INFLUENCE OF CORN CROP HARVEST ENDPOINT ON FEEDLOT PERFORMANCE, BEEF QUALITY AND SENSORY TRAITS, AND RETURN TO CORN LAND

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Abstract

Forty-nine Charolais x Red Angus steers (initial average BW = 536 kg) were fed individually in a Calan-Broadbent feeding system to evaluate performance and meat quality characteristics and interactions resulting from performance and crop yield when corn is harvested as either silage (SIL), earlage (EAR), high-moisture corn (HMC), or dry corn (DRC). Steers were randomly allocated to 1 of 4 dietary treatments where SIL, EAR, HMC, or DRC constituted 75% of diet DM. The remaining of SIL, EAR, HMC and DRC diets contained 11% haylage (0% for SIL), 10% modified wet corn distillers grains (MDGS), 4% liquid supplement with Rumensin (SUPP) and 11% DRC (SIL only). Gross return (gross \$/hd) was determined as dollars remaining after subtracting non-corn crop expenses (cattle purchase, veterinary medicine, yardage, bedding and purchased feed ingredients) from gross cattle sale. Value of each corn crop endpoint was determined from corn grain worth (\$/56 lb) and its relationship to corn grain content in SIL, EAR, and HMC crops. This value was compared to SIL, EAR, HMC worth determined by ANOVA (crop equivalent \$/bu). Value of each corn crop endpoint was also determined by dividing gross return (gross \$/hd) by hectares used to raise crop. The former method is used to determine corn crop endpoint worth for a feeder that purchases crops (owns no land) and the latter is used to determine corn crop endpoint worth for a feeder who owns corn land. Net return to corn hectares dedicated to cattle feeding during the last 18 years was 6.2 times greater than that realized through marketing corn through a local elevator. Cattle fed HMC had the lowest ($P \leq 0.05$) DMI (dry matter intake). Cattle fed DRC had greater ($P < 0.05$) ADG (average daily gain) than cattle fed the other corn crops. Cattle fed HMC had greater ADG ($P < 0.05$) than those fed SIL. No difference between cattle fed DRC or HMC was observed for feed conversion but feeding either led to greater ($P < 0.05$) feed conversion than SIL or EAR. Final BW (body weight) and HCW (hot carcass weight) were greatest for DRC ($P < 0.05$), intermediate ($P < 0.05$) for HMC and lowest ($P < 0.05$) for EAR and SIL. There was a tendency ($P = 0.08$) for treatment effect on fat thickness wherein cattle fed DRC or HMC tended to have greater fat thickness than those fed SIL. No treatment differences were found for REA (ribeye area) or marbling. Sensory panel evaluation of loin steaks demonstrated that steaks from steers fed either SIL or EAR were juicier ($P > 0.05$) than those fed HMC and that bologna samples from steers fed HMC were toughest and least juicy. There was no effect observed for equivalent value of corn crop ($/bu). Harvesting corn as either SIL, EAR, HMC or DRC had no impact ($P > 0.05$) on crop worth (gross $ return/hectare). Despite performance differences, all harvest end points dedicated to cattle feeding result in greater gross return to corn land than marketing corn through local channels. This permits greater flexibility in corn harvest end point decisions for cattle feeders.

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REVIEW OF LITERATURE

Introduction

Since WWII, crop and livestock segments of the US agricultural industry have become increasingly specialized. Specialization resulted in less diversification and, in some cases, a decoupling between production of crops and livestock. This disintegration of crop and livestock species has also led to a large increase in farm size in order to capture greater advantages in the market. In 1950 there were over 5.65 million farms in the United States with an average farm size of 86 hectares (USDA 1964). In 2016, farm numbers decreased to 2.06 million with double the farm size reported in 1950 (USDA NASS 2017). According to a compilation of census data from USDA-NASS gathered by Aguilar et al. (2015), the number of crop species per farm in the Midwest region declined by 19.3% between 1978 and 2012.

Loss of diversification and increase in size of farms led to a need for greater external inputs, particularly in synthetic fertilizer and pest control chemicals for crop farms and feed for livestock feeders, as well as more specialized equipment. Crop farmers spent an average of $12,331 per farm on fertilizer and soil conditioners in 2015 (USDA NASS 2016), while in 1971 only $1,111 was spent per farm for these products. Average yearly inflation rate accounts for only half of this increase. Nation-wide, the use of synthetic fertilizer has risen from 6.8 million tonne (metric ton) in 1960 to 19.8 million tonne in 2011, with a peak in 1981 of 21.5 million tonne. Total land in farms in the United States has decreased from 486 million hectares in 1950 to 369 million hectares in 2015. Although production efficiency has increased substantially during this time, current farm practices are utilizing nearly four times as much synthetic fertilizer per hectare compared to 1950. These facts have given rise to a growing public concern of the environmental impact caused by specialized operations. As a result, renewed interest in enhancing production diversity in farms is increasingly evident today. Many crop and livestock farms are beginning to utilize cover crops in an effort to restore soil quality properties, reduce chemical runoff, and even increase forage supply for cattle.

The Midwest region of the United States encompasses the Corn Belt, an area of the country that is known for its fertile soil which allows for abundant crop yields. The Midwest accounted for 26% of all agricultural commodities sold in the United States in 2007. Despite the perceived benefits of animal production in the Midwest, most cattle fed in the US are fed in southern states; where the environment is more favorable for growing cattle. Southern states such as Texas and Kansas have long dominated the cattle feeding industry. A dry climate is more favorable for feeding cattle as less rainfall results in less climatic stress on animals and a reduced threat of excessive runoff from livestock manure into waterways. The longer cold season and greater amount of precipitation found in the northern states can result in increased morbidity, mortality, and costs associated with bedding animals as well as increased energy requirements of the animal. Despite favorable environmental factors, cattle feeding has begun to shift further into the Midwest in recent years. Since 2001, the combined number of cattle on feed in Texas and Kansas declined by 14.6%. Meanwhile, cattle on feed in Nebraska, Iowa, and South Dakota increased by 12.9% over the same period of time (USDA NASS 2016). Additionally, Minnesota reached the top 14 states for cattle on feed in feedlots of 1,000 or more head in 2014 for the first time since 1995. A key factor in this shift northward is the availability of high-quality feedstuffs and co-products, particularly those produced from corn grain, that are present in the Corn Belt. As a result, the Midwest has seen an increase in integrated crop and livestock systems (farmer-feeders). Cattle feeding has the potential to continue to increase in this region as long as work continues to determine the most efficient, profitable, and sustainable end point for corn harvest in crop land that is designated for cattle feeding.

Agronomics

Three important factors must be considered when determining the most efficient end point for corn crop harvest: 1) yield per hectare, 2) cattle weight gain, 3) and feed efficiency for animal gain. However, soil quality properties must also be considered to ensure the long-term success of crop farming and cattle feeding in this region of the country. Harvest endpoints such as high-moisture corn (HMC) and dry-rolled corn (DRC) allow for maximum return of crop residue, while crops like earlage and silage do not return as much residue to the ground surface. Leaving crop residue on the soil surface has benefits as fertilizer and organic matter addition which permit a dollar value to be assigned.

Research conducted at the University of Nebraska Lincoln used the nutritive value of corn stover to assign a dollar value to the product as fertilizer(Wortmann, 2012). When utilizing corn stover as a roughage source or as bedding, its value can be calculated by determining the value it brings to soil as fertilizer source. Fertilizer value of corn residue left in the field is calculated by analyzing stover to determine nutrient composition and multiplying the value by cost of the corresponding fertilizer nutrient. In general, approximately 1 tonne (metric ton) of crop residue is produced per tonne of corn grain harvested per hectare (Wortmann, 2012). The relationship between tonne/hectare of grain and tonne of stover/hectare is explained by the DM proportion of corn grain to whole plant DM, which according to Ladely et al. (1991) and Johnson et al. (1966), corn kernel DM makes up 50% of whole plant DM. Aside from soil quality benefits associated with crop residues, the opportunity to use crop residue as bedding and/or roughage contributes to integrating crop and cattle feeding operations, especially in the upper Midwest where bedding of barns or open pens is required.

