed with SM-SS and LG-NI steers. The hypothetical population had HCW of 388 ± 3.5 kg. Using the SEM as a metric, the variation was slightly reduced but is likely not of large enough magnitude to be biologically relevant. It should be acknowledged, however, that if a greater gain response was observed with the SS then the variation in the hypothetical population would have been reduced further.

IMPLICATIONS

A significant interaction of frame size and backgrounding implant status was not observed in these experiments. Smaller and larger-framed steers responded did not differ in response to implants used in these experiments. The growth response expected from larger-framed cattle was observed. In general, larger-framed steers consume more feed, and exhibited increased rates of gain. However, smaller-framed steers were more feed efficient. While the larger-framed steer may be desirable for an increased rate of gain and an increased carcass weight, the smaller-framed steer may be desirable in certain production scenarios where feed costs are high or heavy carcass discounts are incurred. If consumers want a well marbled cut but the size of a ribeye is a concern, the smaller-framed steer certainly provides an advantage over the larger-framed steer.

Steers of different frame sizes responded similarly to implants, which allows designing implant strategies to be less complicated. Implanting steers with an estrogenic implant during the backgrounding-phase increased hot carcass weights without decreasing marbling scores, and previous exposure to anabolic hormones did not alter the response to the terminal implant. The latter lends evidence that implant responses are additive throughout phases of production in a well-designed strategy. Estradiol increases the frame size of steers; however, when similar doses of estradiol are compared, trenbolone acetate does not further increase frame size.

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Table 3.1. Actual formulation and nutrient composition of diets fed in Exp. 1^{1,2}

Item	Days of experiment			
	1-35	36-69	70-90	91-161
n, samples	5	5	3	10
Dry-rolled corn, %			49.67	67.98
High-moisture ear corn, %	51.52	54.70	24.55	
Dried distillers grains, %	16.50	14.59	11.91	
Modified distillers grains, %				19.56
Corn silage, %	25.00	25.68	8.90	
Sorghum silage, %				7.58
Liquid supplement 1 ³ , %	5.00			
Liquid supplement 2 ⁴ , %		5.03	4.97	4.88
Pelleted supplement ⁵ , %	1.98			
Dry matter, %	60.66	60.22	73.57	68.85
Crude protein, %	13.65	12.56	12.22	14.19
Neutral detergent fiber, %	21.31	21.06	15.00	14.37
Acid detergent fiber, %	9.62	9.92	6.06	5.40
Ash, %	3.73	3.66	2.87	3.51
Ether extract, %	4.11	4.07	3.86	4.35
NEm ⁶ , Mcal/kg	1.89	1.88	2.04	2.09
NEg ⁶ , Mcal/kg	1.24	1.23	1.37	1.40

¹Dry matter basis

²Calculated from weekly ingredient assays and batching records

³Contained 39% crude protein as nonprotein nitrogen on a dry matter basis and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)

⁴Contained 39% crude protein as nonprotein nitrogen and 648 mg/kg monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN) on a dry matter basis and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)

⁵Contained 1665 mg/kg monensin (Rumensin 90; Elanco Animal Health)

⁶NEm = net energy for maintenance; NEg = net energy for gain; Calculated from tabular NE values (Preston, 2016)

Table 3.2. Actual formulation and nutrient composition of diets fed in Exp. 2^{1,2}

Item	Days of experiment			
	2-70	71-77	78-110	111-168
n, samples	10	1	5	9
Dry-rolled corn, %		13.70	37.54	34.44
High-moisture corn, %				34.34
High-moisture ear corn, %	62.58	60.30	39.10	
Dried distillers grains, %	16.51	17.25	18.27	18.08
Grass hay, %	15.76	3.69		
Oat hay, %				8.12
Liquid supplement ³ , %	5.15	5.06	5.09	5.02
Dry matter, %	69.98	70.48	74.30	79.52
Crude protein, %	12.91	13.22	13.82	13.94
Neutral detergent fiber, %	25.39	18.35	15.21	17.03
Acid detergent fiber, %	12.17	7.63	5.68	6.82
Ash, %	6.59	5.33	4.73	5.07
Ether extract, %	3.95	3.97	3.98	3.46
NEm ⁴ , Mcal/kg	1.85	1.97	2.05	2.10
NEg ⁴ , Mcal/kg	1.19	1.31	1.38	1.42

¹Dry matter basis

²Calculated from weekly ingredient assays and batching records

³Contained 39% crude protein as nonprotein nitrogen and 648 mg/kg monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN) on a dry matter basis and provided vitamins and minerals to meet nutrient requirements (NASEM, 2016)

