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Evaluation of growth promoting implant strategies and days on feed on finishing heifer performance and evaluation of optimal reimplant times for finishing heifers and steers

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EVALUATION OF GROWTH PROMOTING IMPLANT STRATEGIES AND DAYS ON FEED ON FINISHING HEIFER PERFORMANCE AND EVALUATION OF OPTIMAL REIMPLANT TIMES FOR FINISHING HEIFERS AND STEERS

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EVALUATION OF GROWTH PROMOTING IMPLANT STRATEGIES AND DAYS ON FEED ON FINISHING HEIFER PERFORMANCE AND EVALUATION OF OPTIMAL REIMPLANT TIMES FOR FINISHING HEIFERS AND STEERS

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Two experiments evaluated the effects of delayed, long-acting coated implants or uncoated implants to non-implanted heifers fed for constant or varying days on feed. In Exp. 1, heifers were implanted with either Revalor-XH on d 1, Revalor-200 on d 1, Revalor-XR on d 1, or Revalor-200 on d 70 compared to non-implanted control heifers when fed for an average of 198 d. In Exp. 2, heifers were implanted with Revalor-200 on d 1 and reimplanted with Revalor-200 on d 100, Revalor-XH on d 1, or not implanted and fed for different days on feed: 151, 165, 179, or 193. Implanting heifers increased BW, ADG, G:F and HCW compared to non-implanted heifers with no differences between implant strategies. As heifers were fed for longer DOF, ADG and G:F decreased. Implanting and increasing DOF substantially increased BW and HCW but increasing initial implant dosage did not result in a performance advantage when heifers were fed for varying DOF.

Two experiments evaluated the effect of timing of administering a terminal implant in heifers and steers when fed for 180 days. In Exp. 3, heifers were implanted with Revalor-IH and reimplanted with Revalor-200 at 20, 60, 100 or 140 DOF. In Exp. 4, steers were implanted with Revalor-IS and reimplanted with Revalor-200 on 20, 60, 80,

100 or 140 DOF. In Exp. 3, final BW, ADG, G:F, HCW and LM area responded quadratically and were maximized between 88 and 103 on terminal (DOT) implant. In Exp. 4, carcass-adjusted final BW, ADG, G:F and HCW responded quadratically and was optimized between 87 and 104 DOT. Therefore, the optimal duration for a terminal implant appears to be between 80 and 120 DOT, with an average of 96 DOT for both heifers and steers.

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Introduction

Profitability in the cattle feeding industry is driven by weight gain and efficiency in the feedlot. The feeding industry is constantly evolving and adapting innovative technologies to achieve more profit efficiently.

Steroidal combination implants have been extensively used and studied for over 50 years. Implants have consistently been shown to increase gain and hot carcass weight by increasing frame size and delaying fattening (Reinhardt, 2007; Smith et al., 2018). However, due to this effect, cattle must be fed for longer days on feed (DOF) to achieve similar fatness to non-implanted cattle. Traditionally, the payout of most uncoated implants is approximately 60 to 120 days (Mader, 1998). More recently, cattle producers have been feeding cattle for longer DOF which causes logistical issues for reimplanting. The FDA has approved the use of coated implants, which delays the release of the partial or entire dose of the steroidal hormones until approximately 70 to 80 d after implanting. These long-lasting implants may remove the need to reimplant, potentially reducing the cost and logistical issues sometimes associated with reimplanting.

The ideal time to administer the terminal implant following an initial implant has recently been of interest. Duckett and Pratt (2014) demonstrated that both steers and heifers given an initial implant and reimplanted with a combination terminal implant had a 20% increase in ADG and 13.5% increase in G:F compared to non-implanted cattle. However, the data describing the optimal time to administer a terminal implant are limited, and most recommendations come from anecdotal evidence or consultant's individual experiences.

Therefore, the objectives of this study were: to evaluate the effects of coated long-acting, delayed release implants in heifers fed for constant DOF or the effect of traditional, aggressive implant strategies compared to long lasting implants when heifers are fed varying DOF (Exp. 1 and 2) and evaluate and define the optimal time to reimplant heifers and steers following a mild initial implant (Exp. 3 and 4).

CHAPTER I. Review of Literature

Overview of Implants

Growth Promoting Anabolic Steroids

Anabolic steroids are a group of natural or synthetic estrogens (female hormone) or androgens (male hormone) approved for use in beef cattle for growth promoting purposes (Meyer, 2001). Since the 1950s, many steroid hormone drugs have been approved for use in beef and sheep production, including estrogen, progesterone, testosterone, and synthetic versions of all compounds (FDA, 2017). These compounds have been shown to improve growth rate, feed efficiency and protein deposition in experimental or commercial use (Montgomery et al., 2001). According to the USDA National Animal Health Monitoring System survey of feedlots in 12 major cattle feeding states with over 1,000-head capacity, 97% of all cattle entering the feedlot at greater than 318 kg were implanted at least one time. Of that 97%, 30% were implanted twice. Furthermore, 60% of the cattle implanted once received an androgenic compound and of the cattle implanted twice, 78% received an androgenic compound (Duckett and Andrae, 2001; Johnson and Beckett, 2014).

Implants are approved for most segments of beef production, including suckling, grazing, and finishing steers and heifers (Duckett and Andrae, 2001) and if used properly, can have a substantial return on investment (Hutcheson, 1993). While the return on investment varies, it is estimated to be greater than $5 per $1 spent (ZoBell, et al., 2000).

There are several diverse types of single and combination ingredients used in implants, including Estradiol-17β (E17), zeranol, trenbolone acetate (TBA), and

progesterone. However, most implants are comprised of estrogens, androgens, progestins, which are all naturally-occurring in all animals, regardless of gender (Johnson and Beckett, 2014). These compounds, or the combination of two, account for all commercially available implants (Botts, 1997). It is estimated that nearly two-thirds of all marketed implants in the United States are a combination of TBA/E17 (Johnson and Beckett, 2014), and therefore will be the focus for this review. Implants are approved to be administered subcutaneously in the middle third of the back of the ear, which allows for a slow, consistent steroid release into the blood stream to be administered to body tissues, without the implant site (ear tissue) entering the human food supply (Johnson and Beckett, 2014).

Mode of Action

Steroidal hormones elicit a response by working through the endocrine and paracrine systems and their hormones to regulate growth and protein metabolism (Meyer, 2001). In general, steroid implants act primarily by binding to cytosolic receptors, which then act on the nucleus to promote gene expression and translation of growth-promoting hormones such as IGF-1 and growth hormone (Bryant et al., 2010). It is widely accepted that cattle implanted with a combination of TBA and E17 experience a synergistic effect and show an increase in performance compared to cattle implanted with TBA or E17 alone (Pampusch et al., 2008; Reinhardt, 2007). However, it is important to evaluate these compounds individually first to fully understand how they work effectively together.

Estradiol-17β has a greater anabolic effect compared to androgens in cattle and sheep and growth related to E17 seems to be dose-dependent (Meyer, 2001). Meyer

(2001) proposed possible indirect and direct effects of E17. The author discussed that E17 stimulates and increases estrogen receptors on the skeletal muscle cells, which in turn, increases stimulation of muscle mRNA to increase protein anabolism and mineral retention. Estradiol-17β acts indirectly on the hypothalamus to secrete more growth-hormone releasing hormone or directly by stimulating the pituitary gland to secrete more growth hormone, and therefore increase growth hormone receptors in the liver, and release more insulin-like growth factor 1 (IGF1) into the blood stream (Trenkle, 1997; Meyer, 2001). Increased levels of IGF-1 and IGF-1 mRNA have a positive effect on increasing protein accretion of existing muscle fibers and promoting hypertrophy of skeletal muscle (Kamanga-Sollo et al., 2008; Johnson and Beckett, 2014). However, to sustain long-lasting hypertrophy since the number of muscle fibers is essentially fixed at birth, there needs to be proliferation of new cells through stimulation of inactive satellite cells by IGF-1 (Johnson and Chung, 2007; Kamanga-Sollo et al., 2008).

Trenbolone belongs to a group of the most efficient anabolic steroids, likely due to its multiple hormonal activity (Meyer, 2001). While the exact mechanism of trenbolone on growth and efficiency of cattle is not completely understood, it is believed that trenbolone acts like other androgens, and exhibits strong binding to the androgen receptor, progestin receptor, and glucocorticoid receptor (Meyer, 2001). Meyer (2001) also proposed that trenbolone suppresses tyrosine amino transferase and consequently prevents amino acid catabolism when compared to testosterone or other androgens. Furthermore, the author concludes that trenbolone acts as an anti-glucocorticoid by binding to the glucocorticoid receptor and further prevents catabolic activity. While it is thought that TBA has very limited stimulatory effect on muscle IGF-1, it is believed that

TBA is the most efficient at acting directly on the muscle cells through several pathways to promote proliferation of bovine satellite cell cultures (Pampusch et al., 2008; Johnson and Beckett, 2014). However, as previously mentioned, the combination of E17 and TBA have a greater response than when E17 or TBA are used independently (Hayden et al., 1992; Dayton and White, 2008; Pampusch et al., 2008; Johnson and Beckett, 2014). It is believed that E17 stimulates muscle protein deposition and TBA works to enhance this effect, and because of the increase of muscle protein deposition, it is the increase in muscle synthesis and not the decrease of muscle protein degradation that causes the responses observed from the use of combination implants. However, the exact mechanism of how these two hormones work on other growth promoting hormones and their receptors and tissues is not fully understood and warrant further research (Hayden et al., 1992; Pampusch, et al., 2008).

Using a combination implant of TBA/E17 promotes an increase in muscle hypertrophy and protein synthesis in the first 40 days after implantation compared to non-implanted cattle (Johnson and Chung, 2007; Chung et al., 2012). To support increased muscle hypertrophy and protein synthesis, quiescent cells, which contribute to the growth plateau observed in control cattle, must be activated, increase DNA, and then be acted upon by growth factors, such as IGF-1, to further promote cell growth and proliferation (Johnson and Chung, 2007; Dayton and White, 2008; Chung et al., 2012). Combination implants lead to an increase in IGF-1 and IGF-1 mRNA in longissimus muscle, which can support an increase in muscle hypertrophy (Johnson and Chung, 2007). Additionally, TBA/E17 has been shown to increase the rate in which cell proliferation occurs in vitro (Dayton and White, 2008).

Release Rate and Factors that Influence

There are two distinct styles of manufacturing of implants: compressed pellets and silastic rubber. Generally, silastic rubber is used with estradiol implants, whereas compressed pellets can be used with TBA, E17, or combination implants. Because compressed pellets are the most common implant type, they will be the focus of this review. These types of pellets are generally a mix between the active ingredient and a carrier, such as lactose, cholesterol, or a large polymer of polyethylene glycol (Preston, 1999; Cady et al., 2002). The use of lactose or cholesterol allows the compressed pellets to dissolve completely overtime at rates dependent on several factors, such as type of carrier used and pressure utilized to form the compressed pellet (Istasse et al., 1988; Jennings, 2012). Targeted release rate to the animal is between 0.75 mg/day/animal to 1.2 mg/day/animal, which is desired to attain the performance response for the period that the animal is in the feedlot (Cady, 2002).

Compressed implants were first used when diethylstilbestrol (DES) was approved for implanting instead of oral dose in 1955 (Raun and Preston, 2002). As previously mentioned, compressed implants can be made with a variety of carriers, with lactose and cholesterol being the most common. Lactose makes hard pellets that are well absorbed, and is generally used in short-term implants, as lactose degrades over a 60 to 80-day period. Cholesterol, on the other hand, dissolves and releases active ingredients at a much slower rate, making it ideal for long-term implants (Bartle et al., 1992). Additionally, compressed pellets can include an antibiotic pellet, which prevents infection at implant site (Stevens et al., 1999). While cholesterol is generally utilized in long-acting implants, Preston (1999) found that a response was sustained for 84 but not 126 days. Because of

this, some implants are encapsulated in a polymer or osmotic membrane to modulate the release rate (Preston, 1999). The pellets are generally 3 mm to 6 mm in length, with 4 to 5 mm being preferred. The pellet diameter varies from 2 mm to 4 mm, with a preferred diameter of 2.5 to 3.5 mm. These pellets may also have a beveled edge (Cady, 2002).

The pressure used to form compressed implants is vital to the rate of release of the active ingredient and ultimately, the payout of the implant; however, most levels of pressure are confidential and not reported in the literature (Preston, 1999). The pressure is measured in kiloponds (kp) and Revalor implants are compressed at 7.14 kp, and while the exact value of force utilized to compress Synovex and Component is unknown, it is presumably similar (Cady, 2002; Jennings, 2012). In general, the more compressed a pellet is, the slower degradation rate and the slower release of the active ingredient.

Payout of Hormones after Implanting

The first most extensive look at hormonal payout of implants was observed with implanting at various times with DES. Implants from different lots and manufacturers were evaluated and it was found that the implants had different half-lives and percentages remaining after 60 days, regardless of the manufacturer claim, all exhibiting first-order release patterns (Preston, 1999). Similar release patterns were observed with E17 + progesterone implants. These results and the first-order kinetics demonstrate that there is a greater release of implant hormone during the first 60 days post implantation, with measurable implant hormone being observed up to 120 days post-implantation (Preston, 1999).

While the concentration of hormones, namely TBA and E17, in blood, plasma, and serum can provide useful information, it is noted there are limitations in their meaning due

to considerable variation (Preston, 1999). Release of active ingredients in hormones are generally biphasic, which results in an initial peak in concentration of circulating hormones 1 to 3 d after implanting, followed by a decline in concentration following first order kinetics (Brandt, 1997; Preston, 1999). A threshold concentration is also considered where there is no further animal response expected. The threshold concentration for E17 is thought to be between 3 and 5 pg/ml, while the threshold level of TBA has been difficult to define and is still unclear because there are still elevated levels remaining after 120 days (Preston, 1999). When heifers were implanted with TBA alone or in a combination implant, peak serum TBA levels were observed 1 day after implantation, decreased over time, and showed a minor peak around day 56 and further decreased through day 140. However, in the same study, E17 levels were elevated 1 day after implanting, but did not peak until 56 days after implanting. Comparable results were shown in steers (Preston, 1999).

Serum Urea-Nitrogen

Steroidal implants work as a repartitioning agent and work to increase the amount of protein deposition and retention in the animal compared to fat (Bryant et al., 2010). The increase in protein retention, and ultimately muscularity, can be observed in a decrease of serum urea-nitrogen. The lower serum urea nitrogen levels indicate alterations in nitrogen metabolism and protein turnover in implanted heifers. These changes can also be attributed to an increased requirement for amino acids (Galbraith, 1980). Heitzman and Chan (1974) found that heifers implanted with 300 mg of TBA showed decreased plasma urea-nitrogen 14 days post-implantation and remained lower than non-implanted heifers until 49 days post-implantation. In similar studies, plasma urea nitrogen was decreased, but total plasma protein was not affected when cattle were

fed a 12% CP diet (Jennings, 2012). Further, Parr and others (2014) found that when steers where implanted with either Revalor-S or Revalor-XS, serum urea-N concentrations increased over time, but implanted cattle had lower levels of serum urea-N compared to non-implanted steers.

Non-Esterified Free Fatty Acids

In general, implanting does not alter NEFA concentrations in finishing cattle (Galbraith, 1980; Parr, et al., 2011). Enright and others (1990) evaluated the effect of subcutaneous growth promoting injections (growth hormone and/or estradiol) on 63 Friesian steers and found that there was no effect on NEFA levels in cattle that received any growth hormone or estradiol treatment. Similarly, when Parr et al. (2014) evaluated the effects of no implant, Revalor-S or Revalor-XS on blood metabolites of steers (n=168), they found that NEFA levels were not affected by implant treatment, but increased over time, independent of implant treatment.

Live Animal Performance Response to Implants

Live animal performance in response to implant treatments has been shown to be altered significantly. Duckett et al. (1997) summarized 77 research trials that utilized single or multiple implants across both steers and heifers and evaluated the effect on live performance. The authors found that both steers and heifers implanted with a combination of TBA/E17 performed significantly better than animals that received either an estrogen or androgen implant alone. Furthermore, implanting with a combination implant increased ADG by 8 to 20%, DMI by 7% and improved feed efficiency by 5 to 10% depending on heifers or steers. Animals that were given an estrogen only implant showed a 9-14% improvement in gain, 4% increase in DMI, and a 4-5% improvement in

efficiency. Steers that received an androgen only implant showed a 16% increase in gain, but there were no other performance responses observed.

Bartle and others (1992) evaluated the effect of TBA/E17 combination implants and the optimum combination for steer performance. Combination implant treatments included a 5:1 ratio of TBA/E17 and consisted of 20 mg TBA/4 mg E17, 80 mg TBA/16 mg E17, or 140 mg TBA/28 mg E17. Additionally, there was a non-implanted control treatment, and steers that received either 140 mg TBA alone or 30 mg of E17 alone. The authors found that there was a linear increase in ADG among the combination implants and ADG was increased 18% over the control. Feed efficiency also improved linearly with higher dose implants. Steers that were implanted with only E17 showed a 7% increase in ADG and a tendency to improve feed efficiency. The authors recognized that these values were slightly lower than other values previously reported but contributed that to the longer duration of this feeding study (168 days) and the potency of E17 implants in longer day feeding trials. Trenbolone acetate implants alone had no effect on performance characteristics over the control. Therefore, the author concluded that a combination implant of 140 mg TBA/28 mg E17 resulted in the greatest performance advantage compared to non-implanted or single E17 implanted cattle.

Guiroy and others (2002) summarized 13 implant trials that utilized 15 different implant strategies, including a combination of non-implanted control, single implants, and combinations of implants in both heifers and steers. The authors concluded that there was an improvement in ADG and feed efficiency in both steers and heifers treated with an implant strategy compared to non-implanted cattle. Furthermore, this summary further confirmed previous work that anabolic implants increase the mature body size of steers.

Bryant et al. (2010) compared 2 different implant strategies in both steers and heifers compared to non-implanted controls. In steers, steers implanted with Revalor-IS and reimplanted with Revalor-S had 10% greater final BW, 19% improvement in ADG, 12% increase in G:F and 9% greater DMI compared to non-implanted steers. Heifers that received Revalor-200 at trial initiation and fed for 120 d had an 4.4% increase in final BW and 14% greater ADG compared to non-implanted heifers.

Duckett and Pratt (2014) analyzed the implant response of over 30 implant trials updated since 1997 and found that implanting with estrogenic implants or combination implants resulted in a 16 to 20% increase in ADG and a 9 to 14% improvement in feed efficiency in steers compared to a nonimplanted control. Furthermore, Duckett and Pratt evaluated the economic impact of using anabolic implants and the added performance. The authors found that using modern prices, a combination implant would increase returns by $163/head and if two combination implants were used, there would be an estimated return of $218.58/head over non-implanted cattle. Therefore, the use of anabolic implants for growth and performance purposes has become a regular practice among feed yards to improve performance and cost of gains.