Determining the amount of corn residue to remove from corn land involves complex interactions between soil variety, tillage type, field terrain, yearly precipitation, and cropping system. Sufficient research has been conducted in recent years to guide decision making for this process. Coulter and Nafziger (2008) and Sindelar et al. (2013) evaluated effects of residue removal and tillage system on corn grain yield and economically optimum N rate (EONR) for the following year in continuous corn (CC) cropping systems. Sindelar et al. (2013) discovered an increase in grain yield by 7 to 24% when stover was removed across all tillage systems. These results were in close agreement with those of Coulter & Nafziger (2008) who reported a 12% increase in grain yield for no-till (NT) systems with full residue removal, but no increase in yield for chisel-tillage (CT) system with residue removal. These results are due in large part to increased soil temperatures and less ground coverage of residue allowing for better seed emergence conditions, which are often a limiting factor in the upper Midwest.

Additionally, in regards to nitrogen requirements, Coulter & Nafziger (2008) found that stover removal in CC systems decreased EONR by 11% and Sindelar et al (2013) determined that when no residue was removed, EONR increased by 13%. This effect is likely caused by increased N immobilization in response to greater incorporation of corn residue. High C:N ratio of corn stover causes residue to break down at a slower pace, leading to reduced levels of available N for the new plant. Results from a thirteen year study conducted by Linden et al. (2000), evaluating corn grain and stover yields as affected by tillage practice and residue removal, found that removal of all residue had little effect on yield long term. Decreased yields were found for residue removal systems during dry years. However, no effect on yield was seen during years with normal rainfall. Yield reduction during dry years was likely a result of reduced organic matter and water holding capacity of the soil. However, manure application to corn land by farmer-feeders may offset this organic C loss as a result of residue removal (Sindelar et al., 2013).

Perhaps the greatest benefit of farmer-feeder operations is the ability to maximize nutrient cycling by incorporating the fertilizer value of manure. Characterizing nutrient composition of livestock manure presents a unique challenge due to variability in diet composition and manure storage method, and nutrients must be characterized before application to comply with EPA standards. Generally, 80% of manure P is present in the settled solids of manure and is insoluble, while N is split nearly equally between solid and liquid fractions (Lorimor et al., 2008). Nitrogen present in the liquid fraction of manure is soluble and thus, vulnerable to volatilization as ammonia. Precise application of manure to corn land can be as effective as synthetic N fertilizer for improving crop yield without negative effects on ground water quality (Zhang et al., 1998). However, N content of manure decreases at a rapid rate, especially in liquid or slurry type manure, due to volatilization of soluble N in the form of ammonia. Urea contained in urine is the primary source of ammonia, which typically accounts for 52% of N in manure (Killorn, 1995).

Crops require N and P at a 5:1 ratio, however cattle manure used as fertilizer typically has a 2:1 N to P ratio (Erickson et al., 1998). To ensure environmentally responsible application of cattle manure, P application rate should be used as the basis for application rather than N application rate; additional N may need to be added to the crop. Results from Zhang et al. (1998b) suggest that manure should be applied to crop land at total N (TN) rate double that of TN rate for urea fertilizer to achieve similar yields because urea N is primarily in the inorganic form. However, this is not a best management practice as P was most likely over-applied. When applying beef cattle manure, it is important to consider only 30% to 40% of total N present at application is in the inorganic form, and readily available to the crop over the first year. Through mineralization of organic N over the second and third year, 10% and 5% of N applied the first year is still available to the crop, respectively (Killorn, 1995). Therefore, if manure is applied to a field for 3 consecutive years, by the third year an additional 15% of N will be available to plants beyond the fertilizer value of the manure at time of spreading (10% from year 2, 5% from year 1 application); thus, making it important to consider adjustment in N value using application rates of previous years.

Integrated crop and livestock systems have had great success in improving soil properties and net return to farms. Anderson and Schatz (2002) reported that farm net worth was increased by nearly $9,000 per year for farms with crops and beef cows compared to farms with only crops grown. Ability of beef cows to utilize crop residues for feed without affecting soil properties plays a large role in increased net worth. A primary concern of cattle grazing crop residues or cover crops is the amount of soil compaction that occurs and its effects on crop yields in subsequent years. A two year, farm-scale study conducted by Tracy and Zhang (2008) evaluated the effects of an integrated crop and livestock system of soil compaction and crop yield. They found no consistent trend between cattle grazing and increased soil compaction; however, the data did suggest that grazed cropland may show increased compaction during dry years. Their study determined that if any soil compaction did occur, it was made null by spring cultivation. Subsequently, a numerical increase in soil compaction was found for cropland with cattle presence compared to continuous corn cropping systems. A 4-year study conducted by Maughan et al. (2009) also found no negative impacts on soil compaction or quality and determined that corn yield was increased through the addition of winter cover crops grazed by cattle over the continuous corn system.

Corn Harvest Endpoint

Traditionally, cattle have been fed a ration containing high grain concentration because of lower cost per unit of energy in comparison to that of forages. Corn grain is comprised of approximately 72% starch. Typical feedlot diets are composed of 75% or more grain, making starch the primary energy source for cattle. As technology and research progressed through the history of cattle feeding, more extensive processing methods have been realized to provide substantial increases in performance and feed efficiency of cattle. According to Owens et al. (1997), any processing method that reduces particle size or alters the protein matrix that encapsulates starch granules achieves greater starch utilization by the animal. Increased gain and efficiency will be achieved so long as the increased rate of fermentation does not cause a drastic drop in rumen pH and lead to acidosis (Fulton et al., 1979). The effectiveness of processing corn to increase its nutrient availability is supported by Ladely et al. (1995), who determined that grain processing method has a 66% greater impact on feed efficiency than that of corn variety when comparing three corn hybrids of varying rates of in vitro starch disappearance processed as either DRC or HMC.

Many integrated crop and livestock famers (farmer-feeders) benefit from harvesting field corn at different harvest endpoints to spread out their harvest time. This greatly reduces the amount of field drop, or damaged ears that fall off the plant due to environmental conditions, which frequently increases with time as the crop dries down prior to harvest. Farmers commonly utilize extended field drying time to reduce energy costs of further drying harvested corn before storage. However, increasing time spent in the field significantly increases field drop losses due to wildlife and environmental conditions. By harvesting the crop as earlage or HMC, at approximately 25 to 40% moisture, farmers can reduce this field drop by up to 8% (Mader, et al., 1974).

Whole plant corn silage is a commonly utilized feed ingredient in livestock operations, especially for dairy producers. Within feedlots, silage is not utilized as a high energy feed source as many grain crops are, but rather is fed to cattle primarily as a roughage source. Silage is considered a quality source of effective neutral detergent fiber (eNDF) which in addition to aiding in reduction of the incidence of digestive disorders, also has a greater digestibility than comparable eNDF sources such as straw, low quality hay, or corn stalks. By harvesting the whole plant roughage in addition to the kernels, increased dry matter yields per hectare are a major advantage of silage compared with dry corn harvest.

Corn hybrid, maturity at time of harvest, and environmental conditions all affect nutrient composition of corn silage, earlage, HMC, and DRC. As the corn plant matures, starch content increases while fiber digestibility decreases. Feedlot producers may benefit from slightly delaying silage harvest to take advantage of further starch accumulation in the kernels, while dairy producers would likely benefit from harvesting slightly earlier to take advantage of greater fiber digestibility. Depending upon feedstuffs available to producers, harvest time will vary based on ration needs.

High moisture ensiled corn and earlage are two other commonly harvested feeds that offer higher energy relative to silage but have been shown to have variable feeding values. Over the years, researchers and feeders determined proper harvest techniques to maximize potential feeding value of these variable crops. Research conducted by Plegge et al. (1985), Hanke et al. (1986 and 1987), and Owens & Thornton, (1976) evaluated the effect of moisture, and thus maturity, on cattle performance for earlage and HMC.