⁴NEm = net energy for maintenance; NEg = net energy for gain; Calculated from tabular NE values (Preston, 2016)

Table 3.3. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on interim performance corresponding to management in steer calves fed for 161 d in Exp. 1¹

Item	Frame Size ²			SS	Implant ³		Pooled SEM
	SM	LG	P-value		CH	P-value	
Backgrounding-phase⁴							
n, steers	63	64	-	64	63	-	-
n, pens	8	8	-	8	8	-	-
Initial body weight, kg	287	360	<0.01	324	323	0.75	1.1
Interim body weight, kg	421	504	<0.01	463	461	0.55	2.8
Average daily gain, kg	1.59	1.71	0.03	1.66	1.64	0.64	0.033
Dry matter intake, kg	8.11	9.23	<0.01	8.77	8.57	0.22	0.104
Dry matter intake/MBS ⁵ , g/kg	99.4	97.4	0.22	99.4	97.4	0.22	1.04
Gain:feed	0.196	0.185	0.06	0.190	0.191	0.80	0.0037
GED ⁶ , Mcal/kg	3.82	3.99	0.21	3.95	3.87	0.55	0.090
Finishing-phase⁴							
n, steers	63	63	-	63	63	-	-
n, pens	8	8	-	8	8	-	-
Interim body weight, kg	421	503	<0.01	463	461	0.63	2.8
Final body weight, kg	562	651	<0.01	608	606	0.65	3.7
Average daily gain, kg	1.84	1.92	0.09	1.88	1.88	0.88	0.031
Dry matter intake, kg	11.12	12.42	<0.01	11.83	11.71	0.64	0.165
Dry matter intake/MBS ⁵ , g/kg	106.5	105.5	0.54	106.3	105.6	0.64	1.12
Gain:feed	0.166	0.155	<0.01	0.160	0.161	0.63	0.0018
GED ⁶ , Mcal/kg	5.47	5.82	0.01	5.66	5.62	0.69	0.073

¹Shrink (3%) was applied to all body weights

²SM = smaller-framed; LG = larger-framed

³SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84; CH = implanted with 14 mg estradiol benzoate and 100 mg trenbolone acetate on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

⁴Backgrounding-phase = d 1 to 84; Finishing-phase = d 85 to 161

⁵MBS = Metabolic body size, calculated as weight^{3/4} (Kleiber, 1961)

⁶GED = Gain energy density, calculated as estimated retained energy divided by average daily gain

Table 3.4. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on cumulative and carcass adjusted performance in steer calves fed for 161 d in Exp. 1¹

Item	Frame Size ²			Implant ³			Pooled SEM
	SM	LG	<i>P</i> -value	SS	CH	<i>P</i> -value	
n, steers	63	63	-	63	63	-	-
n, pens	8	8	-	8	8	-	-
Live Weight Basis							
Initial body weight, kg	287	360	<0.01	324	323	0.83	1.0
Final body weight, kg	562	651	<0.01	608	606	0.65	3.7
Average daily gain, kg	1.71	1.81	0.02	1.77	1.75	0.71	0.024
Dry matter intake, kg	9.55	10.76	<0.01	10.23	10.07	0.34	0.111
Dry matter intake/MBS ⁴ , g/kg	102.0	100.9	0.34	102.1	100.8	0.26	0.81
Gain:feed	0.179	0.168	<0.01	0.173	0.174	0.51	0.0015
GED ⁵ , Mcal/kg	4.61	4.87	<0.01	4.78	4.70	0.30	0.048
Carcass-Adjusted Basis							
Final body weight ⁶ , kg	553	645	<0.01	603	595	0.12	3.2
Average daily gain, kg	1.65	1.77	0.01	1.74	1.69	0.21	0.024
Gain:feed	0.173	0.165	0.03	0.170	0.168	0.58	0.0023

¹Shrink (3%) was applied to all body weights

²SM = smaller-framed; LG = larger-framed

³SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84; CH = implanted with 14 mg estradiol benzoate and 100 mg trenbolone acetate on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

⁴MBS = Metabolic body size, calculated as $\text{weight}^{3/4}$ (Kleiber, 1961)

⁵GED = Gain energy density, calculated as estimated retained energy divided by average daily gain

⁶Calculated as hot carcass weight divided by 0.625

Table 3.5. Main effects of frame size and backgrounding estradiol benzoate and progesterone or estradiol benzoate and trenbolone acetate on carcass characteristics, empty body fat, and calculated frame score of steer calves fed for 161 d in Exp. 1