In general, anabolic implants, and more specifically, combination implants, have been shown to improve ADG and feed efficiency when compared to non-implanted cattle in both steers and heifers. With the increased ADG and efficiency, profitability from implanted cattle has increased. Furthermore, implanted cattle have increased mature body size, which potentially translates into more saleable weight, further increasing profitability.

Carcass Response to Implants

Duckett and Pratt (2014) summarized the effect of anabolic implants on carcass characteristics of steers utilizing the same study as previously outlined. The authors reported that a single estrogenic implant increased HCW by 3% over non-implanted steers, but a single combination implant or reimplanting later in the finishing phase resulted in a 6 to 7.5% increase in HCW over a negative control. Bryant et al. (2010) found that steers implanted twice in the finishing phase (Revalor-IS followed by Reavlor-S) had 11% greater HCW when compared to non-implanted steers. When steers were implanted once during the finishing phase, LM area was increased by 5.8% and if implanted twice, LM area increased 9% over non-implanted cattle. Furthermore, there were no reported changes in fat thickness related to implant strategies, thus the increase in LM area was directly related to the increase of HCW, so only a minor change in yield grade was attributed to implanting (Duckett and Pratt, 2014).

Duckett and Pratt (2014) also reported that skeletal maturity increased with the use of anabolic implants. When estrogenic implants were used, skeletal maturity was advanced by 20 to 24% in steers. A linear increase in maturity with the number of combination implants used in the finishing phase was also reported. However, if an implant was given later in the finishing phase (for example, around day 60), there was no difference in maturity score compared to non-implanted steers, but cattle implanted on day 0 showed increased maturity scores of 11 to 16 points.

Duckett and Pratt (2014) observed a decrease in marbling scores when either estrogenic or combination implants were utilized. When a single estrogenic implant was used, marbling score was decreased by 3.75%, whereas with the use of a combination or

multiple implant strategy, marbling score was reduced by 7.5 to 11.5% compared to non-implanted cattle. Furthermore, the authors correlated the decrease in marbling score to the increase in LM area observed with implanted cattle and found that there is a negative relationship between the two variables. This means that as LM area increases due to implant strategy, marbling score is reduced because of a dilution effect when cattle are fed to similar DOF. Johnson et al. (2013) found that when cattle were fed on a time constant-basis, implanted cattle had a 7% reduction in fat cover, implying that although cattle gain faster than non-implanted cattle, they do not accumulate fat at a proportional rate for the increase in growth observed with implanting. However, many research trials comparing implant strategies have shown minimal differences in fat thickness due to implanting (Duckett and Pratt, 2014).

Johnson et al. (1996) utilized 64 crossbred steers in a serial slaughter experiment to observe the effects of a combination implant on live performance, carcass characteristics, and fat deposition compared to non-implanted control cattle. Cattle were implanted with Revalor-S (Merck Animal Health) or given no implant and were harvested on one of 4 days consisting of days 0, 40, 115 or 143. The dates were chosen to provide an initial carcass composition (d 0), day of maximum response to the implant (d 40), the manufacturer's recommended date of harvest (d 115) and when circulating hormones were projected to return to baseline levels (d 143). Overall, there were no reported differences in HCW (353 kg vs 332 kg, respectively) or fat thickness (0.84 cm vs 0.77 cm, respectively) between implanted and control cattle, although these numbers were numerically increased. Between d 40 and 115, implanted cattle had greater LM area compared to non-implanted cattle, but this advantage was not maintained at 143 days.

Furthermore, there were no significant effects on marbling score between d 40 and 115, but implanted cattle had a lower numerical marbling score compared to control cattle at 143 days. Because of no observed effect on HCW, LM area, or fat deposition, there were no differences in calculated yield grade among treatments. The lack of differences could be due to the small number of cattle utilized or because of loss of potency of implants later in the feeding phase (Johnson, 2013).

In a review by Montgomery et al. (2001), heifers that received an androgen implant or a combination implant during the finishing phase had heavier HCW and an increase in LM area compared to heifers that received only an estrogen-based implant or no implant. Reimplanting heifers also resulted in heavier HCW and further increase in LM area compared to non-implanted heifers. Additionally, Duckett et al. (1997) found that the use of a single implant in heifers doesn't seem to improve yield grade, however, reimplanting (regardless of the implant combination) seems to improve yield grade, likely due to a decrease in fat thickness in relation to HCW. While there is still a performance increase from the use of implants in heifers, the magnitude in which heifers respond is lower compared to steers.

Platter et al. (2003) found that in eleven implant strategies, including lifelong implanting, steers that received two or fewer implants produced carcasses with greater USDA marbling scores than cattle that received four or five implants in their lifetime and non-implanted negative controls had the greatest marbling score compared to all implant strategies. However, marbling score was not affected by implant strategies implemented prior to the finishing phase. Samber et al. (1996) reported that steers that were implanted three times in their lifetime had lower USDA marbling scores and carcasses grading

choice or prime compared to non-implanted cattle or cattle that were delay implanted by 30 d and only given two lifetime implants. All studies discussed thus far have been conducted on an equal DOF basis. Nichols et al. (2002) reported that when cattle are finished to the same physiological endpoint, the percentage of protein, adipose, and bone is similar with implanted or non-implanted cattle, yet implanted cattle maintain an advantage in BW. This is due to implants causing an increase in the growth curve, which modifies the use of protein vs fat deposition and modification of nutrient supply. This is an important management strategy for feed yards to maintain performance advantages without sacrificing carcass merit.

Implant Strategies and Ideal Reimplantation

As previously discussed, it is important for feed yards to consider and predict carcass composition, especially with the use of implants. The length of anabolic activity, which is commonly referred to as payout, is important to consider when designing an implant program and these programs should be designed to achieve predetermined performance and carcass goals (Brandt, 1997). Vasconcelos and Galyean (2007) surveyed 29 consulting nutritionists representing all cattle feeding areas of the United States and respondents were responsible for approximately 69% of cattle on feed and provided their recommended days on terminal implant. Of the 29 consultants surveyed, 21 consultants recommended that the maximum days be 110 or 120 d or less. This is important to note because as cattle are being fed longer days on feed, the need for reimplanting and management increases in importance.

As previously discussed, active hormone components are generally delivered by dissolution of the carrier in the implant or by dissociation of the hormone from a rubber

carrier vehicle. The rate of release of the hormone from either method is the primary determinant of payout period, which is defined as the length of time that an implant can promote growth (Reinhardt, 2007). However, regardless of the payout period, an animal requires a threshold level of exogenous hormone for a growth response to be observed. With implanting, the highest level of delivered hormones are observed in the first 30 days after implanting, and as delivery slows, the hormone levels fall below the threshold level and growth enhancement seizes (Reinhardt, 2007). However, by reimplanting, feedyards can manage the minimum threshold and restart the release pattern, allowing the growth promoting benefits to continue with cattle fed longer DOF (Reinhardt, 2007).

Guiroy et al. (2002) studied the effect of particular implant strategies on their ability to change final BW when animals are adjusted to same final body composition leading to the ability for feeders to be able to choose the implant strategy that is the most appropriate for different classes of animal and in turn, maximize profitability and meat quality. The authors concluded that anabolic implants increase mature body size of cattle and that implanted steers should be harvested at 39.5 kg heavier final BW and implanted heifers at 16.8 kg heavier final BW compared to non-implanted controls to achieve similar marbling scores. The decrease in physiological age is what causes the decrease in marbling score when animals are fed to similar DOF because the implanted animals are at a leaner stage of growth compared to non-implanted cattle (Reinhardt, 2007). Therefore, animals who receive a more aggressive implant or multiple implants will require more DOF to reach the same empty body fat percentage and equal carcass composition (Guiroy et al., 2002).

Mader (1997) determined that implant strategies should match implant dosage or potency to the animal's age, weight, and production goals to maintain blood hormone levels in an optimum response range. Implant strategies can be tailored to fit the individual feeder's animal type and marketing opportunities by altering the dose of hormone administered or the frequency of implanting. This could be of particular importance when feeding large-framed continental breeds, which would likely require less hormone to achieve desired carcass growth, whereas a British-influenced breed may tolerate more aggressive implant strategies to encourage lean muscle deposition, without sacrificing their inherent ability to deposit intramuscular fat (Johnson et al., 2013). Ultimately, to gain optimum growth benefits of the implant, it is necessary to leave the implant in the animal throughout the entire payout period, which is generally 50 to 200 days, depending on the implant (Johnson et al., 2013).

Other implant strategies have evaluated the effect of various initial implant doses followed by a common terminal implant on growth performance and carcass characteristics. Hilscher et al. (2016) evaluated three different initial implant strategies in heifers that included: 80 mg TBA + 8 mg E2 (Revalor-IH, Merck Animal Health), 140 mg TBA + 14 mg E2 (Revalor-H, Merck Animal Health), and 200 mg TBA + 20 mg E2 (Revalor-200, Merck Animal Health), followed by 200 mg TBA + 20 mg E2 (Revalor-200) 89 d later. The authors found no differences in final BW, DMI, ADG, G:F, or HCW regardless of initial implant strategy. The author reported a tendency for a lower calculated YG for more aggressive initial implants and a decrease in marbling score as initial implant dose was increased. Oney et al. (2018) observed similar results in steers when initial implant strategies were compared. There were no differences reported in

feedlot performance or carcass performance. However, when the author analyzed interim performance, the cattle that were more aggressively implant initially gained faster and more efficiently early in the feeding period but lost the advantage as the feeding period progressed. These data from Hilscher et al. (2016) and Oney et al. (2018) suggest that aggressive initial implants have minimal impact on growth or carcass performance, however, mild initial implants may be less detrimental on quality grade when cattle are fed for the same number of days.

Steroidal implants are an effective non-nutritional management tool that feeders and producers can utilize to increase the performance and economic efficiency of beef cattle (Nichols et al., 2002). However, because of alterations in physiology of beef cattle when implants are used, it's important to feed cattle longer DOF or to a similar compositional end point to avoid negative effects on carcass merit and marbling scores (Johnson et al., 2013).

Predicting Carcass Composition

Serial Harvest

Serial harvest experiments have been vital in determining and understanding carcass composition of beef cattle. The use of serial harvest has allowed researchers to understand how cattle grow and accrue protein and fat as the animal matures from birth of harvest. This information can then be used to predict the most effective nutritional and marketing strategies for certain classes of cattle. Haecker (1915) recorded one of the first serial harvest experiments that followed animals from approximately 1 week to 25 mo of age, harvesting a representative animal to analyze for body composition. The author utilized 260 steers and the representative animal was harvested at 45 kg and every 45 kg

period thereafter. The harvested animal was analyzed for chemical composition. The data show that there are minor variations and remarkable uniformity in the composition of steers in the designated growth periods with very limited variation in red meat of animals of the same breed and age. The most notable change in carcass composition occurs in fat deposition. There is a higher affinity for accruing protein from 45 kg to 318 kg, but after 318 kg, animals begin depositing more fat rather than protein. However, this experiment was done using British breeds, which tend to finish and mature at a more rapid rate when compared to Continental breeds. Koch et al. (1976) studied the growth period of 14 different breed combinations that included both British and Continental breeds. The steers that had Continental influence took more DOF to reach the same fatness as cattle of British influence, however, at the same end point, the Continental steers had more red meat and ultimately greater retail product. Steen and Kilpatrick (1995) supported these findings and they concluded that animals with Limousin and Belgian Blue influence had greater lean content in their carcasses with larger eye-muscles and a greater yield of saleable red meat, leading to a more profitable carcass. This was further solidified using the Germplasm Evaluation Program at the U.S. Meat Animal Research Center. Wheeler et al. (2005) concluded at constant BF thickness, carcass from British-influenced steers were lighter than Continental-influenced, and British influenced cattle were earlier maturing, requiring less DOF to reach a consistent 25% fat trim endpoint. Berg and Butterfield (1968) harvested four Hereford calves at birth and then every 6 months following until they were 24 months of age and were able to identify that animals increase bone mass early in development, muscle intermediate, and fat late in development, or between 12 and 18 mo of age. Serial harvest studies like the ones previous outlined are vital to the development

of nutritional requirements for energy of maintenance and gain in beef cattle, which are useful to determining the change in carcass composition over the feeding period.

Bruns et al (2004) evaluated the changes in carcass composition over the course of an entire feeding period, rather than just focusing on animal performance at one-time period. Serial harvest groups were targeted so that their HCW would be approximately 204, 250, 295, 340, and 386 kg. As DOF increased, live BW, HCW, dressing percent, LM area, fat thickness, yield grade, and marbling score all increased linearly. The authors also reported that as DOF increased, ADG decreased linearly. In a review by Streeter et al. (2012), ADG was decreased and feed efficiency was decreased in steers fed for additional days, but heifers decreased ADG at an increasing rate and increased feed efficiency when DOF were increased. However, Zinn et al (1970) found that ADG increased with increasing time on feed, but there were no significant differences in ADG after 120 DOF.

Vasconcelos et al. (2008) performed a feedlot trial utilizing 560 steers to evaluate the effect of varying days on feed on performance and carcass characteristics. Treatments included steers fed for 137 d to imitate under-finished cattle, 157 and 177 days to reach appropriate market condition, and 198 days to imitate over-finished cattle. Cattle were stratified by predicted DOF required to reach Choice grade and treatments were then assigned randomly within strata. Consistent with data previously discussed, final BW increased as DOF increased. Average daily gain and feed efficiency responded quadratically, which agrees with data previously reported from Van Koevering et al (2005). Relative to carcass characteristics, there was a linear increase in HCW, dressing percent, and 12^{th} rib fat observed as DOF increased. Further, yield grade, marbling score, LM area, and kidney-pelvic-heart fat responded quadratically to increased DOF.

Streeter et al. (2012) pooled three large pen studies to evaluate the effect of days on feed (146, 167, or 188 d) on performance and carcass parameters and economic returns based on marketing strategy when feeding heifers. Much like the previous data presented, the author found a quadratic increase in live final BW (final BW= -0.0081*day^2 +2.8061*day +1114.3) and a linear increase in HCW (HCW= 1.8554*day + 708.7), dressing percent, and percent grading choice or better, but a 7% decrease in ADG and 8% decrease in feed efficiency.

While serial harvest experiments are usually difficult to appropriately conduct, they have been proven to be vital to understanding changes in growth patterns and in turn help with more accurate feeding and marketing programs.

Value of Additional Days on Feed

Utilizing data from serial harvest trials and carcass composition models, feedlot managers can make more informed marketing decisions that are the best fit in individual operations. This information can help feed yard managers know when to market cattle for maximum profitability. Producers use various methods of pricing cattle at harvest. Marketing strategies for selling fed cattle include live BW basis, HCW basis, or carcass value grid basis. Depending on the marketing strategy decided upon by the feed yard manager, some have reduced the number of days on feed striving for premiums for yield-driven grids or have kept cattle on feed for additional days on feed to achieve premiums for higher grading cattle (Feuz, 2002). Hicks et al. (1987) found that cattle that were fed for longer days on feed had heavier HCW and in turn, returned more profit because of extra pounds sold. However, the author cautions that an increase in time led to a decrease in live performance, and therefore, if marketed in a different scenario, could be less

economically favorable due to increased feed costs and potential for overweight carcasses.

Feuz (2002) conducted a simulation analysis to analyze the effects of altering days on feed to achieve different carcass goals relative to different pricing structures. In general, the author found that it was profitable to increase DOF due to the improvement in quality grade and overall increase in pounds sold, which offsets the discounts for undesirable yield grades and increased feed costs. The opposite was found in cattle that were fed for two fewer weeks. Due to the loss in HCW, as well as no quality grade advantage, there was a negative return in all scenarios that were simulated. The author concluded that HCW is the driving factor in profitability and cattle should be fed longer to achieve more revenue from more marketed pounds. Wilken et al. (2015) further expanded on these ideas. Utilizing regression analysis, the author found that dressing percentage increased linearly through the feeding period and could be utilized to predict carcass weight from shrunk body weight at any point during the feeding period. Additionally, the analysis found that BW and HCW increased linearly. However, while live BW gain decreased during the feeding period, carcass weight gain remained constant. Further utilizing regression analysis, the carcass weight gain expressed as a percentage of BW gain, it is concluded that weight gain is transferred to the carcass linearly and approached 100% as it approached the end of the feeding period. The author concluded that producers should feed cattle fewer days if selling on a live basis to overcome losses in live gain and efficiency but should feed cattle longer if selling on a carcass basis to maximize revenue potential from additional HCW. Wilken et al. (2015) further concluded that carcass feed efficiency decreases linearly on a live basis and

quadratically on a HCW basis, which may alter the most profitable time for producers to market their cattle on a BW or HCW basis. When modeled at $3.50/bu corn price, the BW cost of gain ($/kg) increased quadratically ($y= 0.578 + 0.0011x + 0.000008 x^2$) from approximately $1.00/kg to $1.50/kg of gain when cattle were fed for 20% longer DOF. The HCW cost of gain responded quadratically ($y = 0.93 – 0.002x+ 0.00003 x^2$), suggesting that there is a slight decrease in COG when cattle are marketed early and increases as cattle are fed longer DOF. This could be of great importance when feed costs are high and margins low, which would promote marketing cattle on a BW basis to minimize losses or continuing to feed for 25% longer if marketed on HCW basis, as the additional weight from added days minimizes costs for additional DOF.

Body Measurements

Advancements in understanding how carcass composition changes over time through serial harvest studies has been instrumental in understanding appropriate times to market fed cattle. Furthermore, body measurements can be useful in improving our knowledge of carcass composition and providing more readily available tools to predict terminal endpoints. Body measurements and the factors that affect the values, including breed type, weight, condition, frame and sex have been studied extensively for over 70 years and in a review by Bruns and Pritchard (2003), their influence on body measurements, either alone or in combination, are described in detail.

Although weight has been the primary method for how producers gauge performance, there have been many research results that have confirmed that weight is related to frame, backfat and muscling of the cattle (Bruns and Pritchard, 2003). Dolezal et al. (1993) found that increased age of feeder cattle and decreased frame size was

associated with fewer DOF. When muscle thickness was evaluated, No. 3 steers, or steers with less muscling, required more days on feed with no differences between No. 1 or No. 2 steers. However, these effects were not consistent among age or frame size subclasses and cannot be applied to all groups of cattle. Tatum (1986) conducted an objective analysis on the effects of frame size and muscularity to describe morphological differences in yearling cattle. It was found that there was a strong correlation ($r = 0.96$) between frame size and mature body weight at any age. Additionally, the author concluded that 95% of variation among subclasses of cattle can be described by two criteria: differences in frame size and dimensional variation corresponding to differences in muscularity.