The primary benefit of processing and ensiling grain is to improve starch availability of corn grain by reducing particle size, thus exposing starch granules, and to allow feed to ferment which will gelatinize starch granules and disrupt the protein matrix encapsulating the granules. Other advantages include increasing yields, greater palatability, elimination of drying costs, additional highly digestible fiber in earlage, and extended residue grazing seasons for both feeds; especially in the upper Midwest where more snowfall occurs. Possible disadvantages of these feeds consist of greater inventory carrying cost, potential for excessive spoilage if proper storage practices are not employed, and variable fermentation and nutrient profiles which require greater attention from nutritionists.

Earlage is a broad term that describes the corn crop that follows silage harvest time frame and is harvested as 1) ensiled corn grain, cobs, husks, and in some cases, the upper portion of the stalk often referred to as snaplage or 2) only the corn grain and cob which is referred to as high-moisture ear corn (Lardy, 2016). Although the time frame for harvesting earlage fits nicely between silage and dry corn harvest, there is only a short window of opportunity for successful crop harvest. According to Mahanna (2008), earlage should be harvested and stored at 35 to 40% whole plant moisture. At this point, the corn plant has just reached full maturity, or blackline stage, and the plant will lose moisture at a rate of approximately 0.5 to 0.8% per day. This dry-down rate can be as high at 1% per day in dry environments or if a hard freeze occurs (Mader & Rust, n.d.), giving a harvest window of approximately 5 to 12 d. According to Ma & Dwyer (2001), late-maturing varieties of corn will dry down at a faster rate as they near maturity compared with early-maturing varieties. The most accurate method for measuring crop moisture for earlage harvest is by testing the kernel moisture. Kernel moisture provides a more consistent moisture reading compared to testing the whole plant moisture which has been found to vary with environmental conditions and corn hybrid. It is recommended to not harvest earlage at less than 28% kernel moisture as whole plant moisture will generally read 5% higher than kernels (Mahanna, 2008).

Harvesting earlage at optimum moisture will ensure that starch content is maximized, while enough moisture is still present for the fermentation process to fully proceed, ensuring greater cob digestibility. Earlage can be stored in a variety of silo types and, similarly to silage, it should also be inoculated, packed, and covered when it is stored. Benefits of harvesting earlage for cattle feeding over harvesting dry corn include 10% to 20% greater DM yields per hectare (depending on harvest technique and equipment used) compared with dry or high moisture corn. Further benefits include increased digestibility due to fermentation of corn grain and roughage fractions, and reduced ensiling time required compared with silage or high moisture corn when harvested at recommended moisture levels and stored properly. Added sugars from the cob, allow earlage to be fully fermented in as little as 2-3 weeks (Mahanna, 2008).

High moisture corn is more commonly harvested than earlage but harvesting high moisture corn can lead to issues with consistency at feed-out. Factors such as moisture concentration at storage, kernel particle size, and method and length of storage can affect quality of grain at feedout (Teeter et al., 1979); (Goodrich et al., 1975). There is a large amount of interest in feeding HMC due to its high feeding potential, yet the research community is still working to understand factors affecting quality. The primary benefit of harvesting and feeding HMC is that as moisture content increases, the digestibility of the grain will increase as well: recommended moisture concentration of HMC at harvest overlaps with the low range of harvest moisture for earlage. An adequate range for corn moisture at harvest is between 25% to 33% (Mader & Rust, n.d.), however, a more optimum range of 29% to 31% should be targeted (Owens et al., 1999).

Depending upon moisture content, corn processing techniques may differ in order to ensure complete fermentation of the grain during storage. If high moisture grain is being harvested at lower moisture (23% to 26%), it is especially critical to grind corn rather than rolling it at ensiling based on feed conversion and corn ME values found in a review by Owens et al. (1997). Grinding will result in smaller particle size which allows for greater starch exposure during ensiling. Length of HMC storage can also impact digestibility of the grain. Benton et al. (2005) found that in situ starch disappearance in the rumen increased substantially in the first month of storage and continued to increase as storage time increased to eight months, especially for drier corn. These results suggest that feeding management of HMC should be adjusted so that grain harvested first (typically higher in moisture) should be fed first (Fred Owens, n.d.). Increased risk of spoilage and storage loss is a possible limitation of harvesting corn crop as HMC compared to DRC (Mader & Rust, n.d.). In addition, harvesting corn as HMC reduces marketing flexibility and increases inventory carrying costs.

Feeding dry rolled corn is perhaps the most flexible method of handling corn for cattle feeding. Dry field corn can be harvested at any time after physiological maturity, although it should not be harvested until it is further dried in the field. To reduce field and harvest loss corn should be harvested above 20% moisture, but below 25% to prevent excessive moisture levels which, as mentioned earlier, greatly increase artificial drying costs. Dry corn can be marketed at harvest or stored long periods of time with minimal loss before being rolled, ground, steam flaked, or even reconstituted according to feeding needs. Additionally, there is potential for less inventory carrying costs and dry corn that is not fed can be marketed through local channels. In addition, data from some studies suggest that there is no economic benefit to rolling or cracking corn with an added cost of 5% to 10% (Loerch and Gorocica, 2006). A review conducted by Owens et al. (1997) found that there was no advantage in body weight-adjusted ME of the grain when fed as whole or ground corn. This would suggest that feeding corn whole may be beneficial as no additional processing costs would be present. Multiple sources suggest this may be the case for younger cattle which typically chew feed more thoroughly, while heavy cattle have greater gain when fed cracked corn (Owens et al., 1997 and Gorocica and Loerch, 2005).

Energy content of corn endpoints

The feeding value of feedstuffs is composed of three factors: nutrient content, digestibility, and intake. The primary benefit of processing grain is to improve starch availability and digestibility of the corn grain. Particular processing methods aim to efficiently enhance digestibility and palatability without adversely affecting ruminal pH, causing digestive disorders. In addition to site and extent of digestion, rate is also important, especially with high starch diets usually found in the feedlot industry. When starch rapidly ferments in the rumen, such as that seen with HMC above 30% moisture, rapid production of organic acids will cause a rapid decrease in rumen pH. This in turn lowers DMI due to either the development of digestive disorders or chemostatic controls of satiety. Increased rate and extent of digestibility may lead to negative consequences as increased digestibility leads to an increase in acid production in the rumen, and thus a higher chance of developing sub-acute acidosis. Acidosis, even in mild presentation, leads to depressed feed intake which may limit gains thereby reducing efficiency expected with HMC. Consequently, lowered average daily gains are expected for cattle fed rapidly fermenting grains, but lower intakes than expected may result in greater feed conversion efficiency.

Site of digestion influences the energetic efficiency of feeds. In a review by Owens et al. (1986), it was estimated that cattle are 42% more efficient in utilizing starch digested in the small intestine or abomasum compared to the rumen. However, it is difficult to utilize increased starch digestion in the small intestine because any process that would allow for starch to pass through the rumen undigested will likely cause a greater amount of starch to pass to the large intestine where further digestion cannot compensate for reduced ruminal fermentation. Fermentation of starch in the large intestine requires degradable protein for microbial digestion, thus processed grains that are not fermented in the rumen do not increase NEg utilization by the animal (NRC 2016).

Macken et al. (2006) reported improvements in dietary NEg of 10.3% for high moisture corn over dry rolled corn. This is substantially higher than values found by Owens et al. (1997) who determined only 4.5% increase in observed ME in a review of 605 comparisons. The findings of Owens et al. (1997) are in line with those of the NRC

(2016) which report an increase of 3.2% in ME and 4.5% in NEg when comparing HMC to DRC. The large variation in feeding value of high moisture corn can likely be attributed to large differences often seen in processing and storage methods (Stock et al., 1991).