Item	Frame Size ¹			Implant ²			Pooled SEM
	SM	LG	<i>P</i> -value	SS	CH	<i>P</i> -value	
n, steers	63	60	-	61	62	-	-
n, pens	8	8	-	8	8	-	-
Hot carcass weight (HCW), kg	346	403	<0.01	377	372	0.12	2.0
Dress ³ , %	61.47	61.95	0.14	61.86	61.56	0.32	0.205
Back fat thickness, cm	1.20	1.31	0.10	1.27	1.24	0.67	0.041
Ribeye area (REA), cm ²	79.84	85.64	0.01	83.33	82.16	0.48	1.129
REA/HCW, 6.45 cm ² /45.4 kg	1.63	1.50	<0.01	1.56	1.56	0.96	0.018
Calculated Yield Grade	3.05	3.32	0.02	3.18	3.19	0.96	0.067
Marbling score ⁴	563	569	0.69	556	576	0.18	9.8
Kidney pelvic heart fat	2.14	2.01	0.18	2.03	2.11	0.41	0.064
Quality Grade							
Prime, %	0.00	0.00	-	0.00	0.00	-	-
Premium Choice, %	1.68	3.17	0.59	0.00	4.87	0.08	1.990
Average Choice, %	22.04	26.76	0.55	26.17	22.62	0.65	5.616
Low Choice, %	65.17	51.42	0.13	55.40	61.18	0.52	6.384
Select, %	11.11	18.65	0.24	18.43	11.33	0.27	4.589
Empty body fat ⁵ , %	29.34	30.61	0.01	29.97	29.98	0.98	0.259
AFBW ^{5,6} , kg	526	590	<0.01	562	554	0.19	3.6
Calculated FS ^{5,7}	4.75	6.74	<0.01	5.87	5.62	0.18	0.117

¹SM = smaller-framed; LG = larger-framed

²SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84; CH = implanted with 14 mg estradiol benzoate and 100 mg trenbolone acetate on d 1 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

³Calculated as hot carcass weight divided by final body weight

⁴Small⁰ = 500, Modest⁰ = 600

⁵Estimated using equations of Guiroy et al. (2001)

⁶AFBW = Final shrunk weight at 28% empty body fat

⁷Estimated using final shrunk weight at 28% empty body fat and data from Fox et al. (1992)

Table 3.6. Main effects of frame size and backgrounding estradiol benzoate and progesterone on interim performance corresponding to management in steer calves fed for 168 d in Exp. 2¹

Item	Frame Size ²			Implant ³			Pooled SEM
	SM	LG	<i>P</i> -value	NI	SS	<i>P</i> -value	
Backgrounding-phase⁴							
n, steers	80	79	-	80	79	-	-
n, pens	10	10	-	10	10	-	-
Initial body weight, kg	308	371	<0.01	339	340	0.04	0.3
Interim body weight, kg	436	503	<0.01	466	474	0.01	1.7
Average daily gain, kg	1.52	1.57	0.14	1.50	1.59	0.01	0.021
Dry matter intake, kg	8.68	9.84	<0.01	9.14	9.38	0.01	0.055
Dry matter intake/MBS ⁵ , g/kg	102.4	103.0	0.49	101.8	103.7	0.03	0.53
Gain:feed	0.175	0.160	<0.01	0.165	0.170	0.08	0.0018
GED ⁶ , Mcal/kg	4.14	4.58	<0.01	4.40	4.32	0.31	0.050
Finishing-phase⁴							
n, steers	79	79	-	80	78	-	-
n, pens	10	10	-	10	10	-	-
Interim body weight, kg	436	503	<0.01	466	474	0.01	1.7
Final body weight, kg	587	660	<0.01	618	629	<0.01	1.9
Average daily gain, kg	1.79	1.87	0.01	1.81	1.84	0.24	0.018
Dry matter intake, kg	11.41	12.68	<0.01	11.82	12.27	<0.01	0.044
Dry matter intake/MBS ⁵ , g/kg	106.0	107.0	0.04	105.2	107.8	<0.01	0.31
Gain:feed	0.157	0.147	<0.01	0.154	0.150	0.15	0.0015
GED ⁶ , Mcal/kg	5.89	6.29	<0.01	5.99	6.19	0.05	0.064

¹Shrink (3%) was applied to all body weights

²SM = smaller-framed; LG = larger-framed

³NI = non-implanted during backgrounding-phase, implanted with 24 mg estradiol and 120 mg trenbolone acetate on d 84; SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 2 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

⁴Backgrounding-phase = d 1 to 84; Finishing-phase d 85 to 168

⁵MBS = Metabolic body size, calculated as weight^{3/4} (Kleiber, 1961)

⁶GED = Gain energy density, calculated as estimated retained energy divided by average daily gain