Ultrasound technology has proven to be useful in helping predict carcass composition using objective measurements at various stages in the feeding period without having to utilize serial harvest methods. Ultrasound systems have allowed researchers and producers to estimate backfat thickness quickly, which is vital because backfat has been recognized as the single best parameter for estimating carcass yield grade and composition. Because backfat thickness increases at definite rates, it can be useful to project future cutability grades, especially in research protocols (Brethour, 1992). Additionally, ultrasound technology has been found to be reliable and accurate, with carcass and ultrasound traits positively correlated in a moderate to high magnitude ($r= 0.76$-0.93; Brethour, 1992). Aside from predicting carcass composition or yield at a certain time point, ultrasound technology can be used to sort and select cattle prior to the finishing phase to better predict an optimal endpoint (Basarab et al., 1999). However, ultrasound technology doesn't come without some limitations, and may underestimate

backfat thickness in fatter cattle and overestimate fat thickness in leaner cattle (Williams, 2002) and is time and labor intensive.

Basarab et al. (1999) evaluated the effect of sorting by weight or sorting by a system that utilizes a combination of weight, ultrasound backfat thickness and marbling score, on the subsequent effects of performance and carcass merit. The author found that using a sorting system utilizing parameters estimated from ultrasound technology clustered cattle into more uniform feeding and marketing groups prior to the finishing phase. In addition, the more uniformly sorted cattle showed positive effects on growth, feed efficiency, and carcass yield and quality grades. With these observed benefits, the author estimated that ultrasound technology could increase profitability by greater than $21.44 per head.

Unfortunately, the cost of implementation, labor of licensed technicians, and repeatability of measurements remain major barriers. Houghton and Turlington (1992) defined the two biggest limitations of the repeatability of ultrasound as the population variation influence on correlation coefficients (either over- or underestimating), correlation coefficients not describing bias from different techniques, technicians or other sources, and producers not appropriately understanding how to interpret correlation coefficients. The authors also reported that there can be much variation in ultrasound results caused by differences in hide thickness, hair, and degree of fat at the point of ultrasound measurements. Williams (2002) reported that backfat measurements using ultrasound were more reliable because they were one dimensional, whereas LM area is on different planes. Ultrasound also requires clipping of hair at the point the measurement is to be taken, application of oil, and multiple measurements to predict LM area and

backfat, which is added time and expense in addition to the training or hiring of a certified technician. MacDonald et al (2006) suggested that the cost of implementing ultrasound is minimal on a per head basis if a large number of animals are measured, but if a fewer number of animals are ultrasounded late in the finishing phase, potential performance decreases may become cost inhibiting. While subjective and objective measurements have been useful in sorting cattle into more uniform marketing groups, there may be simpler and cost-effective methods to predicting carcass composition and ideal marketing times.

Importance of Weight

As previously discussed, researchers frequently want to determine the differences in carcass composition among live animals or carcasses on different treatments, but sacrificing live animals is not always a feasible option (Hedrick, 1983). Therefore, it has been accepted that weight has the most impact among measurable variables in predicting carcass composition in a live animal and can explain up to 60% of the variation in ADG throughout the animal's lifetime (Hammock and Shrode, 1986; Feuz, 2002).

Simpfendorfer (1974) summarized the relationship and impact of BW on carcass composition of British beef breeds from birth through maturity. The author found that cattle with similar mature sizes, 95.6 to 98.9% of variation in chemical components and empty body energy of the carcass was accounted for by variation in body weight. This relationship has allowed for the formulation of different equations and computer models that account for the variation of BW on final carcass composition (NASEM, 2016). Perry and Fox (1997) utilized 120 steers representing different breeds to further determine a set of predictive equations to depict carcass fat percentage and yield grade in live cattle to

optimize sale points. Steers were fed to reach a carcass endpoint of 275, 300 or 360 kg. Live carcass measurements were taken using ultrasound and carcass measurements were taken at a commercial harvesting facility after a 24-h chill. Using these measurements, the authors were able to construct a set of equations that predict carcass and empty body composition, which allows for producers to determine incremental cost of gain and predict quality and yield grade to optimize the conditions in which cattle are marketed.

Cooper et al. (1999) found a relatively strong correlation (r = 0.46 to 0.86) between weight at reimplant and HCW, which allows for the ability to potentially identify overweight carcasses at the time of reimplant. While manual palpation or ultrasound was successful in predicting carcass weight in this trial, identifying yield grade concerns and estimating back fat was not successful. The author concluded that ultrasound accounted for 15 to 25 percent of the variation in carcass fat thickness, while manual rib palpation explained between 5 and 12 percent of carcass fat variation.

MacDonald et al. (2006) demonstrated through different sorting systems that cattle that were sorted based on BW prior to the finishing phase and then marketed at different end points based on BW were more successful than other more expensive sorting methods. The author suggested that sorting on BW alone likely allows producers to reduce discounts on overweight carcasses and feed lighter animals for more days to gain additional HCW.

Overall, BW has been shown to be a feasible and accurate measurement to predict optimal HCW and marketing date. It is the easiest, and potentially most cost effective, measurement to obtain that can provide the most application to feed yard personnel.

Conclusions

Exogenous steroid implants have been approved and extensively used in the feedlot industry over the last 50 years. Nearly all cattle entering the feedlot receive at least one implant during the finishing phase. These implants help cattle increase the amount of protein deposited and HCW, and delays the rate of fattening, therefore, increasing yield grade and potentially decreasing quality grade. Additionally, implants improve feed efficiency and ADG. There are many different options feedlots can use and adapt to fit their implant program, therefore giving them the flexibility to find a program that fits their goals and maximizes their return on investment (Nichols et al., 2009). With the increases in performance and HCW, implants allow feedlots to sell more total retail product, potentially making the supply chain more profitable.

In addition to implants, serial harvest studies have helped with understanding how cattle deposit protein and fat relative to DOF. As cattle are fed longer DOF, ADG and feed efficiency decrease, while live BW and HCW increase. This allows more saleable product, which, in general, minimizes the costs associated with feeding extra DOF.

The beef industry is constantly evolving and adopting innovative technology to increase efficiency and profitability of fed cattle while also feeding for longer DOF when market conditions allow. Therefore, the objectives of these studies were: to evaluate the effects of coated long-acting, delayed release implants in heifers fed for constant DOF or the effect of traditional, aggressive implant strategies compared to long lasting implants when heifers are fed varying DOF (Exp. 1 and 2) and evaluate and define the optimal time to reimplant heifers and steers following a mild initial implant (Exp. 3 and 4).

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CHAPTER II. Evaluation of coated steroidal combination implants on performance and carcass characteristics of finishing heifers fed for constant or varying days on feed

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Abstract

Two experiments evaluated the effect of delayed and long-lasting implant strategies for finishing heifers. In Exp. 1, heifers (n=500; initial BW = 280; SD = 21 kg; 10 pens/treatment) were utilized in a generalized randomized block design to evaluate the effects of coated trenbolone acetate (TBA) and estradiol (E2) implants (Merck Animal Health, De Soto, KS) on growth performance, carcass characteristics, and serum metabolites when heifers are fed for 198 d. The five treatments included no implant (**CON**), Revalor-XH on d 1 (200 mg TBA/20 mg E2, partially coated; **XH**), Revalor-200 on d 1 (200 mg TBA/20 mg E2, noncoated; **E200**), Revalor-XR on d 1 (200 mg TBA/20mg E2, coated; **XR**) or Revalor-200 on d 70. (**D200**). Blood was collected on d 1, 35, 70, 105, 140, and 175 and sera was harvested for further analysis of blood urea-N (BUN), IGF-1, 17β-trenbolone (17β-TbOH) and NEFA concentrations. Implanted heifers were heavier, gained more, and were more efficient ($P \leq 0.03$) compared to CON, but no differences were observed between implant treatments ($P \geq 0.21$). Implanted heifers had greater HCW and dressing percent, but lower marbling scores compared to CON ($P \leq 0.04$), with no differences between implant treatments ($P \geq 0.38$). Blood urea-N levels increased as days on feed (DOF) increased ($P < 0.01$), NEFA levels decreased as DOF increased ($P < 0.01$), and IGF-1 levels increased as DOF increased ($P < 0.01$), regardless of implant treatment. There was an implant × time interaction ($P < 0.01$) for 17β-TbOH respective to the implant's release pattern and payout. In Exp 2., calf-fed heifers (n = 720; initial BW = 281; SD= 10 kg; 6 pens/treatment) were utilized in a 3 × 4 factorial arrangement with 3 implant strategies and 4 serial harvest dates. Implant treatments included no implant **(CON)**, Revalor-200 on d 1 followed by Revalor-200 on d 100

(200), or Revalor-XH **(XH)** on d 1. Serial harvest days included 151, 165, 179, and 193 DOF. There were no serial harvest × implant treatment interactions ($P \geq 0.23$) for growth performance or carcass characteristics ($P \geq 0.31$). Final BW increased linearly ($P < 0.01$) ADG tended to decrease linearly ($P = 0.10$), and G:F decreased linearly ($P = 0.02$). Fat depth, marbling score, and yield grade increased linearly ($P < 0.01$) as DOF increased. Implanted heifers had heavier HCW, gained more, and were more efficient compared to CON ($P \leq 0.04$). Non-implanted heifers had greater USDA marbling score ($P < 0.01$) compared to implanted cattle, and XH tended to have a greater marbling than 200 ($P = 0.10$). Implanting and increasing DOF substantially increased HCW but increasing initial implant dosage did not result in a performance advantage when heifers were fed for varying DOF.

Keywords: Implants, Payout, Serial Harvest

Introduction

Growth promoting implants have been proven to be a safe and effective tool in the feedlot industry to increase gain and hot carcass weights in steers and heifers (Duckett et al., 1997; Bruns et al., 2005; Folmer et al., 2009). Implants obtain this response by increasing frame size and delaying fattening, which requires cattle to be fed to longer days on feed (DOF) to achieve similar empty body fat percentage as non-implanted cattle (Reinhardt, 2007; Smith et al., 2017).

Traditional, uncoated combination implants have a payout period of 60 to 120 d (Mader, 1998), which then requires reimplantation if cattle are fed for over 120 d. More recently, beef producers have been feeding for longer DOF, which can cause logistical

issues for reimplanting strategies. The FDA has approved coated implants in the last decade that can be used for cattle fed for 200 d post implantation. Coating technology on these implants can delay the partial or entire dose of steroids until approximately 70 to 80 d after implantation, which can deliver similar performance as a traditional initial implant given on arrival followed by a terminal implant approximately 100 d prior to slaughter. For example, Nichols et al. (2014) reported no differences in final BW, ADG, G:F or carcass characteristics for steers given either an initial implant + terminal implant or one partially coated implant of the same hormonal concentration and fed for 157 d. Therefore, the objective of this study was to evaluate feedlot and carcass performance of long-fed heifers given new partially-coated (Revalor-XH) or fully coated (Revalor-XR) implant program, compared to traditional implant strategies or no implant and fed for similar or varying DOF.

Materials and Methods

All procedures used in these experiments were reviewed and approved by the University of Nebraska- Lincoln Institutional Animal Care and Use Committee (IACUC).

Experimental Design and Procedures: Exp. 1

Crossbred heifers (n = 500; initial BW = 280; SD = 21 kg) were utilized in a generalized randomized block design with 2 initiation blocks and 2 BW blocks within start time. Heifers were assigned randomly to one of 50 pens (10 heifers/pen) and pens were assigned randomly to one of five treatments. Treatments included: no implant (**CON**), Revalor-XH on d 1 [200 mg trenbolone acetate (TBA) and 20 mg estradiol (E2), partially coated (**XH**); Merck Animal Health, DeSoto, KS], Revalor-200 on d 1 (200 mg

TBA/20 mg E2, Merck Animal Health, noncoated; **E200**), Revalor-XR on d 1 (200 mg TBA/20mg E2; Merck Animal Health, coated; **XR**) or Revalor-200 on d 70 (200 mg TBA/20 mg E2; Merck Animal Health, noncoated; **D200**). All implants contained 10 pellets (20 mg TBA/2 mg E2 per pellet), but coating technology varied among implants. Revalor-XR contained 10 coated pellets that are designed to be released approximately 70 to 80 days after implanting. Revalor-XH contains four uncoated pellets (80 mg TBA and 8 mg E2) for immediate release and 6 coated pellets (120 mg TBA and 12 mg E2) to release approximately 70 to 80 d after implanting.

Heifers were sourced from auction markets and transported to the University of Nebraska Eastern Research and Extension Center (ENREC) research site located near Mead, NE. At the time of feedlot arrival, all heifers were individually identified (panel tag, electronic button, and metal clip). All heifers received an infectious bovine rhinotracheitis (IBR) virus, parainfluenza-3 (PI_3) virus, bovine viral diarrhea (BVD) virus (types I and II), bovine respiratory syncytial virus (BRSV), *Mannheimia haemolytica* and *Pasteurella multocida* combination vaccine (Vista Once, Merck Animal Health), a *Clostridium chauvoei, specticum, novyi, sordellii, perfringens* Types B, C, and D bacterin-toxoid (Vision 7, Merck Animal Health), a 10 percent fenbendazole oral suspension for the control of lung worms, stomach worms, and intestinal worms (Safe-Guard Dewormer, Merck Animal Health), a synthetic prostaglandin to induce luteolysis (Estrumate, Merck Animal Health), and one percent doramectin injectable for treatment and prevention of gastrointestinal and external parasite control (Dectomax, Zoetis Inc., Florham Park, NJ).

Before initiation of the trial, heifers were limit fed at 2% of BW for 5 d a diet consisting of 50% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50% alfalfa hay (DM basis) to minimize variation in gastrointestinal fill (Watson et al., 2013). Heifers were weighed (Silencer Squeeze Chute; Moly Mfg. Inc., Lorraine, KS: scale readability ± 0.45 kg) two consecutive days (d 0 and 1) to establish initial BW. Heifers were blocked by d 0 BW (light and heavy), stratified by BW within blocks and assigned randomly to pen within block. Initiation of trial was also used as a block, with 2 starting dates 1 week apart and 25 pens starting each week. Pens were assigned randomly to one of five treatments with 10 pens per treatment. Light and heavy blocks consisted of four replications and one replication, respectively, for block one and one replication and four replications, respectively, for block two. On d 1 (May 20, 2016 for block 1 and May 27, 2016 for block 2) heifers were implanted with their respective treatment. Implants were administered in the middle one-third of the ear using a Revalor implant gun (Merck Animal Health). Sentinel heifers (n = 3 heifers/pen; 30 heifers/treatment) were identified prior to initiation of the study based on the average of the d 0 and d 1 BW measurements. The 3 heifers/pen with an average d 0 and d 1 BW closest to the mean BW of their home pen were selected for blood collection. Blood samples were taken via tail venipuncture from sentinel heifers prior to feeding on d 1, 35, 70, 105, 140 and 175 using BD Vacutainer Serum collection tubes (BD, Franklin Lakes, NJ). If tail venipuncture was unsuccessful, jugular venipuncture was used. Whole blood samples were allowed to clot at 4° C for 24 h prior to sera harvest to be used for quantifying circulating concentrations of blood urea-N (BUN), non-esterified fatty acid concentration (NEFA), IGF-1, and 17β-

TbOH. On blood collection days, cattle were also individually weighed in the morning prior to feeding to establish interim performance.

All heifers were adapted to a common finishing diet over a 24-d period consisting of four adaptation diets. The amount of wet distiller's grains (WDGS), Sweet Bran, and supplement were held constant at 15%, 25% and 4% (DM basis) of the diet, respectively. The amount of dry rolled corn (DRC) and high moisture corn (HMC) were gradually increased while replacing alfalfa. The first adaptation diet consisted of 11% DRC, 0% HMC, and 45% alfalfa hay and was fed for 5 d. The second adaptation diet was fed for 5 d and consisted of 18.3% DRC, 2.8% HMC and 35% alfalfa hay. The third adaptation diet included 23.3% DRC, 7.7% HMC and 25% alfalfa hay and was fed for 7 d. The fourth and final adaptation diet included 28.3% DRC, 12.7% HMC, and 15% alfalfa hay and was fed for 7 d. The finishing diet included 32.3% DRC, 16.2% HMC, and 7.5% grass hay, replacing alfalfa hay.

Heifers were housed in open feedlot pens with approximately 91 cm of linear bunk space and 56 m^2 pen space per heifer. Feed bunks were assessed once daily at approximately 0600 for presence of feed. Feed amounts were increased or decreased daily to maintain an ad libitum bunk management approach. Cattle were fed once daily between 0700 and 0900 and had ad libitum access to fresh water and respective diet. Diets were mixed and delivered using a truck-mounted feed mixer and delivery unit (Roto-Mix model 420, Roto-Mix, Dodge City, KS). Weekly samples of ingredients were collected by University personnel, composited by month, and sent to a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) to determine CP (Padmore, 1990a; Padmore, 1990b; Gavlak et al., 1996, LECO Corporation), NDF (Mertens, 1992;

ANKOM Technology, 1996; ANKOM Technology, 1998), calcium (Campbell and Plank, 1991; Kovar, 2003), and phosphorus (Campbell and Plank, 1991; Wolf et al., 2003; Kovar, 2003) content of individual ingredients. When refusals were present, orts were weighed, sampled and frozen for later analysis of DM. Dry matter of orts were determined by placing samples in a 60° C forced-air oven for 48 h (AOAC Method 935.29; AOAC, 1999). Cattle were visually evaluated daily by trained UNL personnel. Evaluations include proper functionality of water tanks, integrity of fences and feed bunks, and any abnormal behavior of the cattle. When heifers were determined to be sick, heifers were removed from the pen and taken to the processing facility for diagnosis and appropriate treatment and then returned to their home pen.

On day of shipping, heifers were offered 50% of the previous day's called feed. In the afternoon, all heifers were brought to the handling facility, pen weighed to determine final live BW, and loaded onto trucks. All animals were harvested at a commercial harvest facility (Greater Omaha Packing, Omaha, NE) after 194 d (Block 1) or 201 d (Block 2) on feed. Hot carcass weight and liver scores were recorded on day of harvest. After a 48-h chill, LM area, 12^{th} rib fat thickness, and USDA marbling score were recorded. Yield grade was calculated (USDA, 2016) from the following formula: 2.5 + (0.98425 x 12^{th} rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2). Live final BW was pencil shrunk 4% to calculate dressing percentage and live performance. A common dressing percentage of 63% was used to calculate carcass adjusted final BW, ADG, and G:F.