Moisture content at storage is shown to be a primary factor affecting the feeding value of fermented grain at feed-out time; rate and extent of fermentation during storage will be affected. Goodrich et al. (1975), Plegge et al. (1985), and Hanke et al. (1987) determined that daily gain and feed efficiency are highly correlated to grain moisture. When harvested, processed, and stored at optimum conditions, high moisture corn is as digestible as steam flaked corn at 98 to 99% of total tract starch digestion (Stock et al., 1987). Benton et al. (2005) determined that as moisture content at harvest increases, rate and extent of starch digestibility also increase., Total tract starch digestibility of HMC grain reached 99.2% when HMC was stored at optimum moisture (approximately 30%) (Owens and Zinn, 2005). This is much higher than starch digestibility for DRC, at 89.3%, but similar to steam-flaked corn at 99.1% (Table 2). In a feeding trial, Stock et al. (1991) reported less of a difference in total starch digestibility between HMC and DRC at 97.8% and 92.8%, respectively. Reduced starch digestibility in the former trial is likely due to lower moisture of the ensiled corn at only 27.2% moisture. This moisture level is lower than the recommended optimum moisture content of 29% to 31%. Results from Owens et al. (1997) indicate that when HMC is ground at moisture greater than 27%, ME of the grain increases by 8% and feed conversion is improved by 10.8% compared to DRC. This indicates a greater percent of starch is digested by the animal as moisture increased.

Feedlot performance of corn endpoints

Feed intake is the primary driver of cattle performance. Main factors that determine feed intake are: 1) palatability of the feed 2) physical limitation or gut-fill and 3) chemostatic control which is prevalent in high concentrate diets. An additional issue that can influence intake is the presence of digestive disorders often caused by reduced rumen pH that is associated with rapid digestion of starch found in high concentrate diets. Cattle fed HMC have a higher incidence of subacute ruminal acidosis due to the rapid rate of starch fermentation in the rumen, causing fluctuations in day-to-day feed intake. Fulton et al. (1979) concluded that cattle will reduce intake to maintain rumen pH between 5.5 to 5.6. This is a key reason that performance results of trials from steers fed high moisture corn are so variable.

A primary attraction of HMC is the improved feed efficiency that is often achieved. According to Owens and Thornton (n.d.), for every one point increase in corn moisture content above 23%, energy value of HMC is increased by 0.3%. This is supported by Soderlund (n.d.) who determined that HMC with greater than 27% moisture resulted in a decrease of 0.24 kg of dry matter required per kg of gain and by Owens et al. (1997) who found an improvement in feed conversion of 10.8% at the same moisture range. Owens and Thornton (n.d.) also stated that there is a 1% decrease in feed intake for every 1% increase in moisture content past 24%. Because cattle intake decreases at a faster rate than feed efficiency increases, reduction in ADG is often encountered. Values reported by Owens et al. (1997) support this interaction, with DRC having a 7.7% greater feed intake and 5.5% greater ADG compared with HMC. However, in this same review there was no difference in feed conversion between the two processing methods. This suggests that feeding DRC is more advantageous than HMC to achieve greater weight gain, but greater DMI is expected and therefore limited effect of feed conversion is observed. Vander Pol et al. (2008) conducted a study that compared DRC and HMC with the inclusion of wet distillers grains with solubles and found the two processing methods resulted in similar weight gain and feed efficiency. Macken (2006) reported that there was no difference in rate of gain, but HMC fed cattle gained more efficiently than those fed DRC when wet corn gluten feed was included in the diet.

Performance data for cattle fed earlage is limited, possibly due to earlage not supplying enough energy to be fed at inclusion levels in the diet often seen of corn grain. Unlike silage, earlage can provide high concentrations of energy as well as sufficient fiber in the diet compared to DRC. Hanke et al. (1986a) evaluated the effectiveness of utilizing high moisture snapped ear corn (SEC) in place of silage as a roughage source in high concentrate diets formulated at similar ADF concentrations. They found that SEC resulted in similar DMI, ADG, and feed conversion values. These results could vary greatly between trials or producers depending on how the diet is formulated because the concentration of ADF and NDF present in earlage is highly dependent on moisture content of the feed at time of storage. Results from Hanke et al. (1986b) showed that as plant dry matter increased from 61.5% to 86.9%, ADF and NDF concentrations increased by 39.3% and 40.8%, respectively. Concentration of NDF and ADF increased as the plant matured due to the accumulation of lignin in the cell walls (Figure 3).

High fiber concentration of earlage prevents it from being fed as the only energy source in high concentrate finishing diets, especially when harvested at lower moisture concentration (greater maturity). When earlage was fed at 96% of diet DM in two trials conducted by Hanke et al. (1985), ADG and DMI decreased, and cattle tended to be less efficient. This could be due in part to the fact that SEC in this study was harvested at only 27.5% (much lower than the recommended 35% to 40%) and had high NDF and ADF concentrations of 42.5% and 18.5%, respectively. Values of NDF and ADF concentrations reported by NRC (2016) are only 21.0% and 9.9%, respectively.

Hypothesis

Marketing corn grain through cattle feeding is a more profitable alternative to direct marketing of corn crop through a local elevator. Thus, we hypothesized that the corn harvest endpoint which results in greatest yields and/or results in the most efficient feed conversion will lead to greatest gross return to corn land.

Objectives

Objectives of the current study were to identify interactive effects of corn yield and feed conversion on gross return to corn land and meat quality characteristics of beef by evaluating four corn harvest endpoints.

Chapter II

INFLUENCE OF CORN CROP HARVEST ENDPOINT ON FEEDLOT PERFORMANCE, BEEF QUALITY AND SENSORY TRAITS, AND RETURN TO CORN LAND

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MATERIALS AND METHODS

All animal use procedures were in compliance with the University of Minnesota Institutional Animal Care and Use Committee. Steers in this experiment were housed at the University of Minnesota's Beef Research and Education Complex located in UMore Park (Rosemount Research and Outreach Center; ROC), Rosemount, MN.

Cattle

Forty-nine Charolais-Red Angus steers (initial BW 536 ± 29kg) were utilized in a 108-d completely randomized design finishing experiment. Initial BW was recorded after a 16-h shrink during which steers were not allowed access to feed or water.

Corn Endpoint Harvest Procedure

Corn-endpoint ingredients were harvested from a single field by ROC staff as part of a separate corn component nutrient characterization study conducted by Hohertz et al. (2015). Harvest of corn endpoints was conducted in the fall of 2014, following guidelines of Mueller et al. (1991) and Lardy and Anderson (2010). Corn harvest yields and characteristics are found in Table 1.Scouting of corn plots began at approximately stage 4 of development and occurred weekly. Corn silage and earlage were harvested using a John Deere 7280 self-propelled forage harvester, 6-row header, with harvest beginning 39 and 56 d following silking, respectively. Harvest of HMC and dry corn was conducted using a John Deere S660 combine, 6-row header, and began 70 and 86 d following silking, respectively. Harvest of each ingredient endpoint was performed in contiguous rows at one location in the field. More passes were required as endpoint progressed from corn silage to earlage, and then to corn grain (HMC and DRC) to achieve desired DM yields of each crop. At time of harvest, HMC and DRC were rolled as they were fed into silo bags. All feedstuffs were stored using bag silos until initiation of the experiment in May of 2015.

Treatments and Design

Due to the Calan gate system utilized in this study, requiring cattle be fed by hand, total mixed rations were mixed every two days and stored on a feed pad under roof in close proximity to the bunk line. Because rations were mixed and stored for two days at a time and it being summer, a preservative (MYCO CURB, Kemin, Des Moines, IA or MoldX was added to total mixed rations. Steers were fed dietary treatments once daily at 0730 h. Intakes were adjusted according to amount of feed refused from the previous day's feeding and recorded to determine daily DMI. Along with daily collection of feed refusals, dietary feedstuffs were sampled following mixing of total mixed rations every two days. All feedstuff and feed refusal samples were frozen and stored until laboratory analysis. Steers were implanted with Revalor-XS (Merck Animal Health, Madison, NJ) on d 28. Cattle were fed Optaflexx (Ractopamine hydrochloride, Elanco Animal Health, Greenfield, IN) during the last 28 d of the experiment.