Table 3.7. Main effects of frame size and backgrounding estradiol benzoate and progesterone on cumulative and carcass adjusted performance in steer calves fed for 168 d in Exp 2¹

Item	Frame Size ²			Implant ³			Pooled SEM
	SM	LG	<i>P</i> -value	NI	SS	<i>P</i> -value	
n, steers	79	79	-	80	78	-	-
n, pens	10	10	-	10	10	-	-
Live Weight Basis							
Initial body weight, kg	308	371	<0.01	339	340	0.04	0.3
Final body weight, kg	587	660	<0.01	618	629	<0.01	1.9
Average daily gain, kg	1.66	1.72	<0.01	1.66	1.72	<0.01	0.012
Dry matter intake, kg	10.04	11.26	<0.01	10.48	10.83	<0.01	0.042
Dry matter intake/MBS ⁴ , g/kg	103.2	104.1	0.10	102.4	104.9	<0.01	0.34
Gain:feed	0.165	0.153	<0.01	0.159	0.159	0.78	0.0009
GED ⁵ , Mcal/kg	5.04	5.47	<0.01	5.23	5.28	0.24	0.033
Carcass-Adjusted Basis							
Final body weight ⁶ , kg	581	663	<0.01	616	628	<0.01	1.6
Average daily gain, kg	1.63	1.74	<0.01	1.65	1.71	<0.01	0.010
Gain:feed	0.162	0.154	<0.01	0.158	0.158	0.71	0.0009

¹Shrink (3%) was applied to all body weights

²SM = smaller-framed; LG = larger-framed

³NI = non-implanted during backgrounding-phase, implanted with 24 mg estradiol and 120 mg trenbolone acetate on d 84; SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 2 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

⁴MBS = Metabolic body size, calculated as weight^{3/4} (Kleiber, 1961)

⁵GED = Gain energy density, calculated as estimated retained energy divided by average daily gain

⁶Calculated as hot carcass weight divided by 0.625

Table 3.8. Main effects of frame size and backgrounding estradiol benzoate and progesterone on carcass characteristics, estimated empty body fat, and calculated frame score of steer calves fed for 168 d in Exp 2

Item	Frame Size ¹			Implant ²			Pooled SEM
	SM	LG	<i>P</i> -value	NI	SS	<i>P</i> -value	
n, steers	77	75	-	76	76	-	-
n, pens	10	10	-	10	10	-	-
Hot carcass weight (HCW), kg	363	414	<0.01	385	392	<0.01	1.0
Dress ³ , %	61.92	62.75	<0.01	62.20	62.47	0.23	0.151
Back fat thickness, cm	1.39	1.58	<0.01	1.48	1.50	0.71	0.033
Ribeye area (REA), cm ²	83.76	89.31	<0.01	86.18	86.88	0.34	0.495
REA/HCW, 6.45 cm ² /45.4 kg	1.62	1.53	<0.01	1.59	1.56	0.07	0.008
Calculated Yield Grade	3.15	3.45	<0.01	3.29	3.31	0.73	0.050
Marbling score ⁴	618	621	0.77	623	616	0.54	7.6
Kidney pelvic heart fat	1.95	1.87	<0.01	1.92	1.90	0.22	0.013
Quality Grade							
Prime, %	3.88	5.22	0.69	5.21	3.89	0.70	2.438
Premium Choice, %	13.00	12.01	0.86	10.56	14.45	0.48	3.892
Average Choice, %	40.07	36.15	0.62	41.93	34.29	0.33	5.601
Low Choice, %	39.19	38.52	0.93	34.33	43.38	0.26	5.696
Select, %	3.86	8.10	0.27	7.97	3.99	0.30	2.732
Empty body fat ⁵ , %	30.72	32.23	<0.01	31.42	31.53	0.69	0.202
AFBW ^{5,6} , kg	529	581	<0.01	550	560	0.07	3.4
Calculated FS ^{5,7}	4.82	6.48	<0.01	5.52	5.78	0.05	0.085

¹SM = smaller-framed; LG = larger-framed

²NI = non-implanted during backgrounding-phase, implanted with 24 mg estradiol and 120 mg trenbolone acetate on d 84; SS = implanted with 20 mg estradiol benzoate and 200 mg progesterone on d 2 and with 24 mg estradiol and 120 mg trenbolone acetate on d 84

³Calculated as hot carcass weight divided by final body weight

⁴Small⁰ = 500, Modest⁰ = 600

⁵Estimated using equations of Guiroy et al. (2001)

⁶AFBW = Final shrunk weight at 28% empty body fat

⁷Estimated using final shrunk weight at 28% empty body fat and data from Fox et al. (1992)