Serum Metabolite Analysis

Whole blood samples were centrifuged at 1,250 × g for 20 min at 4 degrees C. Serum was then harvested from each tube and approximately 2 mL allocated in one of three tubes. Two tubes were then frozen at -20° C for later analysis of blood urea-N (BUN) and non-esterified fatty acids (NEFA). One tube was frozen at -80° C for analysis of 17β-TbOH and IGF-1 concentrations.

Urea-N was analyzed using sera by animal and day using an adapted procedure from Smith and Murphy (1993) and quantified using spectrometry and fitted to a standard dilution curve. Standard dilution curve was between 0 and 30 mg/dL. Samples were run in duplicate and considered for re-runs if the coefficient of variation between duplicates was greater than 10%. Non-esterified fatty acid was analyzed using an in vitro enzymatic colorimetric method assay (HR Series NEFA-HR, Wako Pure Chemical Industries, Ltd., Mountain View, CA) and quantified using spectrometry fitted to a standard dilution curve. The standard dilution curve was constructed from values ranging from 0 to 1000 µeq/L. Samples were run in duplicate and considered for reruns if the CV coefficient was greater than 10%.

Circulating sera IGF-1 was quantified via ELISA (Quantikine Human IGF-I ELISA, R & D Systems, Minneapolis, MN). The IGF-I assay was analyzed using sera pooled by pen and day. Prior to analysis raw sera samples were extracted to reduce IGF binding protein interference. The standard curve constructed for the IGF-I assay was between 9.4 and 600.0 ng/mL. Samples were run in duplicate and determinations were considered for re-runs if the CV between duplicate samples were greater than 10%.

Circulating 17β-TbOH concentration was quantified via liquid chromatography-tandem mass spectrometry (LC-MS/MS) using slight modifications to the

procedures described by Blackwell et al. (2014). The 17β-TbOH assay was conducted using sera pooled by pen and day, while, sera from all heifers in CON were pooled by block and day. In 15 mL conical screw top tubes, equal volumes of methyl-tert-butyl-ether (MTBE) and sera (2 mL) were spiked with 10 ng of internal standard (17β-trenbolone-d3, National Institute for Public Health and the Environment of the Netherlands), then placed in an orbital shaker at 300 rpm for 30 min at room temperature. Samples were centrifuged for 5 min at 1500 × g to separate sera and MTBE layers. The MTBE layer was removed and then transferred to 100 × 16 mm borosilicate glass tubes and evaporated to dryness at 35°C under a gentle stream of nitrogen. Samples were reconstituted in 4 mL 80:20 methanol: water (HPLC grade, Fisher Scientific, Hampton, NH). Next, 3 mL of hexane (HPLC grade, Fisher Scientific) was added to the reconstituted samples and samples were vortexed for 30 s. Following the vortex step, samples were centrifuged at room temperature for 5 min at 1500 × *g* in order to separate the water: methanol mixture from the hexane layer, the hexane layer (top) was then discarded, and the hexane wash was repeated. Samples were then dried to a volume of less than 0.5 mL under a gentle stream of nitrogen at 35°C, and 3 mL of 5:95 methanol: water + 0.1% ammonium hydroxide was added to each sample prior to SPE cleanup. Oasis MAX cartridges (3cc/60 mg; Waters Corporation, Milford, MA) were conditioned with 3 mL of methanol and 3 mL of 5:95 methanol: water + 0.1% ammonium hydroxide, samples were passed through, and cartridges were washed with 2 × 3 mL 5:95 methanol: water + 0.1% ammonium hydroxide. Cartridges were then allowed to dry under vacuum for 10 min, and samples were eluted into clean 16 × 100 mm borosilicate glass tubes with 7 mL of methanol. The samples were then evaporated to

dryness at 35°C under a gentle stream of nitrogen and reconstituted in 100 µL of 60:40 methanol: water. The reconstituted sample was passed through a 0.45 µM polypropylene filter into fixed-insert microvials, capped, and stored at -20°C until analysis. Blank (n = 3) and spiked (n = 3) matrix (bovine serum, Sigma-Aldrich, St. Louis, MO) samples were analyzed along with 42 unknowns per sample batch (48 extractions in total) in order to monitor extraction method performance. No steroids were observed above the limit of detection in any solvent or matrix blank. The mean matrix spike recovery (n = 18) for sera was (112.3 ± 20.79%)

Quantification of 17β-TbOH was performed via triple quadrupole LC-MS/MS (TSQ Endura, ThermoFisher). Chromatography was performed using a methanol: water gradient elution taken from Blackwell et al. (2013) and a Gemini-NX C18 column (150 x 2.0mm; Phenomenex, Torrance, CA) with a sample injection volume of 10 µL. Ionization was performed using atmospheric pressure chemical ionization in positive mode. Solvent blanks and check standards were included every 8 and 16 samples, respectively, in instrument runs for quality control purposes. The limit of quantification, as determined by the lowest calibration standard included in sample runs, was 25 pg/mL serum. Values below the limit of quantification were assigned a value of 12.5 pg/mL serum which was half the value of the lowest calibration standard.

Statistical Analysis: Exp. 1

Animal performance and carcass characteristics were analyzed as a generalized randomized block design using the MIXED procedure of SAS (Version 9.4; SAS Institute, Inc., Cary, N.C.) with pen as the experimental unit. Heifers that were removed

or died during the experiment were not included in the analysis. The model included treatment and block as fixed effects. Treatment means were separated using LSD test when the overall F-test was significant. Quality and yield grade distributions were analyzed using the GLIMMIX procedure of SAS using a multinomial approach.

Blood urea-N, NEFA, 17β-TbOH, IGF-1, and estradiol-17β were analyzed using the proc GLIMMIX procedure in SAS as a repeated measure. Treatment, time, and treatment × time interaction was included in the model as fixed effects and block was treated as a random effect. Treatments were analyzed for differences at time point 0, but time point 0 was not included in the model. For all variables, alpha values < 0.05 were considered significant and tendencies were discussed when alpha values were $0.05 \leq P \leq 0.10$.

Experimental Design and Procedures: Exp. 2

A feedlot trial was conducted at the Panhandle Research and Extension Center near Scottsbluff, NE utilizing 720 crossbred calf-fed heifers (initial BW = 281; SD = 10 kg) arranged in a 3 × 4 factorial design. Heifers were assigned randomly to one of twelve treatments consisting of three implant strategies and four serial harvest groups. Implant strategies included a non-implanted negative control (NON), a re-implant strategy providing an initial implant containing 200 mg trenbolone acetate and 20 mg estradiol (Revalor-200, Merck Animal Health) followed by another implant containing 200 mg trenbolone acetate and 20 mg estradiol (Revalor-200, Merck Animal Health) at 100 days on feed (200/200), and a delayed release implant strategy providing an initial implant containing 200 mg trenbolone acetate and 20 mg estradiol (Revalor-XH, Merck Animal Health) at day 0 (XH). The Revalor-XH implant contains ten pellets each with 20 mg

trenbolone acetate and 2 mg estradiol, including four uncoated pellets (immediate release) and six coated pellets, which served as the delayed release portion of the implant. The four serial harvest groups were determined based on time point at which the heifers reached appropriate market condition, in which serial harvest groups would be marketed at 14 d intervals thereafter. Based on the performance and time at which marketing condition was achieved, serial harvest groups consisted of heifers fed to 151 (NORMAL), 165 (PLUS14), 179 (PLUS28), and 193 (PLUS42) days on feed. The trial utilized 72, 10 head pens allowing for six replications per treatment (60 heifers per trt).

On arrival, all heifers were identified and processed. During the identification process, heifers received a panel tag in the left ear with an individual identification number and a metal tag in the right ear with corresponding identification number. All heifers received a *Clostridium chauvoei, specticum, novyi, sordellii, perfringens* Types B, C, and D bacterin-toxoid (Vision 7; Merck Animal Health) for prevention of disease caused by *Clostridium chauvoei* (Blackleg), *septicum* (Malignant edema), *novyi* (Black disease), *sordellii* and *perfringens* Types C&D (Enterotoxemia) and 2 mL Vista Once subcutaneous (Merck Animal Health) for the prevention of respiratory disease caused by IBR, BVD (Type 2), and BRSV and as an aid in the control of disease caused by BVD (Type 1), PI_3, *Mannheimia haemolytica* and *Pasteurella multocida.* Upon processing on d 0, heifers also received 14 mL fenbendazole oral drench (Safeguard, Merck Animal Health) for removal and prevention of worms. Heifers were housed in pens and limit fed until initiation of the trial.

Heifers were limit fed step 1 of the step-up ration at 2% BW per day for 5 consecutive days prior to a 2-d weight collection to minimize variation in gut fill (Watson

et al., 2013). On d 0 of the trial, individual BW was recorded, carcass ultrasound images were collected, and heifers were assigned randomly to one of twelve treatments within three initial start date blocks. Based on treatment assigned, heifers were administered their respective implant while in the chute on d 0. Each treatment was represented equally within start date block with two replications per block for a total of 24 pens (240 heifers). On d 1 of the trial, a pen weight was recorded to serve as the second d weight collection.

Real time carcass ultrasound images were collected on heifers at initiation of trial, 100 d (re-implant), and each d of serial shipping for all heifers remaining (151, 165, 179, and 193 d). Real time carcass ultrasound measurements including LM area, 12^{th} rib fat thickness, and intramuscular fat percent were collected by a Centralized Ultrasound Processing (CUP Lab; Ames, Iowa) certified field technician. Images were captured using an Aloka 500-V unit (Corormetrics Medical Systems, Wallingford, CT) equipped with a 3.5-MHz, 17.2 cm linear array transducer. All images were captured on the right side of each heifer. To capture 12^{th} rib fat thickness and LM area, the heifer was palpated to locate the 13^{th} rib and the transducer was placed laterally between the 12^{th} and 13^{th} ribs utilizing a standoff guide to capture the image. Images for intramuscular fat percent were collected by placing the transducer three-fourths the distance from the medial end of the LM area to the lateral end and horizontally over the 12^{th} and 13^{th} ribs. Ultrasound image interpretation was conducted by a certified technician at The CUP Lab. After interpretation, ultrasound intramuscular fat percent was converted to USDA marbling score utilizing data presented by Wilson et. al. (1999) to allow for comparisons with carcass data post-harvest.

During the trial, bunk space was provided at 54.9 linear cm/heifer and pen space allotted was 6.1 × 4.3 m which equated to 26.2 m^2 per heifer. The step-up period consisted of 21 d including three d on step 1, four d on step 2, seven d on step 3, and seven d on step 4. The common finishing ration fed to all heifers consisted of 58% dry-rolled corn, 7% corn silage, 4% wheat straw, 25% wet distiller's grains plus solubles, and 6% supplement (DM basis). Heifers were fed once daily and provided *ad libitum* access to feed and water throughout the trial.

Statistical Analysis

All data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.). Pen was included as the experimental unit and start block was included as a fixed effect. The model included implant treatments, serial harvest, and the interaction of implant and serial harvest as fixed effects. Treatment × linear serial harvest and treatment × quadratic serial harvest were analyzed. Due to a significant difference in initial pen weights among treatments, initial pen weight was considered a possible covariate and included in the model. If the covariate was determined to be insignificant ($P > 0.10$) for that variable, initial pen weight was removed from the model as a covariate. Pen initial weight was included as a covariate in the model for final and carcass-adjusted end BW, final and carcass adjusted ADG, final and carcass adjusted G:F, and HCW. Orthogonal contrasts were used to test linear and quadratic effects of serial harvest for heifers. Significance was deemed at an alpha value of ≤ 0.05 and tendencies were discussed when alpha values were $0.05 \leq P \leq 0.10$.

Results and Discussion

Experiment 1

Heifers were evaluated for missing or abscessed implants on d 35 and 105 and if found, were removed from trial. Two heifers were removed for missing implants on d 35 (one from each block) and one from d 105 (Block 1). No abscessed implants were observed. Additionally, there was 1 death and 5 removals in block 2 (3 footrot, 1 navel abscess and 1 chronic).

Overall, there was no effect on DMI ($P = 0.22$; Table 2.1) due to implant treatments over the entire feeding period, which is consistent with observations from Duckett et al. (1997) based on DMI as a percentage of on-test BW, potentially suggesting that slight changes in DMI with the use of implants is driven by the increase in BW (Reinhardt and Wagner, 2014). Using carcass-adjusted performance, implanted cattle were 19 kg heavier than CON ($P < 0.01$), but there were no differences between implant treatments ($P \geq 0.87$). All implanted cattle had 7% greater ADG compared to CON cattle ($P < 0.01$) which led to implanted heifers being 4% more efficient ($P < 0.01$). This response has been well documented with implant strategies increasing ADG by an average of 21% and improving feed efficiency by an average 11%, which is greater than what was observed in the current experiment (Duckett et al., 1997; Wileman et al., 2009; Johnson et al, 2013). Kreikemeier and Mader (2004) reported similar results and found that implanted heifers were 11.8 kg heavier, gained 0.108 kg/d more and heifers receiving a combination implant + melengesterol acetate (MGA) were more efficient than heifers receiving a single compound implant or no implant. Heifers implanted with XR, E200 or D200 were the most efficient ($P < 0.01$), but E200 or D200 were not different than XH ($P > 0.29$), and CON was the least efficient ($P = 0.01$) Comparable results were observed when live final performance was evaluated.

Implanted heifers had 11 kg greater HCW than CON ($P < 0.01$; Table 2.1). This response is well documented with an average of 18 to 27 kg of added HCW expected from use of a combination implant (Johnson and Chung, 2007; Johnson et al., 2013; Reinhardt and Wagner, 2014). There were no differences in HCW, dressing percentage, fat thickness, or USDA marbling score among all implanted treatments ($P \geq 0.38$), but CON had a lesser dressing percentage and greater marbling scores compared to implanted heifers ($P \leq 0.04$) in this study when heifers were fed for the same DOF. Kreikemeier and Mader (2004) found no differences in USDA marbling score for heifers given estrogenic implants, trenbolone acetate implants, or no implant; however, heifers given an estrogenic + TBA combination implant had lower marbling scores compared to other treatments. Johnson and Chung (2007) reported no effect of implant treatment on fat thickness compared to nonimplanted animals fed the same number of days. Heifers within XH, XR, and D200 treatments showed an increase in LM area ($P < 0.01$) compared to cattle implanted with E200 or CON, which translated into a lesser calculated yield grade ($P = 0.04$). Previous researchers have suggested that implanting alters intramuscular fat deposition and composition due to a dilution effect with increasing LM area (Duckett et al., 1999). Duckett and Andrae (2001) found implanting cattle with an estrogenic or combination implant reduced marbling score by 4%, but increased LM area by 3 or 4%, respectively.

There was a tendency for a change in the distribution of quality grade ($P = 0.10$) and yield grade ($P = 0.07$) between implant treatments and CON (Table 2.2). Johnson and Chung (2007) noted that the use of growth promotant technologies, such as steroidal implants, shift nutrient use towards lean carcass tissue rather than adipose tissue, which

leads to 10 to 12% more carcass protein in implanted cattle compared to non-implanted controls, which could lead to a shift in yield grade distribution. However, Roeber et al. (2000) reported no differences in final yield grade because the increase in HCW was offset by the increase in LM area in the calculations used to determine final yield grade. Roeber et al. (2000) also reported that the percentage of carcasses grading USDA Prime or Choice ranged from 94.4% in non-implanted control steers to 75% in steers that were implanted with 200 mg TBA + 28 mg estradiol (Synovex Plus, Zoetis). However, in the current study, the effect on percent of heifers grading USDA Choice or Prime was minimal (92.5% CON vs 91.3% all implant treatments).

Interim performance is summarized in Table 2.3. During the first 70 days of the feeding period, heifers implanted with XH and E200 had greater ADG and were more efficient ($P = 0.01$) compared to the other treatments. From days 70 to 140, cattle implanted with XR or D200 gained more and were more efficient ($P < 0.01$) than the other treatments, which is consistent with the delayed release of XR and the delayed implanting of D200 heifers. From d 140 to d 175, all implanted cattle were heavier than CON ($P < 0.01$). Interestingly, from d 140 to the end of the feeding period, the non-implanted heifers were more efficient ($P = 0.01$) than all implanted cattle and the non-implanted heifers gained more than implanted treatments ($P = 0.05$).

Serum metabolite results are summarized in Table 2.4 and Figure 2.1. There were no treatment × time interactions ($P \geq 0.59$) or treatment effects ($P \geq 0.12$) for BUN, NEFA, or IGF-1 circulating concentrations. Blood urea-N concentration increased as DOF increased ($P < 0.01$) from 15.9 mg/dL to 19.2 mg/dL. As DOF increased, NEFA levels were decreased ($P < 0.01$) from an initial level of 330.1 mEq/L on d 1 to 166.9

mEq/L on d 175 across all treatments. Similarly, IGF-1 levels increased over time ($P <$ 0.01) from levels of 50.9 ng/mL at trial initiation to 91.6 ng/mL after 175 d. Smith et al., (2018) evaluated sera IGF-1 levels in steers that were implanted with XR, Revalor-XS (200 mg TBA + 40 mg E2, partially coated; Merck Animal Health), Revalor-200 on d 1 or Revalor-200 on d 70 compared to a non-implanted control. Contrary to Exp. 1, implanted steers had increased sera IGF-1 steers compared to non-implanted controls over 213 d, with levels increasing over time. Similarly, Dayton et al. (1997) observed combination implants increasing circulating IGF-1 concentrations in steers by 40% on d 40 and 35% after 115 DOF compared to steers that were not implanted.

There was an implant treatment × time interaction ($P < 0.01$) for 17β-TBOh levels. At trial initiation, all treatments were below the detection limit of the assay (12.5 pg/mL) and had no circulating 17β-TBOh. Heifers in CON had no detectable 17β-TBOh for the duration of the collections, however, concentrations of 17β-TBOh increased markedly after implantation or expected release of coated implants. After 35 d on trial, E200 had circulating 17β-TBOh of 121.2 pg/mL, which was significantly greater than all other treatments ($P \leq 0.02$). However, over the next 35 d period, XR and E200 had the greatest levels of circulating 17β-TBOh, but they were not different from each other ($P =$ 0.14). There was a tendency for XR to be different than XH (72.6 and 45.9 pg/mL, respectively; $P = 0.06$) after 70 DOF. However, on d 105, XR had the greatest circulating concentration of 17β-TBOh (147.2 pg/mL), which was not statistically different ($P =$ 0.14) from D200, which had a circulating concentration of 103.8 pg/mL. On d 140, XR and D200 continued to have the greatest circulating concentrations of 17β-TBOh, with no statistical differences between treatments (102.2 and 63.4 pg/mL, respectively; $P = 0.19$).