Steers were randomly assigned to 1 of 4 dietary treatments and were individually fed to the nearest 0.05kg in a Calan Broadbent system (American Calan, Inc., Northwood, NH). Dietary treatments were formulated to contain 75% of silage, earlage, HMC, or DRC while the remainder of the diet consisted of MWDGS (modified wet distillers grains with solubles), grass silage, non-crop originated corn (treatment 1 only), and liquid mineral supplement added to provide steers with 281 mg monensin/steer/d

(Rumensin, Elanco Animal Health, Greenfield, IN). Feedstuff and diet nutrient composition values from throughout this experiment (based on weighted composites) are listed in Tables 2 and 3, respectively. Additionally, dietary feedstuff inclusion achieved after weighing contribution of each load mixed throughout the study and respective dietary nutrient compositions consumed (corrected for weighted nutrient composition of feed offered and refused) are listed in Table 4.

Sample Analysis

Prior to laboratory analysis, feedstuffs and feed refusal samples were dried in a forced-air drying oven (Blue M Electric, Thermal Product Solutions, New Columbia, PA) at 60˚ C for a minimum of 48 h. All samples were then ground to pass through a 2-mm screen using a Thomas Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ). Total weight of all feed refused per steer was determined, then each individual feed refusal sample was composited based on individual percentage of total feed refused in order to obtain one composite sample of feed refused per steer. Feedstuff ingredients were composited by weigh period (28 d). Total amount of each feedstuff loaded for mixing in each steer weigh period was determined, and each individual feedstuff amount was then composited based on individual percentage of the total feedstuff loaded in order to obtain a single composite for each weigh period.

Feed refusal and feedstuff composites were mixed and prepared for nutrient composition analyses. Individual samples were analyzed for CP (Method 992.15; AOAC, 1995), NDF (Van Soest, Robertson, & Lewis, 1991), ADF (Method 973.18; AOAC, 2000), and EE (Method 920.39, AOAC, 2000). For CP analysis, all samples were prepared and shipped to an outside lab (University of Florida – North Florida Research and Education Center, Marianna, FL) to be analyzed following the procedure of Ciriaco et al. (2015). All other sample analysis was conducted on campus (University of Minnesota – Haecker Hall, St. Paul, MN). Neutral Detergent Fiber analysis was conducted utilizing an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY), where samples were extracted for 75 min at 100̊ C in NDF solution with heat-stable α-amylase. Prior to NDF analysis, samples that contained EE concentrations greater than 5% (MWDGS, DRC, HMC, earlage, and feed refusals) were pre-extracted following biphasic extraction procedures (Bremer et al., 2010). This procedure was utilized to increase the accuracy of NDF determination. At the completion of analysis, samples were dried overnight at 100 ˚C (Thelco 130DM, Precision Scientific, Chicago, IL), then weighed and NDF percent was calculated. Acid detergent fiber was then analyzed utilizing the same procedure as NDF; however, ADF solution was used instead, and α-amylase was not utilized. Samples were analyzed for EE concentration using an Ankom^{XT10} Extraction System (Ankom Technology, Macedon, NY) for 60 min at 90˚ C with petroleum ether.

Cattle Harvest Processing

On d 109, final BW was recorded after a 16-h shrink period with no access to water or feed. Steers were then housed and fed a common diet for an additional 4 d before being shipped to a commercial abattoir (Tyson Fresh Meats, Inc., Dakota City, NE) to reduce the effect of gut-fill and were harvested the following morning. On day of harvest, HCW and KPH measurements were recorded. Following 48 h of chill, REA, fat depth, and marbling measurements were also recorded. Individual steer performance and carcass characteristics evaluated include initial and final BW, BW gain, DMI, ADG, feed conversion, HCW, dressing percent, marbling score, REA, 12th rib fat thickness, KPH, and USDA Yield and Quality grades. Yield Grade was calculated using the USDA Yield Grade equation: [$YG = 2.5 + (0.98425 * 12^{th}$ rib fat thickness, cm) + (0.20 * KPH%) + (0.00837 * HCW, kg) – (0.0496 * LM area, cm^2)] (Boggs & Merkel, 1993). Carcass adjusted final BW, ADG, and G:F were calculated from HCW using the common dressing percentage of the group (62.6%).

Fresh Beef Fabrication and Collection

Fresh beef primals were fabricated 48 h after harvest by plant personnel according to Institutional Meat Purchasing Specifications (IMPS). Strip loins (IMPS #180) and shoulder clods (IMPS #114) were removed from the right side of the carcass and identified individually by carcass tags cross referenced to live animal visual identification ear tags. The strip loins and shoulder clods were vacuum sealed, cooled, and transported to the Andrew Boss Laboratory of Meat Science on the St. Paul Campus, University of Minnesota. Upon arrival, shoulder clods were inspected to ensure proper sealing and resealed if needed, refrigerated and stored until analysis. Strip loins were processed immediately after arrival.

Strip Loin Preparation and Analysis

Upon arrival, strip loins were evaluated for vacuum purge loss after transport and before fabrication. To determine moisture loss, packaged loins were weighed before opening the package. The loin was opened and removed from the packaging and both were patted dry. Loin and package were then weighed again separately.

Vacuum purge loss (VPL) % = [(initial combined weight – loin dry weight – package weight) / Initial combined weight] * 100

Strip loins were faced on the anterior end perpendicular to the length of the loin. A 50 g backfat sample was collected from the anterior end of each loin before cutting. Six objective color readings (L*, a*, b*; Hunter Lab Miniscan EZ model 4500S, Reston, VA) were taken from each loin. The samples were then vacuum packaged, frozen, and stored at -20 ^{o}C. Seven steaks were serially cut to 2.54 cm thick (automatic slicer, MHS Schneidetechnik GMBH, Abstatt, Germany). The first steak was immediately utilized for drip-loss analysis, second and third for retail shelf-life, fourth and fifth for sensory panel analysis, and the sixth and seventh for cook-loss and Warner-Bratzler shear force analysis.

Drip-loss evaluation was conducted by taking initial weight of each steak. A large paper clip was inserted through one end of the steak to hang for 12 hr. A one-gallon Ziploc bag was paced over the steak and zipped shut to prevent excessive air drying. The steak was then weighed after 12 hr to find % of moisture loss.

Two serially cut steaks from each loin were weighed, (Ohaus Navigator XL, Parsippany, NJ) wrapped in aluminum foil, and cooked (Whirlpool RF263CXTB, Benton Harbor, MI) at 177 ^{o}C to an internal temperature of 71 ^{o}C when measured with a temperature probe (Thermoworks Super-Fast Thermopen, American Fork, UT) at the geometric center of the steak. Steaks were allowed to cool to room temperature before they were re-weighed to calculate percentage cook loss. Cook loss% = [(raw weight – cooked weight) / raw weight] * 100. Steaks were refrigerated at 2 ^{o}C for 24 h and then allowed to come to room temperature (approximately 25 ^{o}C). Steaks were trimmed to only include the longissimus dorsi muscle. Six muscle cores of 1.27 cm in diameter were removed in a parallel direction to the muscle fibers of the steak using a hand corer. Cores were then sheared perpendicular to fiber direction using a texture analyzer with WBSF attachment set to a test speed of 100 mm/min ((Shimatzu Texture Analyzer, Model: EZ-SX, Kyoto, Japan). The average of all 6 cores was taken as a representation of entire loin tenderness.

To evaluate retail shelf life, duplicate steaks were placed on polystyrene trays with polyvinylchloride (PVC) overwrap (oxygen transmission rate 1400 cc/m^2) and stored under cool white fluorescent lighting (Sylvania H968, 100w, 2, 640 LUX) at 2 ^{o}C for seven days. Objective color values (CIE, L*, a*, and b*) were taken every 24 h at three locations on each steak (Hunter Lab Miniscan EZ model 4500S, Reston, VA). Subjective score of lean color, surface discoloration, and overall appeal were evaluated by 15 trained panelists. Panelists evaluated samples every 24 h for 7 d. Lean color was evaluated on a scale of 1 to 8 with 1 being extremely brown and 8 being extremely bright red. Surface discoloration was evaluated on a scale of 1 to 11 with 1 being 91% to 100% discoloration and 11 being 0% to 10% discoloration. Overall acceptability was evaluated on a scale of 1 to 8 with 1 being extremely undesirable and 8 being extremely desirable (AMSA, 2012).

In preparation for the beef steak sensory evaluation, steaks were thawed at 2^{o}C for 48 h. Once thawed, steaks were individually wrapped in aluminum foil and cooked to an internal temperature of 71^{o}C. Temperature was measured by a temperature probe (Pyrex Professional Acurite Thermometer; Racine, WI) placed in the center of the steak, within a standard electric kitchen oven (General Electric® Range, JAS02; Fairfield, CT) heated to 177^{o}C. When fully cooked, the longissimus dorsi muscle was removed and cut into bit-sized cubes (1cm x 1cm x 2.54cm) and transferred into double boilers to keep the samples warm until distribution to panelists.

One hundred thirty-two panelists were recruited by the University of Minnesota Food Science and Nutrition Sensory Center to participate in a fresh beef steak sensory evaluation. Participants were at least 18 years of age, untrained, had no food allergies, and had consumed beef in the last month. Panelists were compensated for their time. The University of Minnesota Institutional Review Board approved the procedures used for utilizing human subjects for consumer panel evaluation of sensory attributes. Panelists received 2 pieces of each sample in 60 ml plastic cups with lids. Panelists were given directions to consume one piece of steak and evaluate it for overall liking, liking of flavor, and liking of texture. They were then directed to consume the second piece of steak and rate toughness, juiciness, and off-flavor intensity of the sample. A 120 point Labeled Affective Magnitude (LAM) scale was used for participants to rate “liking” labeled from *strongest dislike imaginable* on the far left and *strongest like imaginable* on the far right. A 20-point unlabeled scale was used for rating intensity of off flavor, toughness, and juiciness with *none* being on the far left and *extremely* on the far right.

Shoulder Clod Preparation and Analysis

Shoulder clods were removed from the freezer and held at 2 °C for 72 h until cuts were thawed. Clods were left whole and untrimmed and were ground twice (Hobart 4156, Hobart Corporation, Troy, OH) through a 0.375 cm plate. One sample of ground beef (approximately 225g) per clod was placed on a polystyrene tray with PVC overwrap. Both objective and subjective color values were obtained through the same procedures outlined under the steak retail shelf life section with the only difference being 9 panelists participated for fresh ground beef.

A 10 g sample of ground beef from each animal was collected immediately after grinding and a second sample was taken from the beef utilized for retail shelf life evaluation after 7 d. Samples were vacuum packaged and frozen at -20 °C for storage until thiobarbituric acid reactive substances (TBARS) analysis was conducted. Samples were shipped to AURI (Agricultural Utilization Research Institute, Marshall, MN) for analysis. A distillation method utilizing spectrophotometry was used for analysis.

To create the bologna logs, ground clod from 3 animals per treatment were combined to create a composite sample of 11.34kg. Meat was then mixed with a commercial seasoning blend (Bologna SCTP, Newly Wed Food, Chicago, IL), 1.13 kg ice, 30 g sodium tripolyphosphate, and 30 g sodium nitrite cure (Heller’s Modern Cure #47688, Newly Wed Food, Chicago, IL). Each mixed meat composite was placed into a bowl chopper (Alipina, PB 80-890-II Gossau S G Switzerland, speed setting 2, 3-knife head with Alipina tangential form blades) and emulsified until batter reached 10 °C. Batter was then stuffed (Handtmann VF-608, Albert Handtmann Maschimen Fabrik

GmbH & Co., Biberach, Germany) into inedible collagen casings (Bologna 10.8 cm Walsrober Casings, Mar/Co Sales, Burnsville, MN). Bologna logs (11.5 cm diameter) were placed into a commercial smokehouse (ALKAR 1000 Food Processing Oven, ALKAR RapidPak-Inc., Lodi, WI) and cooked to an internal temperature of 65.5^{o}C. Fully cooked bologna was removed from the smokehouse and cooled at 2 ^{o}C for 12 h. Logs of bologna were sliced (Globe Slicer, Model 400, Globe Slicing Machine Co, Inc., Stanford, CT) to 4 mm thick. Two slices of the bologna from each batch were utilized for retail shelf life evaluation. Slices were individually packaged on polystyrene trays and vacuum sealed in 3 ml standard barrier bags (Bunzl PD, North Kansas City, MO). Samples were stored in identical environmental conditions as previous retail shelf life evaluations. Objective and subjective (10 trained panelists) methods used to evaluate bologna samples were similar to those previously used for steak and ground beef evaluation. The single variation in the procedure for bologna shelf life evaluation was that scores were taken every other day and lasted for 14 d.

Consumer bologna sensory evaluation consisted of 116 consumers recruited by the University of Minnesota Food Science and Nutrition Sensory Center. The same requirements utilized for steak sensory panel recruitment were applied again. Slices of bologna were cut into eight pieces and each panelist received two pieces bologna from each dietary treatment. Samples were refrigerated until sampling. The same evaluation scales used for steak sensory were again used for bologna sensory evaluation.

Statistical analysis

Data were analyzed using the Mixed Procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). Experimental unit depicted in this data set was individual animal and dietary treatment was included as a fixed effect. Feedlot performance, meat quality, and economic measures were dependent variable. For feedlot performance and economic values, pen was utilized as a random effect and initial body weight was retained as a covariate. Meat quality characteristics model was analyzed with day as repeated measure, and with the subject as steer. Effects were considered significant when a P value of less than 0.05 was obtained or a trend when P value was less than 0.10. The PDIFF function of LSMEANS was used to evaluate multiple comparisons when significance was present.

RESULTS

Steer Performance

Live steer performance results are presented in Table 5. Dry matter intake was lowest ($P < 0.05$) for cattle fed HMC. Cattle fed DRC had the greatest ($P < 0.05$) ADG and had similar ($P > 0.05$) feed conversion to those fed HMC. Average daily gain for silage-fed cattle was lower ($P < 0.05$) than that of cattle fed HMC or DRC. Cattle fed either SIL or EAR diets had the poorest ($P < 0.05$) conversions of feed to gain. Cattle fed the EAR treatment had intermediate ADG, final BW, and HCW. Final BW and HCW was greatest ($P < 0.05$) for cattle fed DRC, intermediate ($P < 0.05$) for those fed HMC, and lowest ($P < 0.05$) for those fed SIL or EAR. Cattle fed DRC or HMC tended ($P = 0.08$) to have greater fat thickness than those fed SIL. No treatment differences ($P > 0.05$) were found for REA or marbling.

No effect of corn crop endpoint ($P > 0.05$) was determined for value of corn crop expressed as \$/25.4 kg, with or without crop residue value included (Figure 1). Similarly, harvesting corn as Silage, Earlage, HMC or DRC had no impact ($P > 0.05$) on crop value (gross \$ return/hectare) with or without residue value (Figure 2). However, hectares required to feed one steer was lowest ($P < 0.01$) for Silage-fed cattle and greatest for cattle fed DRC.

Color and Retail Shelf Life Evaluation

There were no a* or b* color differences among dietary treatments for steak, fresh ground, or bologna retail shelf life evaluations ($P > 0.05$). Color differences due to treatment were only observed for L* values in bologna evaluation ($P < 0.01$) in which bologna from cattle fed EAR had greatest L* values. No L* differences were observed for steak or fresh ground beef color (Table. 8). No treatment differences were observed for color, discoloration, or desirability during the retail shelf life evaluation (Table. 9).

Sensory Evaluation

Sensory panel results demonstrated that steaks from steers fed either silage or earlage were juicier ($P > 0.05$) than those fed HMC. There was no effect ($P > 0.05$) found for flavor liking, texture liking, toughness, and off flavor for all four treatments (Table. 6). Bologna samples from steers fed HMC were toughest and least juicy ($P < 0.05$). Bologna samples from steers fed EAR and DRC were rated least tough and juiciest ($P < 0.05$). No treatment effects ($P > 0.1$) were found for overall liking, flavor liking, and texture for bologna samples (Table. 7).