By d 175, XH had returned to baseline (≤ 12.5 pg/mL), while D200 maintained the greatest circulating 17β-TBOh concentration at 80.1 pg/mL. These results are comparable to those reported by Smith et al. (2018). Henricks et al. (1997) reported that heifers who received Revalor-H (140 mg TBA + 14 mg estradiol; Merck Animal Health) had increased 17β-TBOh compared to non-implanted heifers until d 84, when all treatments containing TBA decreased in serum 17β-TBOh, more so in the Revalor-H treatment. This is consistent with the steroidal composition of the coated portion of XH. There were no differences between D200 and XR ($P = 0.28$), and there was no difference between XR and E200 ($P = 0.38$) after 175 DOF.

Experiment 2

Initial BW was significant ($P < 0.02$) and included in the model as a covariate if deemed significant. The interactions of treatment × serial harvest, treatment × linear serial harvest, or treatment × quadratic serial harvest were not significant ($P \geq 0.23$) for performance. Implanted heifers had greater final and carcass-adjusted BW compared to CON ($P < 0.01$; Table 2.5), but there were no differences between 200/200 and XH ($P \geq 0.58$). There were no differences in DMI ($P \geq 0.12$) among implant treatments. Carcass-adjusted ADG was greater for implanted heifers compared to CON ($P < 0.01$), but there were no differences between 200/200 and XH ($P = 0.55$). The increase in ADG from implanted heifers led to an improvement in feed efficiency ($P < 0.01$) compared to CON, and 200/200 tended to be more efficient than XH ($P = 0.07$). As previously discussed, the increase in final BW, ADG and G:F observed in implanted heifers compared to non-implanted heifers has been well documented. However, the lack of statistical significance between 200/200 and XH may suggest that a more aggressive initial implant is not of

added benefit. Hilscher et al. (2016) evaluated the effects of an initial implant of Revalor-IH (80 mg TBA + 8 mg estradiol), Revalor-H (140 mg TBA + 40 mg estradiol), or Revalor-200 on heifer growth performance. All treatments received Revalor-200 as a terminal implant 89 d after initial processing. Similar to the results observed in the current study, the author found no differences in final BW, DMI, ADG, or G:F ($P \geq 0.14$) regardless of initial implant strategy. Additionally, Oney et al. (2018) found no differences with increasing implant dose combination on growth performance in calf-fed steers.

Similar to growth performance, there were no serial harvest × implant treatment interactions ($P \geq 0.31$) for carcass characteristics, however, the interaction of serial harvest × implant treatment for backfat tended to be linear ($P = 0.12$). Hot carcass weight was greater for implanted cattle compared to CON ($P < 0.01$), but there were no differences between implant treatments ($P = 0.59$). There were no differences in dressing percent, LM area, or calculated yield grade among all treatments ($P \geq 0.48$), but there was a tendency for CON to have less 12th rib fat compared to heifers implanted with 200/200 or XH ($P = 0.10$). Cattle accrued backfat linearly ($P < 0.01$; Table 2.6), but at different rates ($P < 0.01$) respective to implant treatment. The daily accretion rate for backfat for non-implanted heifers was 0.000781 (± 0.002251) cm (Figure 2.2). Heifers implanted with 200/200 deposited BF at a rate of 0.01735 (± 0.002251) cm per day and the daily fattening rate for XH was 0.01294 (± 0.002251) cm. However, it is important to note the simple effects are an average over all DOF treatments. Marbling score was significantly greater ($P < 0.01$) for CON, with a tendency for XH to have a greater marbling score than 200/200 ($P = 0.10$). Similar carcass results were reported by Hilscher

et al. (2016). The authors found no differences in HCW, LM area, dressing percent, or 12th rib fat among implant treatments, but the mild initial implant (Revalor-IH) had significantly greater marbling scores compared to the higher concentration, more aggressive initial implant strategies. Schneider et al (2007) reported no differences in carcass characteristics that received varying doses of initial implant and Hutcheson et al. (2002) reported no differences in growth performance over the feeding period but observed a decrease in marbling score with the use of implants, consistent with our findings. Therefore, the use of more aggressive initial implants may not provide growth performance incentives during the finishing phase, therefore potentially making it more economically sound to use partially-coated, delayed release implants to achieve comparable growth performance and increased carcass quality as traditional implant protocols without having to reimplant.

As heifers were fed for longer DOF, final BW increased linearly from 567 to 613 kg ($P < 0.01$), while live ADG and G:F decreased linearly ($P < 0.01$; 1.89 kg/d vs 1.72 kg/d; 0.161 vs 0.146). When carcass-adjusted ADG was analyzed, the decrease in ADG in heifers fed for longer DOF tended to decrease linearly ($P = 0.10$), with a lower slope compared to live ADG. Carcass-adjusted final BW increased 19 kg in the first 14-d harvest period, 29 kg in the next 14-d, and 17 kg in the final 14-d period. Vasconcelos et al. (2008) reported similar results and observed a linear increase in final BW and a linear decrease in ADG and G:F as steers were fed for 136 compared to 198 d. As heifers were fed from 151 to 193 d, HCW increased linearly ($P < 0.01$) from 351 kg to 392 kg with the greatest increase in HCW coming from d 165 to 179. There were no differences in dressing percent ($P = 0.49$) but there was a linear increase in BF ($P < 0.01$; Figure 2.2).

Likewise, USDA marbling score and YG increased linearly as cattle were fed for longer DOF ($P < 0.01$). Heifers that were fed for longer DOF tended to have a linear increase in LM area ($P = 0.09$). Consistent with our observations, Rathmann et al. (2012) found that feeding heifers from 127 d to 167 d increased final BW, decreased ADG, and decreased feed efficiency, while having no effect on DMI. Furthermore, the author reported a 22.2 kg increase in HCW in the first 21 d serial harvest period and a 14.9 kg increase in the final 19 d harvest period, while also reporting an increase in 12^{th} rib fat thickness, calculated yield grade, and USDA marbling score as heifers were fed for longer DOF.

Live weight gain to carcass weight transfer was calculated by dividing the HCW slope for DOF treatment by the live final BW slope for DOF treatment. When calculated, heifers transferred 89.5% of gain to carcass weight. This means that towards the end of the feeding period, for every kilogram of additional BW, approximately 0.9 kg of HCW was added (Wilken et al., 2015). This is slightly less than what Wilken et al. (2015) concluded in steers, where weight gain transferred to the carcass approached 100% by the end of the feeding period. In a review by Streeter et al. (2012), the author concluded that the carcass transfer in heifers was 86.6% after the first 21-d serial harvest period, but then declined to 65.8% after 42-d serial harvest period.

Overall, implanting heifers with aggressive implants or implants with coating technology for delayed and extended release had increased carcass-adjusted final BW, ADG and were more efficient than non-implanted control heifers. However, the release rate (coated, uncoated, or delayed implant) did not affect performance of heifers fed for the same DOF (Exp. 1) and a more aggressive initial implant did increase final BW or

ADG (Exp. 2). As heifers were fed for increasing DOF, final BW increased linearly, while ADG and G:F decreased linearly, with no interaction with implant type.

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Table 2.1. Performance and carcass characteristics of implanted heifers compared to non-implanted control heifers fed for an average of 198 d (Exp. 1)

	Implant Treatment[1]							Pre-planned Contrasts		
	CON	XH	E200	XR	D200	SEM	F-Test	CON vs Implant	XH vs D200	XR vs D200
Performance										
Initial BW, kg	281	281	280	280	280	8.3	1.00	0.94	0.95	0.99
Live Final BW, kg	564	581	577	580	577	12.9	0.26	0.03	0.67	0.69
Adj. Final BW, kg[2]	561	580	580	580	579	12.5	0.09	0.01	0.87	0.90
DMI, kg/d	9.7	10.0	9.9	9.8	9.9	0.26	0.22	0.12	0.28	0.47
Live ADG, kg	1.44^{a}	1.52^{b}	1.51^{b}	1.52^{b}	1.50^{b}	0.044	0.02	<0.01	0.59	0.55
Live G:F	0.148^{a}	0.151^{a}	0.152^{ab}	0.156^{b}	0.153^{ab}	0.0015	0.02	0.01	0.54	0.13
Adj. ADG, kg[2]	1.42^{a}	1.52^{b}	1.52^{b}	1.52^{b}	1.51^{b}	0.039	<0.01	<0.01	0.86	0.84
Adj. G:F[2]	0.147^{a}	0.151^{b}	0.153^{bc}	0.156^{c}	0.153^{bc}	0.0015	<0.01	<0.01	0.29	0.21
Carcass characteristics										
HCW, kg	354	365	365	365	365	7.9	0.09	<0.01	0.88	0.92
Dress, %	62.7	63.1	63.3	63.0	63.2	0.12	0.18	0.04	0.81	0.43
LM area, cm[2]	79.4^{b}	83.9^{a}	80.0^{b}	82.6^{a}	83.2^{a}	0.11	<0.01	<0.01	0.62	0.62
Marbling Score[3]	569	537	534	543	529	10.6	0.09	<0.01	0.61	0.38
Fat depth, cm	1.70	1.65	1.75	1.68	1.63	0.022	0.58	0.70	0.61	0.44
Calculated YG[4]	3.80^{ab}	3.64^{a}	3.90^{b}	3.69^{a}	3.61^{a}	0.077	0.04	0.28	0.78	0.47

[a,b,c] Means within a row without common superscripts differ ($P \leq 0.05$)

[1] Implant treatments include: non-implanted negative control (**CON**), 200 mg TBA + 20 mg estradiol partially coated pellets (Revalor-XH, Merck Animal Health; **XH**), 200 mg TBA + 20 mg estradiol uncoated administered on d 1 (Revalor-200, Merck Animal Health; **E200**), 200 mg TBA + 20 mg estradiol coated implant (Revalor-XR, Merck Animal Health; **XR**) and 200 mg TBA + 20 mg estradiol uncoated administered on d 70 (Revalor-200, Merck Animal Health; **D200**).

[2] Common dressing percentage (63%) used to calculate carcass adjusted performance

[3] USDA Marbling Scores. 400 = small, 500 = modest, 600 = moderate

[4] Yield grade calculated using the following equation: 2.5 + (0.98425 x 12th rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^{2})

Table 2.2. Change in quality grade and yield grade distribution of implanted and non-implanted heifers fed for an average of 198 d (Exp.1)

	Implant Treatment[1]					
	CON[a, xy]	XH[b, x]	E200[b, y]	XR[ab, xy]	D200[b, x]	P-Value
Quality Grade, %						0.10
Prime	14.3	6.2	4.2	9	6.1	
Upper Choice	56.1	55.7	55.4	54.0	49.0	
Low Choice	22.3	26.8	33.2	28.9	35.9	
Select	7.2	10.3	7.1	8.1	9.0	
Standard	0.0	1.0	0.0	0.0	0.0	
Yield Grade, %						0.07
1	1.0	2.0	0.0	2.0	1.0	
2	16.7	16.7	11.6	12.3	16.4	
3	48.6	42.9	37.8	48.4	45.1	
4	28.6	34.3	42.3	34.2	36.4	
5	5.2	3.0	8.3	3.0	1.0	

[1] Implant treatments include: non-implanted negative control (**CON**), 200 mg TBA + 20 mg estradiol partially coated pellets (Revalor-XH, Merck Animal Health; **XH**), 200 mg TBA + 20 mg estradiol uncoated administered on d 1 (Revalor-200, Merck Animal Health; **E200**), 200 mg TBA + 20 mg estradiol coated implant (Revalor-XR, Merck Animal Health; **XR**) and 200 mg TBA + 20 mg estradiol uncoated administered on d 70 (Revalor-200, Merck Animal Health; **D200**).
[a, b] Means within row without common superscript differ ($P \leq 0.05$) for quality grade distribution
[x, y] Means within row without common superscript differ ($P \leq 0.05$) for yield grade distribution

Table 2.3. Interim growth performance of implanted and non-implanted heifers fed for an average of 198 d (Exp. 1)

	Implant Treatments[1]					P-Value		
	CON	XH	E200	XR	D200	F-Test	CON vs Implant	XR vs D200	XH vs D200
Day 0-70									
Initial BW, kg	281	281	280	280	280	1.000	0.94	0.99	0.95
Day 35 BW, kg	322	327	332	321	322	0.21	0.43	0.83	0.33
Day 70 BW, kg	370	379	384	370	370	0.09	0.23	0.96	0.19
DMI, kg/d	8.8	8.9	8.9	8.6	8.9	0.34	0.55	0.16	0.68
ADG, kg/d	1.29[a]	1.42[b]	1.50[c]	1.30[a]	1.31[a]	<0.01	0.01	0.89	0.01
G:F	0.148[a]	0.159[b]	0.169[c]	0.151[a]	0.147[a]	<0.01	<0.01	0.28	<0.01
Day 70-140									
Day 105 BW, kg	426	440	443	436	433	0.13	0.03	0.65	0.30
Day 140 BW, kg	472[a]	494[b]	493[b]	492[b]	491[b]	0.02	<0.01	0.94	0.71
DMI, kg/d	9.8	10.4	10.3	9.9	10.0	0.07	0.06	0.77	0.09
ADG, kg/d	1.46[d]	1.65[bc]	1.57[c]	1.74[a]	1.73[ab]	<0.01	<0.01	0.83	0.08
G:F	0.149[c]	0.160[b]	0.153[bc]	0.176[a]	0.173[a]	<0.01	<0.01	0.54	<0.01
Day 140-End									
Day 175 BW, kg	522[a]	546[b]	543[b]	546[b]	542[b]	<0.01	<0.01	0.54	0.56
Final BW, kg	563	580	577	580	577	0.32	0.04	0.70	0.80
DMI, kg/d	10.6	11.0	10.7	10.8	10.9	0.18	0.06	0.76	0.47
ADG, kg/d	1.57	1.48	1.43	1.51	1.47	0.23	0.05	0.46	0.82
G:F	0.149[a]	0.134[b]	0.134[b]	0.140[ab]	0.134[b]	0.04	<0.01	0.37	0.93

[a, b, c] Means with a row without common superscripts differ ($P \leq 0.05$)

[1] Implant treatments include: non-implanted negative control (**CON**), 200 mg TBA + 20 mg estradiol partially coated pellets (Revalor-XH, Merck Animal Health; **XH**), 200 mg TBA + 20 mg estradiol uncoated administered on d 1 (Revalor-200, Merck Animal Health; **E200**), 200 mg TBA + 20 mg estradiol coated implant (Revalor-XR, Merck Animal Health; **XR**) and 200 mg TBA + 20 mg estradiol uncoated administered on d 70 (Revalor-200, Merck Animal Health; **D200**).

Table 2.4. Blood sera metabolite concentrations in 35-d increments in implanted or non-implanted heifers fed for an average of 198 d (Exp. 1)

	Treatment[1]						P-Value				
	CON	XH	E200	XR	D200	SEM	Time x Treatment	Treatment	Time	Lin.	Quad.
Blood Urea-N, mg/dL						0.82	0.72	0.87	< 0.01	0.75	0.79
d 1[2]	15.2	16.0	15.9	16.2	16.4						
d 35	13.5	12.9	13.1	13.6	14.3						
d 70	16.0	15.9	15.6	15.7	16.8						
d 105	17.4	17.8	18.1	17.7	16.3						
d 140	16.8	17.0	17.4	16.8	16.4						
d 175	18.6	19.1	19.8	20.2	18.3						
NEFA, mEq/L						14.4	0.59	0.87	< 0.01	0.72	0.50
d 1[2]	323.5	340.4	311.7	326.8	348.2						
d 35	177.2	173.8	186.1	162.3	172.7						
d 70	180.1	178.2	208.2	195.6	166.8						
d 105	160.8	167.1	174.8	172.8	172.8						
d 140	191.6	166.8	171.1	184.1	189.8						
d 175	142.4	179.0	174.0	164.1	171.7						
IGF-1, ng/mL						7.7	0.99	0.12	< 0.01	0.06	0.05
d 1[2]	52.2	52.6	53.9	49.2	46.8						
d 35	56.8	71.1	67.4	68.2	66.0						
d 70	73.9	100.6	82.1	85.9	84.1						
d 105	70.7	96.5	87.8	88.0	90.3						
d 140	72.5	95.5	90.6	84.6	88.3						
d 175	82.4	100.1	94.7	86.2	94.5						
17β-TbOH pg/mL[3]						11.7	< 0.01	< 0.01	< 0.01	<0.01	0.37
d 1[2]	ND[3]	ND	ND	ND	ND						
d 35	ND^{b}	53.8^{b}	121.2^{a}	23.2^{b}	ND^{b}						
d 70	ND^{c}	45.9^{bc}	116.5^{a}	72.6^{ab}	ND^{c}						
d 105	ND^{c}	55.8^{bc}	57.1^{bc}	147.2^{a}	103.8^{ab}						
d 140	ND^{c}	39.9^{bc}	24.0^{bc}	102.2^{a}	63.4^{ab}						
d 175	ND^{b}	ND^{b}	21.6^{b}	48.0^{ab}	80.1^{a}						

[a, b, c] Means within rows without common superscripts differ ($P \leq 0.05$)

[1] Implant treatments include: non-implanted negative control (**CON**), 200 mg TBA + 20 mg estradiol partially coated pellets (Revalor-XH, Merck Animal Health; **XH**), 200 mg TBA + 20 mg estradiol uncoated administered on d 1 (Revalor-200, Merck Animal Health; **E200**), 200 mg TBA + 20 mg estradiol coated implant (Revalor-XR, Merck Animal Health; **XR**) and 200 mg TBA + 20 mg estradiol uncoated administered on d 70 (Revalor-200, Merck Animal Health; **D200**).

[2] Days from initiation of trial

[3] ND = Not detectable (12.5 pg/mL)

Figure 2. 1 Effects of implant treatment on circulating sera metabolites (Exp. 1).