Muscle qualities

No treatment effects ($P > 0.05$) were found vacuum purge loss, drip loss, or cook loss evaluation. Additionally, there was no difference ($P > 0.05$) between treatments for WBSF or TBARS.

DISCUSSION

Steer Performance

Cattle fed HMC had lowest DMI ($P < 0.05$) of all rations (10.08 kg). The greater than 7 month storage period likely played a role in decreasing DMI as digestibility of the corn would have increased over the long storage period, as stated by Benton et al (2004). If digestibility of HMC crop was significantly increased, cattle could have suffered from sub-acute acidosis. Additionally, we encountered issues with palatability of HMC diet using the Calan feeding system, which utilizes large removable plastic bins. Because the study was conducted over the summer, heat caused the finer particles of the HMC crop and MWDGS to separate and stick to the bottom of the bins making part of the diet less desirable to the steers. Cattle fed DRC had the greatest ($P < 0.05$) ADG. This is an expected result as DRC-fed cattle also had greater ($P < 0.05$) DMI than those fed HMC. The results obtained in this study are consistent with those reported by Owens et al. (1997) who found that cattle fed DRC had greater DMI and ADG than those fed HMC, however, no difference was observed in feed conversion. No difference was observed for DMI between cattle fed DRC and Silage or Earlage; however, energy intake was higher for cattle fed DRC.

Although cattle fed Silage or Earlage had DMI similar to that of cattle fed DRC (11.71, 11.60, and 11.85 kg, respectively), weight gain and feed efficiency were poorer than HMC and DRC-fed cattle. This is likely due to lower energy content from corn utilized in the diet. Silage diet in this study contained only 45% corn grain. Non-crop originated dry corn accounted for 13% while the silage crop contributed approximately 32% corn grain based on corn grain yields of silage crop at harvest found by Hohertz (2015), which are near matching to those of Pordesimo et al. (2004) . Based on corn grain yield results of earlage crop (Hohertz 2015), earlage used in this study contained approximately 53% corn. It is reasonable to assume that the 8% greater corn grain content in Earlage relative to Silage treatment led to cattle fed Earlage having intermediate ADG relative to those fed Silage or HMC. Cattle fed HMC or DRC also gained more efficiently than those fed Silage. However, when feed to gain is adjusted for carcass weight, cattle fed HMC also gained more efficiently that those fed Earlage.

Performance results of steers fed Earlage are not indicative of those that would be seen in industry. It is important to consider that earlage harvest for this study was done with a silage harvester head raised to just below the cob, resulting in the upper portion of the plant being included in the feedstuff. This may have led to the variable NDF fraction found in our Earlage crop (18.6 to 23.4%) over the feeding period. This, in addition to grass silage being included in the diet at 11%, resulted in the Earlage diet containing roughly 33% roughage; much higher than that of HMC and DRC treatments or the 8 to 12% roughage commonly used for high concentrate finishing diets in the industry. However, when earlage is harvested as high-moisture ear corn (HMEC), ME is found to be 99% that of HMC (Hill et al., n.d.), while the NRC (2016) values earlage ME at 93% of HMC. In the former study, Cattle fed HMC tended ($P < 0.10$) to have greater intakes than those fed HMEC (8.9 kg vs. 8.6 kg, respectively), but ADG and feed/gain were similar ($P > 0.10$). Hill et al. also determined that DM yields per hectare were 18% greater for HMEC due to the added cob weight. Because more DM was produced per hectare and the two feeds had virtually equal ME values, an increase in beef production per hectare of 17% was observed for HMEC.

No difference was found for REA or marbling score among treatments. But, a tendency ($P = .07$) was observed for cattle fed HMC or DRC to have greater backfat thickness. Cattle in the current study had a high initial weight and were on feed for a relatively short period of time. A more significant difference in backfat thickness would be expected for cattle with a longer finishing period or entering the trial at a lower weight. It is not unexpected that cattle fed Silage and Earlage had equivalent marbling scores. Intramuscular fat deposition follows a linear growth pattern (Bruns et al., 2004). As a result, increased energy intake of cattle fed HMC and DRC would not lead to a substantial increase in intramuscular fat deposition so long as cattle fed higher forage diets are in positive energy balance. Hill et al. also determined that DM yields per hectare were 18% greater for HMEC due to the added cob weight. Because more DM was produced per hectare and the two feeds had virtually equal ME values, an increase in beef production per hectare of 17% was observed for HMEC.

Corn Crop Value

The primary objective of the current study was to determine the most economically efficient harvest endpoint for corn crop when marketed through feeding cattle. No treatment effect was found for gross return ($/hectare) or for equivalent crop value of corn grain for live performance or carcass adjusted performance of steers. It is important to note that marketing strategies of fed cattle may impact return and should be considered. Although not statistically significant, HMC treatment resulted in numerically greater return/hectare when carcass adjustment was applied, while all other treatments had greater returns on a live basis.

Vast differences were observed for yield of crop endpoint, performance results of dietary treatments, and economic returns of treatments. This is indicative of a large amount of flexibility available to farmer-feeders depending on their production system. Although cattle fed Silage obtained the poorest performance results, economic return of these steers was not different from steers fed DRC; who gained the greatest, converted feed more efficiently, and resulted in the greatest amount of salable product. Even though feeding silage is associated with poorer performance results, it does allow for greatest DM crop yield, allowing more cattle to be fed. It is important for farmer-feeders to consider more than cattle performance and feed efficiency when deciding on corn harvest endpoint. The fact that treatments were not found to be different in this study provides farmer-feeders with unique flexibility for corn harvest options from an economic perspective.

DiCostanzo (2016) utilized data gathered from Purina close-out reports, Southwest MN Farm Business Management reports, and USDA fertilizer prices to evaluate net return to corn land for crop-only farmers since 1996 and equivalent crop price/ 25.4 kg of corn grain compared to corn market price since 1999 for farmer-feeder operations (Figure. 3). Over the last 21 years, corn-only farmers realized a net return/

hectare of $54.41 based on a 404-hectare land base. Net return to hectares when feeding 1,000 yearlings was found to be $336.82/ hectare over the last 18 years and required only 335 hectares. Over this period farmer-feeders encountered 6 years of negative net return while crop-only farmers with corn encountered 11 years of negative net return. This further demonstrates that not only does cattle feeding increase net return to corn land, but it also lessens the risks of years with negative return due to market volatility.

Research regarding the integration of crop and livestock species is limited, with majority being targeted towards organic crop and animal production or solely environmental factors. However, a review by Anderson and Schatz, (2002) evaluated the economic advantage of integrating crops and beef cows in North Dakota. They found that state average increase in farm net income was nearly $9,000 for crop and beef farms over farms with just crops. High crop production areas in the Midwest provide considerable advantages for raising beef cows due to the large supply of low-value roughages and high protein co-products. A review by Russelle et al. (2007) evaluated the impacts of integrating livestock with crop farms on economic return and environmental improvements. They determined even with lower rates of gain from feeding crop residues, breakeven price was reduced by $2.40/kg of gain for cow-stocker pairs.

Color and Retail Shelf Life Evaluation

No treatment effects were found for objective color score readings for steak and fresh ground beef evaluation. However, bologna samples from steers fed Earlage did result in higher ($P < 0.05$) L* values. The reason for this is unknown, but color readings could have been affected by placement of the sample within the cooler, however we would have expected additional differences if this were the case. Trained panel subjective scoring of color, discoloration, and desirability did not differ among any dietary treatments. These results suggest that no impact on meat quality is achieved by feeding Silage, Earlage, HMC, or DRC.