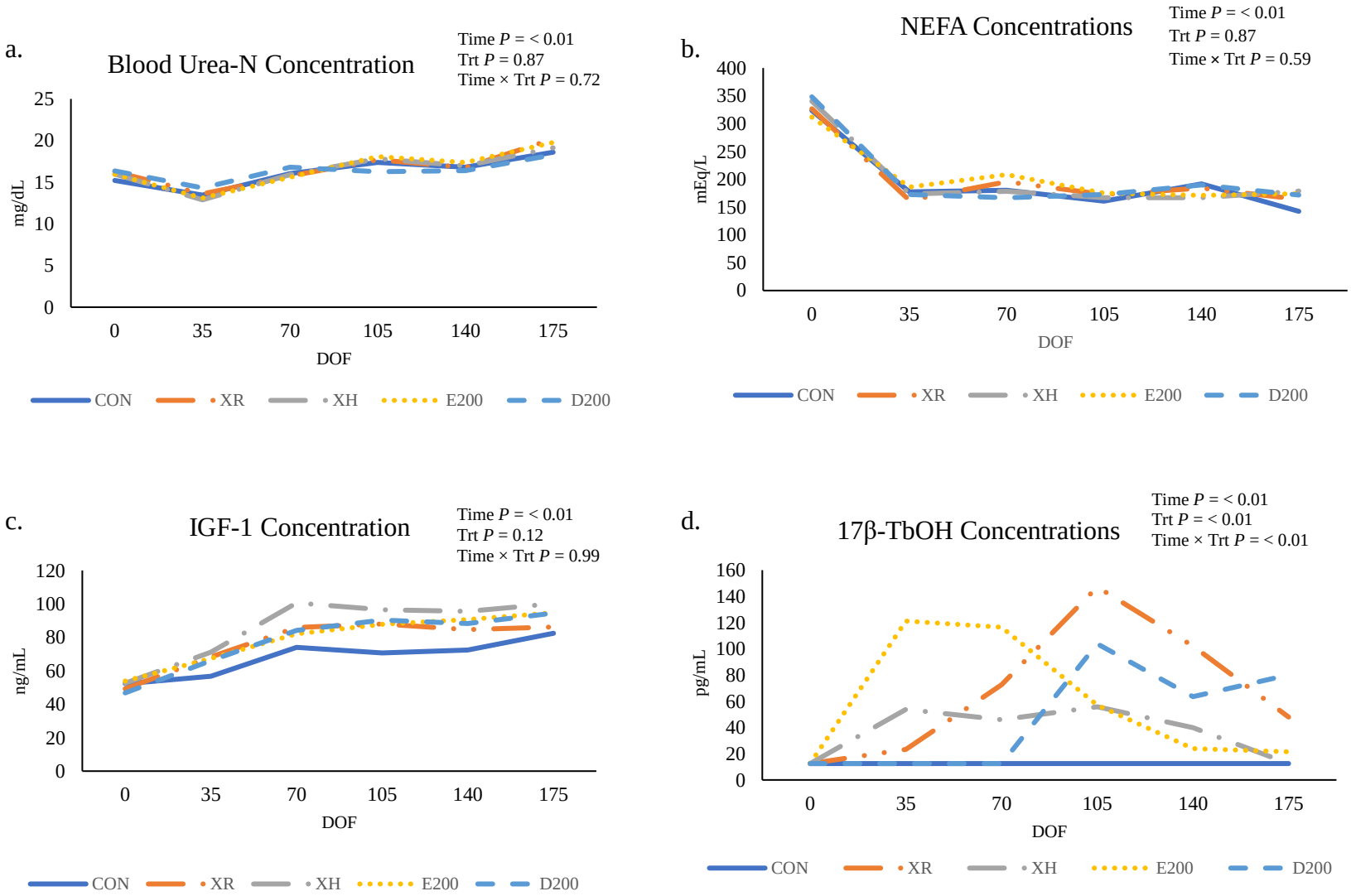


Figure Description: Effect of implant treatment on sera metabolite concentrations in finishing heifers. Treatments included: No implant (CON), Revalor-XH (200 mg TBA + 20 mg E2, Merck Animal Health, De Soto, KS; partially coated; XH), Revalor-200 on d 1 (200 mg TBA + 20 mg E2, Merck Animal Health; uncoated; E200), Revalor-XR (200 mg TBA + 20 mg E2, Merck Animal Health; coated; XR) and Revalor-200 on d 70 (D200). Baseline measurements for 17β-TbOH were less than the lowest detectable level, which is 12.5 pg/mL.

Table 2.5 Performance and carcass characteristics for heifers implanted with no implant, Revalor-200 on d 1 and re-implanted with Revalor-200 on d 100, or Revalor XH on d 1 (Exp.2)

Item	Treatments[1]			SEM	CON vs Implanted	200/200 vs XH
	NON	200/200	XH			
Final Pen BW, kg[2, 6]	575	597	595	2.8	<0.01	0.98
Carcass Adjusted Final, kg[3, 6]	577	598	596	3.0	< 0.01	0.58
DMI, kg/d	11.6	11.7	11.8	0.1	0.12	0.15
Live ADG, kg[6]	1.71	1.84	1.83	0.016	0.04	0.68
Carcass Adjusted ADG, kg[3, 6]	1.72	1.85	1.83	0.02	< 0.01	0.55
Live G:F[6]	0.147	0.158	0.154	0.0013	< 0.01	0.05
Carcass Adjusted G:F[3, 6]	0.148	0.158	0.155	0.001	<0.01	0.07
HCW, kg [6]	364	377	375	2	< 0.01	0.59
Dress, %	63.2	63.2	63.4	0.002	0.74	0.48
LM area, cm^2	78.1	80	78.7	1.9	0.63	0.67
12th rib backfat thickness, cm	1.85	1.91	1.91	0.01	0.10	0.94
Marbling score[4]	567	533	549	7	< 0.01	0.10
Calculated YG[5]	3.98	4.07	4.11	0.11	0.44	0.79

[1] Treatments include: No implant **(CON)**, 200 mg TBA + 20 mg E2 (Revalor-200, Merck Animal Health) on d 1 and re-implanted with Revalor-200 on d 100 **(200/200)**, or 200 mg TBA + 20 mg E2 (Revalor-XH, partially coated; Merck Animal Health) **(XH)**

[2] Final Pen BW pencil shrunk 4%

[3] Carcass-adjusted performance calculated by HCW divided by a common dressing percent of 63%.

[4] 400 = small, 500 = modest, 600 = moderate

[5] Yield grade calculated using the following equation: 2.5 + (0.98425 x 12th rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2)

[6] Initial BW was used as a covariate in the model

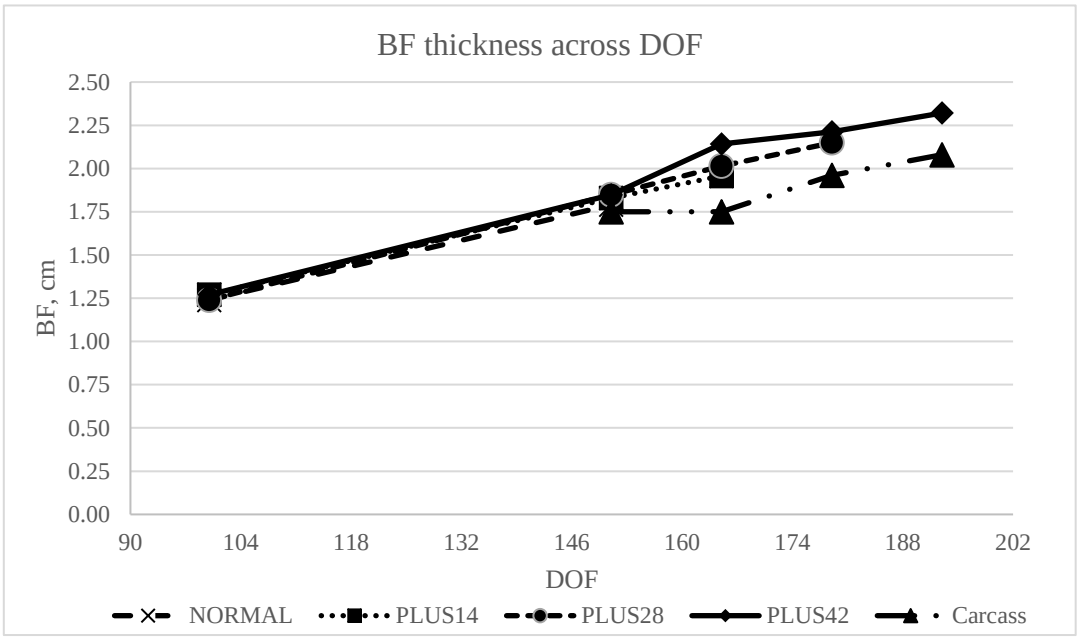
Table 2.6. Growth performance and carcass characteristics of heifers fed for 151, 165, 179 or 193 days on feed (Exp. 2)

	Treatments[1]						Contrasts	
Item,	NORMAL	PLUS14	PLUS28	PLUS42	SEM	F-Test	Linear	Quadratic
Final Pen BW, kg[2, 6]	567	579	597	613	3.3	< 0.01	< 0.01	0.46
Carcass Adjusted Final, kg[3, 6]	558	577	606	623	4.0	< 0.01	< 0.01	0.78
DMI, kg/d	11.7	11.7	11.8	11.8	0.10	0.72	0.38	0.84
Live ADG, kg[6]	1.89	1.81	1.76	1.72	0.02	< 0.01	< 0.01	0.20
Carcass Adjusted ADG, kg[3, 6]	1.83	1.79	1.81	1.77	0.02	0.18	0.10	0.99
Live G:F[6]	0.161	0.155	0.15	0.146	0.0021	< 0.01	< 0.01	0.25
Carcass Adjusted G:F[3, 6]	0.156	0.154	0.154	0.151	0.002	0.1	0.02	0.84
HCW, kg[6]	351	363	382	392	2.0	< 0.01	< 0.01	0.79
Dress, %	62.3	62.8	63.9	64	0.002	0.49	0.13	0.63
LM area, cm^2	77.4	76.1	82.6	80.6	2.6	0.17	0.09	0.99
12th rib backfat thickness, cm	1.75	1.75	1.96	2.08	0.03	< 0.01	< 0.01	0.09
Marbling score[4]	538	521	565	574	8	< 0.01	< 0.01	0.11
Calculated YG[5]	3.83	4	4.04	4.34	0.13	0.05	< 0.01	0.60

[1] Treatments include: 151 **(NORMAL)**, 165 **(PLUS14)**, 179 **(PLUS28)**, or 193 **(PLUS42)** days on feed.
[2] Final Pen BW pencil shrunk 4%
[3] Carcass-adjusted performance calculated by HCW divided by a common dressing percent of 63%.
[4] 400 = small, 500 = modest, 600 = moderate
[5] Yield grade calculated using the following equation: 2.5 + (0.98425 x 12^{th} rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2)
[6] Initial BW was included as a covariate in the model

Figure 2.2. Effect of implant treatment and DOF on backfat thickness of heifers fed varying DOF (Exp. 2)

A.



B.

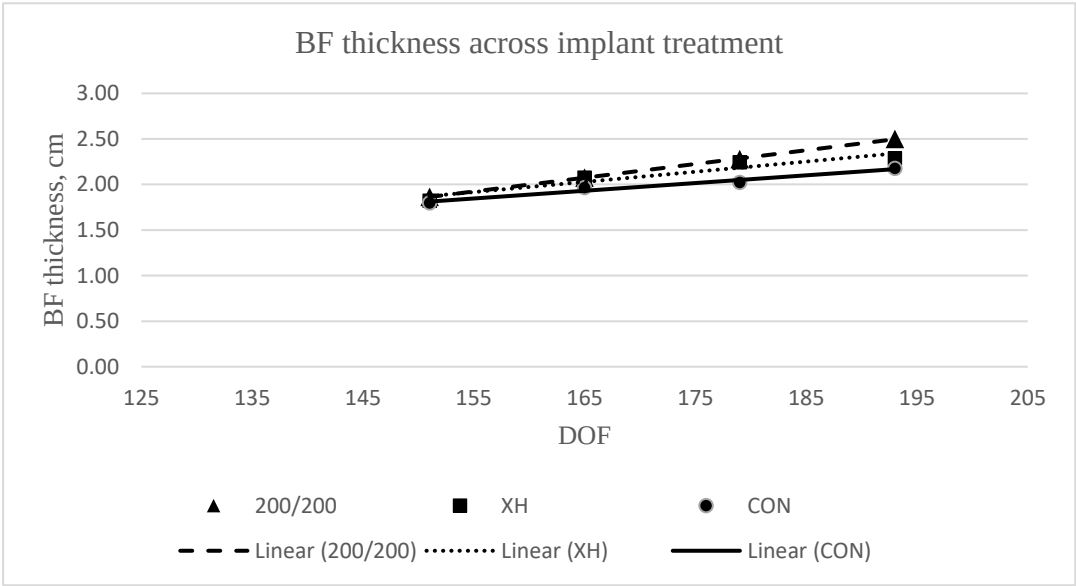


Figure Description: Backfat thickness increased linearly ($P < 0.01$) as cattle were fed from 151 to 193 DOF, with no implant treatment × serial harvest interaction ($P = 0.26$). There was a tendency for an implant treatment × linear serial harvest interaction ($P = 0.12$). Treatments included: No implant (CON), Revalor-200 (200 mg TBA + 20 mg E2, Merck Animal Health, De Soto, KS; uncoated) on d 1 and reimplanted with Revalor-200 on d 100 (200/200), or Revalor-XH (200 mg TBA + 20 mg E2, Merck Animal Health; partially coated; XH). The equations for effect of implant across DOF were:

y = 0.00781x (± 0.002251) + 0.6459 (± 0.3888) ($P < 0.01$; CON),

y = 0.01735x (± 0.002251) – 0.8880 (± 0.3888) ($P < 0.01$; 200/200),

y = 0.01294x (± 0.002251) – 0.1453 (± 0.3888) ($P < 0.01$; XH).

CHAPTER III. Evaluation of day of administration of 200 mg TBA and 20 mg estradiol steroidal implant on heifer and steer performance and carcass characteristics

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Abstract

Two experiments evaluated the optimal time of administration of a terminal combination implant following a mild combination implant on finishing heifer and steer performance. In Exp. 1, crossbred heifers (n = 1,867; initial BW = 268; SD = 9 kg) were utilized in a 181-d finishing study to evaluate the effects of 4 different days on terminal (DOT) implant (160, 120, 80 and 40 DOT) on growth performance and carcass characteristics. Heifers were given an initial implant of 80 mg trenbolone acetate (TBA) + 8 mg estradiol (Revalor-IH, Merck Animal Health, De Soto, KS) on d 1. Terminal implant included 200 mg TBA + 20 mg estradiol (Revalor-200, Merck Animal Health). No difference was observed in DMI ($P \geq 0.12$), but a quadratic response ($P \leq 0.04$) was observed for final BW, ADG and G:F, and were greatest for cattle fed 80 DOT when carcass-adjusted performance was evaluated. Hot carcass weight was greatest at 80 DOT ($P = 0.03$; quadratic). However, LM area and dressing percentage were greatest at 120 DOT ($P \leq 0.10$; quadratic). Solving for first derivative, each variable was optimized between 88 and 103 DOT, with an average of 94 DOT. Interestingly, there was less than 1% difference in ADG and G:F when implanted 21 days either side of optimal DOT. In Exp. 2, crossbred steers (n = 800; initial BW = 330; SD = 25 kg) were utilized in a 180-d finishing study to evaluate 160, 120, 100, 80 or 40 DOT on growth performance and carcass characteristics. All steers were given an initial implant (80 mg TBA + 16 mg estradiol; Revalor-IS, Merck Animal Health) on d 1 followed by a terminal implant (Revalor-200, Merck Animal Health). DMI was the lowest for 40 DOT ($P \leq 0.04$), with no differences between other treatments ($P \geq 0.11$). Carcass-adjusted final BW, ADG, and G:F responded quadratically ($P \leq 0.05$), with 80 to 120 DOT being the greatest, with

less than 2% difference over the 40 d period. Hot carcass weight increased quadratically ($P = 0.03$), LM area increased linearly ($P < 0.01$), and there were no differences in fat thickness, marbling score, or calculated yield grade ($P \geq 0.27$) as DOT increased. When solved for the first derivative, final BW, ADG, G:F, and HCW were optimized between 87 and 104 DOT. The optimal DOT appears to be between 80 and 120 DOT, with an average of 96 DOT for both steers and heifers. These data show flexibility in reimplant windows, allowing feedlot personnel flexibility in making management decisions to best suit their labor, weather and marketing constraints.

Keywords: Implants, Payout, Reimplanting

Introduction

Anabolic implants are a proven management tool that have been shown to increase performance and efficiency in feedlot cattle for more than 50 years (Hickman et al., 1994; Nichols et al., 2002). Since the approval of implants in 1954, many combinations of dosage and ratios of steroid hormones have been approved for use in cattle (Nichols et al., 2002). However, many implants only last 60 to 120 d until no longer effective. Many times, cattle require more than 120 days on feed, which then creates the need for two or more implants during the finishing phase to optimize performance. When steers were implanted with a combination (trenbolone acetate + estradiol) implant as an initial implant and reimplanted with a combination implant, ADG was improved by 20% and feed efficiency was improved by 13.5% compared to non-implanted steers (Duckett and Pratt, 2014). However, with an increased demand for improved gains and efficiency, while also feeding cattle longer days on feed, there are limited data on the optimal time to administer a terminal implant. Therefore, the objective

of these experiments was to identify the optimal time for administering a terminal combination implant following a mild combination initial implant in heifers or steers fed for approximately 180 d.

Materials and Methods

All procedures used in these experiments were reviewed and approved by the University of Nebraska- Lincoln Institutional Animal Care and Use Committee (IACUC).

Experimental Design and Procedures

Experiment 1

A study was conducted at a commercial feedlot (Barton County Feeders) near Ellinwood, KS. Crossbred heifers (n = 1,867; initial BW= 268; SD = 9 kg) were utilized in a randomized complete block design with six blocks consisting of 4 adjacent pens per block. Heifers were received from 10 sale barns in Kansas (n = 9) and Nebraska (n = 1). On arrival, heifers were allowed *ad libitum* access to fresh water and long-stemmed hay. Cattle were randomly allotted to 4 different sort pens (5 animals at a time) until the desired head count was achieved in each pen or until there were no more animals in the respective purchase group. In this case, the next purchase group was continued sorting into the 4 different pens 5 animals at a time. This allotment procedure was repeated until all pens were filled to a similar bunk space and pen space per animal. Treatments were assigned randomly to pens within block and consisted of 4 different days on terminal (DOT) implant (160, 120, 80 and 40 d).

Heifers were received at a commercial feedyard over the course of approximately 3 weeks and during this time had ad libitum access to water and long-stemmed hay.

Heifers were processed according to the standard operating procedures of the facility. Heifers were identified with color-coordinated and numbered tags in each ear. The right ear tag contained the lot number and the left ear tag contained the lot number and the individual animal ID number. Heifers were vaccinated for infectious bovine rhinotracheitis (IBR), bovine viral diarrhea virus (BVDV) (types 1 and 2), parainfluenza$_3$ (PI_3), bovine respiratory syncytial virus (BRSV), *Mannheimia haemolytica*, and *Pasteurella multocida* (Vista Once, Merck Animal Health, DeSoto, KS). In addition, heifers received an injection of one percent doramectin for treatment and prevention of gastrointestinal and external parasites (Dectomax; Zoetis Animal Health, Florham Park, NJ), oral drench of fenbendazole for removal and prevention of worms (Safeguard; Merck Animal Health), topical application of one percent lambda-cyhalothrin for the control of lice and horn flies (Exile, Aspen Veterinary Resources, Liberty, MO) pour onto the back, metaphylaxis injection of an antibiotic for the control of respiratory infection caused by *Mannheimia haemolytica, Pasteurella multocida,* and *Histophilus somni* (Zuprevo, Merck Animal Health), and a growth implant (80 mg of trenbolone acetate + 8 mg of estradiol, Revlor-IH Merck Animal Health) under the skin of the posterior, middle third of the ear. Approximately 15 to 20 days after processing heifers were revaccinated for IBR, BVDV types 1 and 2, PI_3, and BRSV (Vista 5 SQ, Merck Animal Health).

Heifers received their terminal implant (Revalor-200; 200 mg of trenbolone acetate + 20 mg of estradiol, Merck Animal Health) at 160, 120, 80, and 40 days prior to predetermined harvest dates based on assigned treatment. In addition, heifers were revaccinated (Vista 5 SQ, Merck Animal Health) at reimplant.

Heifers were housed in 24 dirt-surfaced pens providing 33.3 linear cm of bunk space and 22 m^2 of pen space per heifer. Diets were fed three times daily at approximately 0700, 1000, and 1350 h. Trained personnel evaluated heifers for overall wellbeing daily. Pens within a block were treated the same as it pertains to transitioning onto the finishing ration. Heifers were fed a starter ration, which included 29% steam-flaked corn, 22.2% WDGS, 38% alfalfa hay, 7% corn silage, and 3.8% supplement (DM basis), for 4 to 6 days. Alfalfa hay and corn silage were replaced with steam-flaked corn as steps progressed. Heifers were fed half of their diet as the starter ration and half as ration 2 for 2 to 4 days before being fed ration 2 alone for 5 to 6 days. Heifers were then transitioned to ration 3 using a 50:50 blend of ration 2 and ration 3 before being fed ration 3 alone for 5 to 6 days. Finally, heifers were transitioned to the finishing ration using a 3 to 4-day split feeding of both rations 3 and the finisher. The finisher ration included 66.6% steam-flaked corn, 18% WDGS, 4.3% mixed hay, 3.2% corn silage, 2.9% tallow, and 5% supplement. Supplement was formulated to provide 300 mg monensin (Rumensin, Elanco Animal Health, Greenfield, IN), 90 mg of tylosin (Tylan, Elanco Animal Health), 0.5 mg of melengestrol acetate (MGA, Zoetis Animal Health), and 50 g Bovamine Defend (Nutrition Physiology Company, Overland Park, KS) per heifer daily and 250 mg of ractopamine hydrochloride (Actogain, Zoetis Animal Health) per heifer daily during the last 28 DOF.

Heifers were on trial for approximately 181 d prior to harvest. On the morning of shipping prior to feeding, heifers were weighed by pen on a large platform scale. Heifers were then transported to a commercial abattoir located in Holcomb, KS. Heifers were processed on May 24th, 2016 (1 block), June 2nd, 2016 (1 block), June 7th, 2016 (2

blocks), and June 14th, 2016 (2 blocks). Heifers were kept with their pen mates during the shipping and harvest process. Trained personnel at the abattoir collected carcass measurements using camera grading system. Carcass weight, liver score, USDA quality grade, USDA yield grade, kidney, pelvic, and heart fat, 12th rib fat thickness, LM area, and marbling score were collected for each animal at the abattoir. Average dressing percentage was calculated using the total carcass weight and shrunk (4%) final weight of the entire pen. Calculated yield grade was calculated using the following: 2.5 + (0.98425 x 12th rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2).

Statistical Analysis Exp. 1

Growth performance and carcass characteristics were analyzed using the MIXED procedure of SAS (9.3, SAS Institute, Cary, NC). Pen was the experimental unit and block was included as a random effect. Linear and quadratic contrasts of DOT were used to compare treatment differences. Treatment averages were calculated using the LSMEANS option of SAS. Quality and yield grade distributions were analyzed using the GLIMMIX procedure of SAS using a multinomial approach. Data were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

Experiment 2

A feedlot study was conducted at the University of Nebraska Eastern Nebraska Research and Extension Center (ENREC) near Mead, NE. Crossbred yearling steers (n = 800; initial BW = 330; SD = 25 kg), were utilized in a generalized randomized block design with two initiation times and three BW blocks within initiation time. Steers were sourced from auction markets and transported to the research site. At the time of feedlot

arrival, all steers were individually identified (panel tag, electronic ear button, and metal clip). Steers received an infectious bovine rhinotracheitis (IBR) virus, parainfluenza-3 (PI_3) virus, bovine viral diarrhea (BVD) virus (types I and II), bovine respiratory syncytial virus (BRSV), *Mannheimia haemolytica* and *Pasteurella multocida* combination vaccine (Vista Once, Merck Animal Health), a *Clostridium chauvoei, specticum, novyi, sordellii, perfringens* Types B, C, and D bacterin-toxoid (Vision 7, Merck Animal Health), a 10 percent fenbendazole oral suspension for the control of lung worms, stomach worms, and intestinal worms (Safe-Guard Dewormer, Merck Animal Health), and one percent doramectin injectable for treatment and prevention of gastrointestinal and external parasite control (Dectomax, Zoetis Inc.). Five d prior to trial initiation, steers were limit fed a common diet of 50% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50% alfalfa hay at 2% of BW and weighed for 2 consecutive d (d 0 and 1) to establish initial BW and to limit differences in BW due to gastrointestinal fill (Watson et al., 2013). Using d 0 weights, steers were blocked by BW (n=3), stratified within block, and assigned randomly to pens (n=40). Pens were assigned randomly to one of five treatments with 20 steers per pen and 8 pens / treatment.

All steers were implanted with 80 mg TBA and 16 mg E2 on d 1 (Revalor-IS, Merck Animal Health). Treatments consisted of varying days on terminal implant (160, 120, 100, 80, 40 d). Terminal implant included 200 mg of TBA and 20 mg of E2 (Revalor-200, Merck Animal Health). All cattle were implanted under the skin of the posterior, middle third of the ear.

Steers were adapted to a common finishing diet over a 24-d period consisting of four adaptation diets. The amount of wet distiller's grains (WDGS), Sweet Bran, grass

hay and supplement were held constant at 15%, 25%, 6% and 4% (DM basis) of the diet DM, respectively. The amount of dry rolled corn (DRC) was gradually increased while replacing alfalfa. The first adaptation diet consisted of 12.5% DRC and 37.5% alfalfa hay and was fed for 5 d. The second adaptation diet was fed for 5 d and consisted of 22.5% DRC and 27.5% alfalfa hay. The third adaptation diet included 32.5% DRC and 17.5% alfalfa hay and was fed for 7 d. The fourth and final adaptation diet included 42.5% DRC and 7.5% alfalfa hay and was fed for 7 d. The finishing diet included 50% DRC, 15% WDGS, 25% Sweet Bran, 6% grass hay and 4% supplement, all on DM basis. The supplement was formulated to provide 30 g/ton of monensin (Rumensin, Elanco Animal Health) and 8.9 g/ton DM tylosin (Elanco Animal Health).

Steers were housed in open feedlot pens with approximately 45.5 cm of linear bunk space and 28 m^2 of pen space per head. Feed bunks were assessed once daily at approximately 0600 for presence of feed. Feed amounts were increased or decreased daily to maintain an ad libitum bunk management approach. Cattle were fed once daily between 0700 and 0900 and had ad libitum access to fresh water and feed. Diets were mixed and delivered using a truck-mounted feed mixer and delivery unit (Roto-Mix model 420, Roto-Mix, Dodge City, KS). When refusals were present, orts were weighed, sampled and frozen for later analysis of DM. Dry matter of orts were determined by placing samples in a 60° C forced-air oven for 48 h (AOAC Method 935.29; AOAC, 1999). Cattle were visually evaluated daily by trained UNL personnel. Evaluations include proper functionality of water tanks, integrity of fences and feed bunks, and any abnormal behavior of the cattle. When steers were determined to be sick, steers were

removed from the pen and taken to the processing facility for diagnosis and appropriate treatment.

On day of shipping, steers were offered 50% of the previous day's called feed. In the afternoon, all steers were brought to the handling facility, pen weighed to determine final live BW, and loaded onto trucks. All animals were harvested at a commercial harvest facility (Greater Omaha, Omaha, NE) after 180 d on feed. Carcass data collection was performed by UNL personnel. Hot carcass weight and liver scores were recorded on day of harvest. After a 48-h chill, LM area, 12^{th} rib fat thickness, and USDA marbling score were recorded using camera grading. Yield grade was calculated (USDA, 2016) from the following formula: 2.5 + (0.98425 x 12^{th} rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2). Live final BW was pencil shrunk 4% to calculate dressing percentage and live performance. A common dressing percentage of 63% was used to calculate carcass adjusted final BW, ADG, and G:F.

Statistical Analysis Exp. 2

Growth performance and carcass data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute, Cary, NC). Pen was the experimental unit and BW block, initiation block and BW block nestled within initiation block were included as fixed effects. Linear and quadratic DOT contrasts were used to compare treatment differences. Quality and yield grade distributions were analyzed using the GLIMMIX procedure of SAS using a multinomial approach. Data were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

Results and Discussion

Exp. 1

There were no differences in initial BW between treatment groups ($P \geq 0.18$; Table 3.1). Dry-matter intake was the same for all treatments ($P \geq 0.12$). Using carcass-adjusted performance, there was a quadratic response to final BW ($P = 0.04$) and ADG ($P = 0.01$) with 80 DOT having the greatest ending BW and gain, and in turn, being the most efficient ($P = 0.01$; quadratic).

Figure 3.1 illustrates the quadratic response and the respective regression equations of each variable. Each of these variables were optimized between 88 and 103 DOT with an average optimal DOT of 94 (87 d on initial implant) when heifers are fed for 181 d. However, growth performance was only reduced by 1% when calculated at 21 days on either side of the first derivative. These results suggest that the feedyard operator has a 40 d window to move the scheduled terminal implant date around with minimal effects of growth performance.

Interim growth performance data are summarized in Table 3.2. Interestingly, ADG was different between days 0 and 21 ($P = 0.02$). These differences were not expected and are not due to any treatment effect since the experimental treatment had not been applied at this point. As expected, ADG and G:F were greater ($P \leq 0.05$) in each period following the day when the terminal implant treatment was applied. The only exception was ADG in the last period when the 40 DOT treatment was applied, in which ADG was similar ($P \geq 0.05$) between the 80 and 40 DOT treatments. This may suggest that the terminal implant was not fully utilized and had not completely released all the

hormones in the last 40 d period. The heifers that received the shortest DOT (i.e., 40) treatment also had the longest days on initial implant (i.e., 141 days). Therefore, the ADG response in the 40 DOT treatment may also be due to the terminal implant and less response from the initial implant due to length of implant window.

Carcass characteristics are summarized in Table 3.3. Hot carcass weight and LM area responded quadratically ($P \leq 0.03$) to DOT, with the greatest HCW response at 80 DOT and the greatest LM area at 120 DOT. Dressing percentage tended to respond quadratically ($P = 0.06$), with 120 DOT having the greatest dressing percent. Interestingly, USDA marbling score increased linearly ($P = 0.03$) as DOT decreased. Bruns et al (2005) observed that cattle implanted with greater doses of TBA + estradiol early in the feeding period had in decreased marbling scores, which agrees with our observations as marbling score was affected the greatest when cattle received both the initial and terminal implant within the first 20 DOF (160 DOT). Contrary to these results, Duckett (2004) concluded that reimplanting with a combination implant half way through the feeding period resulted in lower marbling scores, therefore contributing the effects on marbling to timing of terminal implant administration compared to cattle given only an initial implant. Quality grade ($P < 0.01$) and yield grade ($P < 0.01$) distributions were both altered by days on terminal implant (Table 3.4). Calculated yield grade did not change across treatments ($P \geq 0.25$), which does not agree with observations by Duckett et al. (1997), who observed decreased yield grades due to decreased fat thickness in heifers given two implants.

Experiment 2

Dry matter intake was the least for 40 DOT ($P \leq 0.04$, Table 3.6), with no differences between the other treatments ($P \geq 0.11$). This agrees with Milton et al. (2000) who found that steers either delay implanted or implanted with a combination implant and reimplanted with a combination implant 82 d prior to harvest had the greatest DMI compared to cattle given a less aggressive dose or only implanted on d 1. Carcass-adjusted final BW responded quadratically ($P = 0.03$) with 100 DOT having the greatest final BW, but 100 DOT was not different from 120 DOT ($P = 0.82$). Carcass-adjusted ADG responded quadratically ($P = 0.02$), with 100 and 120 DOT being the greatest, but not different ($P = 0.87$) and 80 DOT being intermediate ($P \geq 0.57$). There was less than 1% difference in carcass-adjusted ADG between 80, 100 or 120 DOT. When solved for the first derivative, ADG was maximized at 99 DOT. Carcass-adjusted G:F also responded quadratically ($P < 0.01$), with 160 DOT being the least efficient, but no differences between other treatments ($P \geq 0.13$). Compared to 120 DOT, there was a 1.6% increase in G:F when cattle were reimplanted 100 days prior to harvest and a 0.5% increase in G:F for 100 DOT compared to 80 DOT. There was a 1.2% improvement in G:F when steers were reimplanted 80 d prior to slaughter compared to 120 DOT. When solved for the first derivative, G:F was maximized at 87 DOT. These results disagree with Rumsey et al. (1992), where steers implanted 60, 90, or 120 d prior to harvest had similar ADG and feed efficiencies regardless of implant protocol. Johnson et al. (2013) concluded to gain optimal benefit from an implant, it is vital to utilize the implant until most of the hormone has been paid out.

Interim data are presented in Table 3.7. As expected, ADG and G:F were greater in most cases in each period following the day in which the terminal implant was applied.

The exception to this was when the 120 DOT treatment was applied. There were no statistical differences in ADG or G:F between treatments ($P \geq 0.16$), but the 120 DOT treatment was not numerically greater compared to the other treatments. There was a tendency ($P = 0.06$) for ADG to be different among treatments during d 82 to 101, however, the applied treatment (100 DOT) was not the greatest. Because DMI was the lowest for 100 DOT during that period ($P < 0.01$), 100 DOT did have had the greatest G:F during that period ($P = 0.02$).

Carcass characteristics are summarized in Table 3.8. Hot carcass weight responded quadratically ($P = 0.03$), with the greatest at 100 DOT. When solved for the first derivative, HCW was maximized at 104 DOT. There were no differences in BF thickness ($P = 0.81$). The lack of differences in subcutaneous fat thickness is consistent with most research trials that compare various implant schemes (Duckett, 2004). There was a linear increase in LM area as DOT increased, with 100 and 120 DOT having the greatest LM area ($P \leq 0.05$). Al-Maamari et al. (1995) found when steers received an initial combination implant and were reimplanted on d 61 (87 DOT), reimplanted cattle had greater amount of salable lean without increasing the amount of fat trim. There were no statistical differences in USDA marbling scores ($P = 0.27$), however, 100 DOT numerically had the greatest marbling score. Several other studies show a decrease in marbling score with more aggressive implant strategies (Bartle et al., 1992; Platter et al., 2003; Smith et al., 2007) which may be observed with steers with longer DOT, not giving the initial implant enough opportunity to payout. Samber et al. (1996) reported that a decrease in intramuscular fat is expected when combination TBA + estradiol implants are administered more than once or late in the finishing phase, however that was not

observed in this study. In a historical review of the use of implants by Montgomery et al. (2001), the authors reported that delayed implanting or using a mild combination implant initially prevents negative effects on marbling score because it is thought that intramuscular fat deposition happens early in the feeding period. This idea would support 100 DOT having the greatest numerical marbling score without sacrificing other carcass merits. There were no statistical differences observed in calculated yield grade ($P = 0.38$). Likewise, there were no differences in quality and yield grade distribution for DOT ($P = 0.56$ and 0.84, respectively; data not shown). Milton et al. (2000) also observed no differences for marbling score or the percent of steers grading Choice or better when comparing delayed implanting or mild initial implant followed by reimplanting with a combination implant.

Overall, administering an initial implant at the beginning of the finishing phase followed by a terminal implant on average 96 d prior to slaughter increased growth performance and carcass characteristics in heifers and steers when fed for approximately 180 d compared to administering a terminal implant earlier or later in the finishing period. However, with minimal changes in performance and carcass characteristics across treatments when cattle were reimplanted 80 to 120 d prior to harvest suggests feedlot personnel have flexibility in timing of implants with minor impact on performance.

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Table 3.1 Effect of days on terminal implant on growth performance of heifers fed for 181 d (Exp.1)

	Days on Terminal Implant[1]					P-Value	
Item	160	120	80	40	SEM	Linear	Quadratic
Heifers (pens), n	(6) 467	(6) 467	(6) 466	(6) 467	-	-	-
Live Performance							
Initial BW, kg[2]	257	257	257	258	3.3	0.18	0.85
Final BW, kg[2]	544	548	550	547	4.4	0.44	0.25
DMI, kg	8.9	8.7	8.7	8.7	0.11	0.12	0.17
ADG, kg	1.59	1.61	1.62	1.59	0.02	0.69	0.07
G:F	0.179	0.185	0.186	0.183	0.065	0.16	0.02
Carcass-adjusted performance							
Initial BW, kg[2]	257	257	257	258	3.3	0.18	0.85
Final BW, kg[3]	540	545	548	540	4.3	0.33	0.04
ADG, kg	1.56	1.59	1.60	1.57	0.02	0.63	0.01
G:F	0.176	0.183	0.184	0.180	0.065	0.10	0.01

[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IH; Merck Animal Health)
[2] Initial and final BW pencil shrunk 4%
[3] Carcass-adjusted final BW calculated by dividing HCW by common dressing percent of 63.75%

Table 3.2 Effect of days on terminal implant on interim growth performance of heifers fed for 181 d (Exp 1)

	Days on Terminal Implant[1]							
Item	160	120	80	40	SEM	F-Test	Lin.	Quad.
Day 1-20								
DMI, kg	6.5	6.4	6.4	6.4	0.19	0.37	0.67	0.73
ADG, kg/d	2.08[a]	1.97[bc]	1.92[c]	2.06[ab]	0.09	0.02	0.76	0.16
G:F	0.313	0.303	0.293	0.318	0.221	0.08	0.93	0.41
Day 21-61								
DMI, kg	8.3	8.2	8.1	8.2	0.10	0.41	0.46	0.24
ADG, kg/d	1.65[a]	1.49[b]	1.51[b]	1.50[b]	0.04	0.01	0.02	0.06
G:F	0.198[a]	0.182[b]	0.186[b]	0.182[b]	0.131	0.01	0.04	0.15
Day 62-101								
DMI, kg	9.2	9.0	9.0	9.2	0.11	0.29	0.96	0.13
ADG, kg/d	1.63[a]	1.83[b]	1.64[a]	1.63[a]	0.05	0.01	0.37	0.04
G:F	0.177[a]	0.203[b]	0.181[a]	0.177[a]	0.133	0.01	0.26	<0.01
Day 102-141								
DMI, kg	9.6	9.4	9.4	9.4	0.12	0.16	0.28	0.28
ADG, kg/d	1.35[a]	1.39[a]	1.56[b]	1.31[a]	0.06	0.01	0.89	0.02
G:F	0.140[b]	0.147[ab]	0.165[a]	0.138[c]	0.284	0.01	0.58	<0.01
Day 142-181								
DMI, kg	9.5	9.4	9.4	9.2	0.16	0.18	0.26	0.64
ADG, kg/d	1.48[a]	1.54[a]	1.61[ab]	1.70[b]	0.06	0.02	0.02	0.77
G:F	0.156[a]	0.164[ab]	0.169[b]	0.183[c]	0.204	0.01	<0.01	0.60

[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IH; Merck Animal Health)

[a b c] Means without a common superscript within a row are different ($P \leq 0.05$)

Table 3.3 Effect of days on terminal implant on carcass characteristics of heifers fed for 181 d (Exp. 1)

	Days on Terminal Implant[1]					P-Value	
	160	120	80	40	SEM	Linear	Quadratic
HCW, kg	344	348	349	346	2.7	0.32	0.03
Dress, %	63.2	63.5	63.4	63.2	0.23	0.96	0.06
KPH fat, %	2.18	2.13	2.15	2.16	0.035	0.45	0.10
12th rib fat thickness, cm	1.52	1.57	1.57	1.55	0.04	0.70	0.40
LM area, cm^2	79.3	81.7	81.0	79.4	0.87	0.85	0.01
Marbling score[3]	439	441	449	460	9.2	0.03	0.47
Calculated YG[4]	3.47	3.40	3.45	3.50	0.057	0.50	0.25

[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IH; Merck Animal Health)
[3] 400 = small 00; 500 = modest 00; 600 = moderate 00
[4] Calculated using the following equation: 2.5 + (0.98425 x 12th rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2) (USDA, 2016)

Table 3.4. Effect of days on terminal implant on quality and yield grade distribution for heifers fed 181 d (Exp.1)

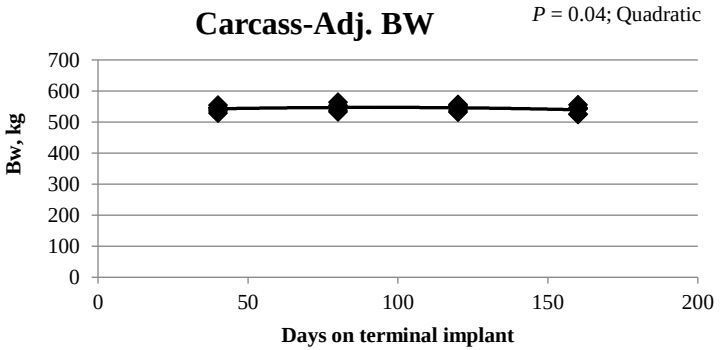
	Days on Terminal Implant[1]				
	160[a, x]	120[b, x]	80[a, x]	40[a, y]	P-Value
Quality Grade, %					< 0.01
Prime	1.8	2.0	2.2	3.9	
Choice	76.8	77.2	81.1	77.9	
Select	21.2	20.4	16.4	17.8	
No Roll	0.2	0.4	0.2	0.4	
Yield Grade, %					< 0.01
1	4.9	5.4	4.5	3.0	
2	22.5	26.0	22.4	23.7	
3	47.4	41.7	48.2	43.8	
4	22.4	24.3	23.0	26.5	
5	2.8	2.6	1.9	3.0	

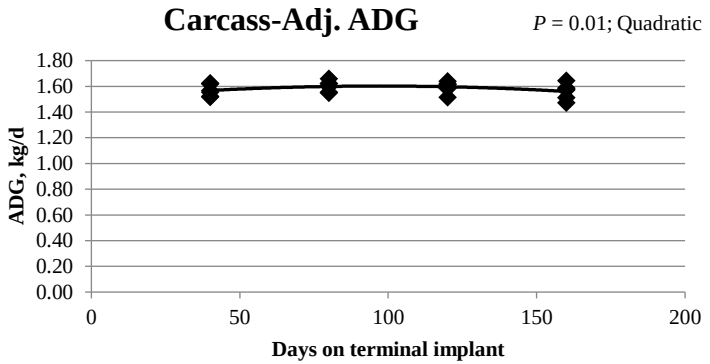
[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IH; Merck Animal Health)

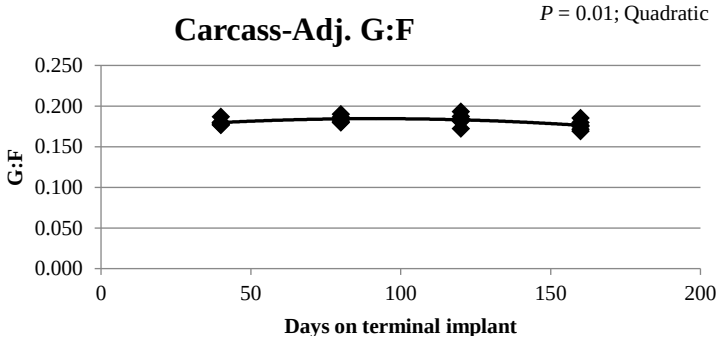
[a, b] Means without common superscripts differ ($P \leq 0.05$) for quality grade distribution

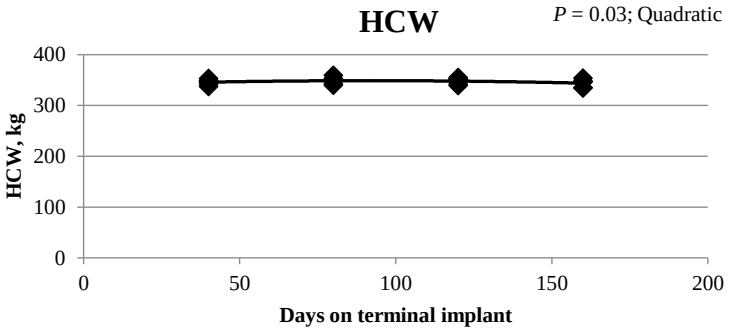
[x, y] Means without common superscripts differ ($P \leq 0.05$) for yield grade distribution

Figure 3.1 Response curves and equations of varying days on terminal implant for heifers fed 181 d (Exp. 1).









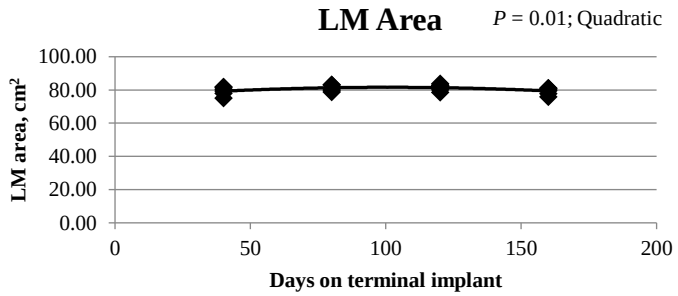


Figure Description: Response to days on terminal implant in heifers that were initially implanted with Revalor-IH (80 mg TBA + 8 mg estradiol; Merck Animal Health) and reimplanted with Revalor-200 (200 mg TBA + 20 mg estradiol) respective to treatment (160, 120, 80, or 40 days on terminal implant). A quadratic response ($P \leq 0.04$) was observed for carcass-adjusted final BW, ADG, G:F, HCW and LM area. When the first-derivative was solved, all variables were optimized between 88 and 103 DOT, with an average of 94 DOT.

Table 3.5. Quadratic equations for response variables when heifers are fed for 181 d (Exp. 1)

Response Variable	Equation	R^2-Value	Quadratic P-Value
Carcass-Adj. BW	$y = -0.00167x^2$ (±0.001305) – 0.31x (±0.2650) + 532.75 (±11.6212)	0.0847	0.04
Carcass-Adj. ADG	$y = -0.00001x^2$ (±0.0000608) – 0.002065x (±0.001235) + 1.5021 (±0.05414)	0.1295	0.01
Carcass Adj. G:F	$y = 0.00000174x^2$ (±0.00498) – 0.000317x (±0.000133) +0.1700 (±0.005835)	0.3002	0.01
LM Area	$y = -0.00063x^2$ (±0.000268) + 0.1272x (±0.05452) + 75.1992 (±2.3907)	0.2083	0.01
HCW	$y = -0.00104x^2$ (±0.000829) – 0.1942x (±0.1685) + 339.67 (±7.3885)	0.0847	0.03

Table 3.6. Effect of days on terminal implant on growth performance of steers fed for 180 d (Exp. 2)

	Days on Terminal Implant[1]						P-Values		
	160	120	100	80	40	SEM	Trt[2]	Linear	Quad
Live Performance									
Initial Weight, kg	330	330	331	331	330	1.4	0.70	0.41	0.96
Final Weight, kg[3]	657	667	672	667	659	4.8	0.17	0.32	0.05
ADG, kg	1.83	1.89	1.90	1.89	1.83	0.025	0.11	0.42	0.03
DMI, kg/d	11.8	11.9	11.8	11.7	11.4	0.09	0.01	0.18	0.93
G:F	0.155	0.158	0.162	0.161	0.160	0.0018	0.04	0.90	0.01
Carcass Adjusted Performance									
Final Weight, kg[4]	672	685	686	681	669	4.3	0.03	0.13	0.03
ADG, kg[5]	1.91	1.98	1.98	1.97	1.89	0.022	0.01	0.18	0.02
G:F[5]	0.161	0.166	0.169	0.168	0.165	0.0014	0.01	0.66	<0.01

[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IS; Merck Animal Health)
[2] F-test for effect of day on terminal implant
[3] Pencil shrunk 4%
[4] Carcass-adjusted performance calculated from HCW using a common dressing percentage of 63%

Table 3.7. Effect of days on terminal implant on interim growth performance of steers fed for 180 d (Exp 2)

	Days on Terminal Implant[1]								
	160	120	100	80	40	SEM	F-Test	Lin.	Quad.
Day 1-20									
DMI, kg/d	9.2	9.4	9.4	9.3	9.2	0.09	0.47	0.16	0.77
ADG, kg	1.54	1.62	1.78	1.54	1.49	0.114	0.48	0.13	0.32
G:F	0.168	0.172	0.189	0.167	0.162	0.0119	0.56	0.16	0.32
Day 21-61									
DMI, kg/d	11.2	11.4	11.1	11.3	11.0	0.14	0.42	0.99	0.96
ADG, kg	2.39	2.14	2.09	2.22	2.16	0.059	<0.01	0.12	0.09
G:F	0.213	0.188	0.188	0.197	0.195	0.0054	0.01	0.17	0.12
Day 62-81									
DMI, kg/d	12.6	12.1	12.3	12.4	11.9	0.15	0.04	0.92	0.35
ADG, kg	2.38	2.52	2.31	2.29	2.25	0.095	0.34	0.44	0.36
G:F	0.188	0.208	0.186	0.183	0.189	0.0077	0.16	0.43	0.17
Day 82-101									
DMI, kg/d	12.3	12.4	11.4	11.8	12.0	0.17	<0.01	0.35	<0.01
ADG, kg	1.67	1.89	1.78	1.58	1.47	0.100	0.06	0.03	0.95
G:F	0.135	0.152	0.155	0.134	0.122	0.0076	0.02	<0.01	0.23
Day 102-141									
DMI, kg/d	12.6	12.8	12.4	12.1	12.1	0.13	<0.01	0.01	0.12
ADG, kg	1.78	2.01	2.04	1.97	1.79	0.054	<0.01	0.09	<0.01
G:F	0.141	0.158	0.164	0.163	0.149	0.0039	<0.01	0.45	<0.01
Day 142-180									
DMI, kg/d	12.3	12.7	12.8	12.7	11.8	0.17	<0.01	0.14	<0.01
ADG, kg	1.22	1.23	1.45	1.52	1.65	0.082	<0.01	0.1	0.08
G:F	0.099	0.097	0.114	0.121	0.139	0.0063	<0.01	0.03	0.25

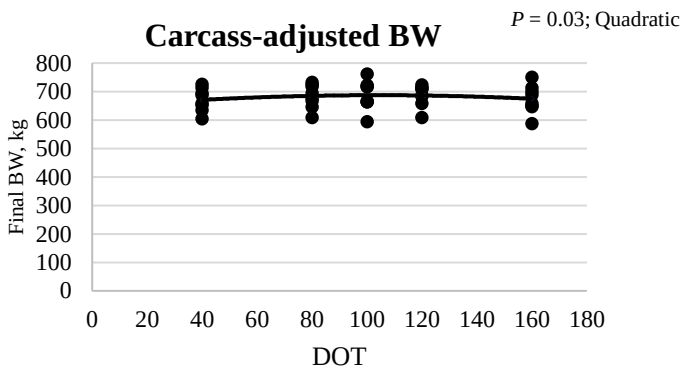
[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IS; Merck Animal Health). Terminal implants were administered on d 21, 61, 101, 121, and 141.

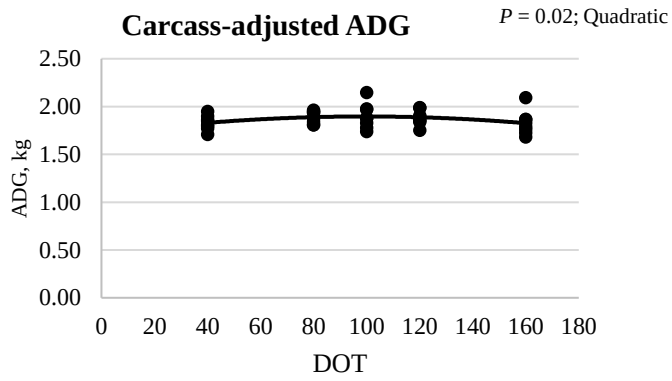
Table 3.8. Effect of days on terminal implant on carcass characteristics of steers fed for 180 d (Exp 2)

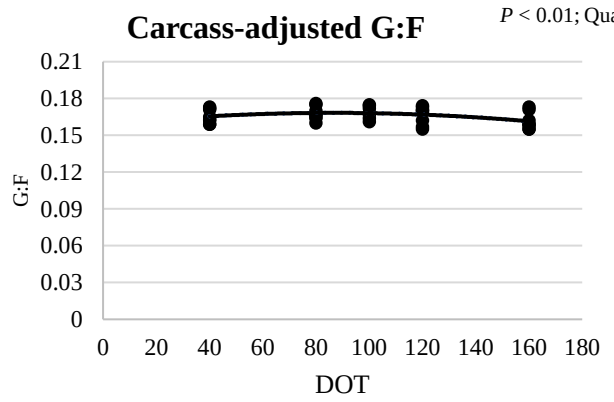
	Days on Terminal Implant[1]						P-Values		
	160	120	100	80	40	SEM	Treatment	Linear	Quad
HCW, kg	424	431	432	429	422	2.7	0.03	0.14	0.03
LM area, cm^2	88.4	90.3	91.6	89.0	89.7	0.52	<0.01	<0.01	0.09
Fat Thickness, cm	1.65	1.63	1.63	1.63	1.60	0.038	0.81	0.66	0.97
USDA marbling [3]	517	530	541	534	534	7.5	0.27	0.60	0.11
Calc. Yield Grade[4]	3.79	3.72	3.69	3.77	3.64	0.060	0.38	0.52	0.89

[1] Days on terminal implant (Revalor-200; Merck Animal Health) after initial implant (Revalor-IS; Merck Animal Health)
[3] 400 = small 00; 500 = modest 00; 600 = moderate 00
[4] Calculated using the following equation: Yield grade calculated using the following equation: 2.5 + (0.98425 x 12^{th} rib fat, cm) + (0.2 x 3.0 [KPH, %]) + (0.00837 x HCW, kg) – (0.0496 x LM area, cm^2)

Figure 3.2 Quadratic response and equations of variables across days on terminal implant for steers fed for 180 d (Exp. 2)







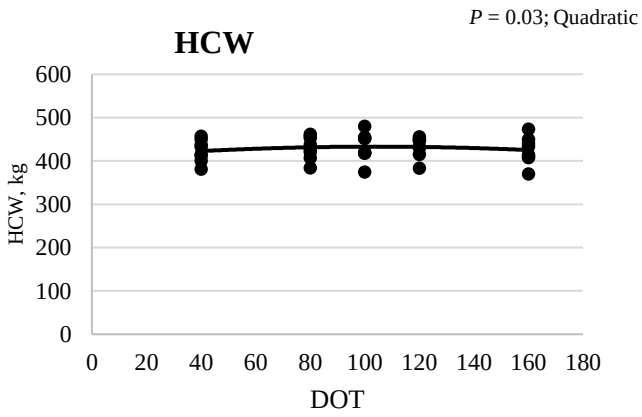


Figure Description: Response to days on terminal implant in steers that were initially implanted with Revalor-IS (80 mg TBA + 16 mg estradiol; Merck Animal Health) and reimplanted with Revalor-200 (200 mg TBA + 20 mg estradiol) respective to treatment. A quadratic response ($P \leq 0.03$) was observed for carcass-adjusted final BW, ADG, G:F, and HCW. When solved for the first derivative, DOT was maximized at 104, 99, 87, and 104, respectively.

Table 3.9 Quadratic equations for response variables when steers are fed for 180 d (Exp. 2)

Response Variable	Equation	R^2-Value	Quad P-Value
Carcass-Adj. BW	$y = -0.00401x^2$ (±0.001125) +0.8352 (±0.2596) + 701.80 (±11.7339)	0.0248	0.03
Carcass-Adj. ADG	$y = -0.0001906x^2$ (±0.0009277) – 0.0037804 (±0.001894) + 1.7087 (±0.0880358)	0.1027	0.02
Carcass Adj. G:F	$y = 0.00000128x^2$ (±0.000000577) – 0.00022x (±0.0001179) +0.1587 (±0.005479)	0.1581	<0.01
HCW	$y = -0.00252x^2$ (±0.0.002664) – 0.5251x (±0.5438) + 405.70 (±11.4725)	0.0247	0.03