Sensory Evaluation

Steaks from steers fed either silage or earlage were juicier ($P < 0.05$) than those fed HMC. Bologna samples from steers fed HMC were also least juicy and toughest of all treatments. These results are in close agreement with Young and Kauffman (1978) who determined that overall desirability was greatest ($P < 0.05$) for cattle fed a high corn silage diet compared to corn grain or haylage fed cattle. Similarly to Young and Kauffman (1978), the significant differences of treatments in the current study are questionable as only small numerical differences were observed. This suggests that when cattle are fed to a similar carcass composition, sensory characteristics of cattle fed high forage diets will be similar to those fed high concentrate rations.

Moisture Loss

No differences ($P > 0.05$) found between treatments for vacuum purge loss, cook loss, or drip loss. These results are not unexpected as water holding capacity has been found to be influenced by muscle pH. Only one steer in the current study was found to be a dark-cutter which will generally increase pH of muscle compared to normal meat, however pH was not measured in this study. As determined by Alberle et al. (2001), cutting a whole muscle into steaks can influence water holding capacity. However, all steaks were cut and treated the same, so we did not expect to encounter large differences in moisture loss.

Warner Bratzler Shear Force (WBSF)

Shear force values have been found to increase as ADG increases (McGregor et al., 2012 and Hornick et al., 1998). Although ADG of cattle fed DRC was 20% higher than those fed Silage, no treatment effect was found for this study. This is likely due to the heavy initial weight of the steers and a shared common background. The former trials do provide start and finish weights of the animals, and the trial conducted by Hornick et al. lasted only 70 d, so comparison to the current trial is difficult. However, a study conducted by Perry and Thompson (2004) that evaluated approximately 7000 cattle finished to three different market weights concluded that ADG had no effect on shear force in temperate climate cattle.

Thiobarbituric Acid Reactive Substances (TBARS)

Dietary treatment had no effect ($P > 0.10$) on TBARS value on d 0 or d 7. It was expected for TBARS to change from d 0 to d 7 due to increased oxidation over time from the presence of oxygen and light. TBARS samples were run a single time, making it difficult to determine significant differences with so few experimental units. It would not be unexpected for values to change if they were run in duplicate.

Conclusion

Data collected from these steers suggests that meat quality is not affected by choice of corn harvest endpoint in the later part of the finishing period. However, the ability of this study to evaluate meat quality characteristics may be limited due to the heavy initial weight of the steers at the start of this experiment and the relatively short days on feed. Economic returns of corn endpoints did not significantly differ. We interpret this to indicate that greater flexibility of harvest endpoint choice is permitted when corn is being marketed through cattle. Farmer-feeders have the flexibility to take advantage of improved farm nutrient cycling, an extended and more flexible harvest period, and reduced market volatility without negatively impacting gross return to corn land.

Table 1. Corn harvest endpoint characteristics

Crop	[1]Yield, tonne/hectare	DM, %	CP, %	NDF, %
Corn silage	35.4	0.373	0.066	0.433
DRC	8.35	0.820	0.082	0.100
Earlage	16.72	0.605	0.070	0.236
HMC	11.12	0.724	0.080	0.101

[1] Yield of crop at harvest DM

Table 2. Feedstuff nutrient composition

Nutrient, DM bases	[1]DM, %	*CP, %	*NDF, %	*ADF, %	*Ether extract, %
Silage	37.3	6.6	43.3	25.6	3.25
Earlage	60.5	7.0	23.6	9.9	3.5
HMC	72.4	8.0	10.1	3.7	3.9
DRC	82.0	8.2	10.0	3.6	3.8
Grass Silage	49.4	14.6	57.7	37.5	3.9
WDGS	28.5	30.6	31.5	15.3	10.8
Non-crop dry-rolled corn	88.5	8.8	9.7	3.6	3.8
Supplement	69	59	0	0	0

[1] DM% represented by average of actual feed samples taken every mix day.

* Nutrient values taken from NRC (2016) until actual analysis in completed.

Table 3. Diet and nutrient composition

Ingredient, % DM	Silage, period 1-3	Silage, period 4	Silage, trial average	Earlage	HMC	DRC
Silage	74.9	55.0	70.0	-	-	-
Earlage	-	-	-	74.9	-	-
HMC	-	-	-	-	74.9	-
DRC	-	-	-	-	-	74.9
Grass Silage	-	11.0	2.8	11.0	11.0	11.0
WDGS	10.0	10.0	10.1	10.0	10.0	10.0
[1]DRC (non-crop)	10.9	17.9	12.9	-	-	-
Supplement	4.0	4.0	4.0	4.0	4.0	4.0
Myco CURB/Moldx	0.2	0.2	0.2	0.1	0.1	0.1
[2]**Diet Composition, %DM**						
DM	40.7	43.7	43.8	54.1	59.8	67.5
CP	12.1	12.4	12.3	12.6	13.6	12.9
NDF	35.7	34.8	35.6	34	17.1	17.2
Fat	3.5	3.6	3.5	3.7	4.3	4.1
NEg	51.6	50.6	51.6	57.6	64	62.7

[1] Dry-rolled corn sourced through the local elevator

[2] Nutrient composition values of diets sourced from UMN Formulation spreadsheet

Table 4. Cumulative animal performance of finishing steers fed different corn crop endpoints

Item	Silage	SE	Earlage	SE	HMC	SE	DRC	SE
Initial BW, kg	534	±12	545	±3	529	±6	538	±9
Live								
DMI	11.71^{b}	±0.30	11.6^{b}	±0.31	10.15^{a}	±0.30	11.85^{b}	±0.31
ADG	1.31^{a}	±0.05	1.34^{ab}	±0.05	1.45^{b}	±0.05	1.62^{c}	±0.05
Feed:Gain	4.15^{a}	±0.14	4.17^{a}	±0.15	3.47^{b}	±0.15	3.35^{b}	±0.15
Out BW	677^{a}	±5	681^{ab}	±5	693^{b}	±5	711^{c}	±5
Carcas Adjusted								
DMI	11.64^{b}	±0.26	11.54^{b}	±0.27	10.11^{a}	±0.26	11.84^{b}	±0.27
ADG	1.27^{a}	±0.05	1.31^{ab}	±0.06	1.45^{b}	±0.05	1.6^{c}	±0.05
Feed:Gain	4.17^{a}	±0.13	4^{a}	±0.14	3.21^{b}	±0.13	3.33^{b}	±0.13
Out BW	675^{a}	±6	678^{ab}	±6	694^{b}	±6	711^{c}	±6

^{ab} Different letters within each row denote significant differences

Table 5. Feedlot live performance results

Item	Silage	SE	Earlage	SE	HMC	SE	DRC	SE
HCW, Live, kg	420^{a}	±4	429^{c}	±4	437^{a}	±4	452^{b}	±4
HCW, ADJ, kg	416^{a}	±5	424^{ab}	±5	437^{b}	±5	452^{b}	±5
BF Thickness, cm	0.86^{e}	±0.11	1.12^{ef}	±0.11	1.19^{f}	±0.11	1.24^{f}	±0.11
REA, cm^{2}	38.86	±0.73	39.88	±0.77	40.89	±0.76	41.15	±0.76
MARB	479	±17	496	±17	478	±17	510	±17

^{ab} Different letters within each row denote significant differences

^{ef} Different letters within each row denote a tendency for values to be different

Table 6. Fresh steak sensory characteristics of cattle fed different corn harvest endpoints

	Harvest Endpoint Treatment*					
	Silage	Earlage	HMC	DRC	SEM	P-Value
Overall Liking	69	71	68	68	1	0.382
Flavor Liking	71	71	69	70	0.5	0.665
Texture Liking	65	67	64	65	0.4	0.738
Toughness	11	10	10	10	0.5	0.672
Juiciness	7^a	7^a	5^b	6^{ab}	3.4	0.018
Off-flavor	4	4	5	4	0.6	0.599

[ab] Different letters within each row denote significant differences

Table 7. Bologna sensory characteristics of cattle fed different corn harvest endpoints

	Stover Treatment*					
	Silage	Earlage	HMC	DRC	SEM	P-Value
Overall Liking	75	78	77	77	0.674	0.194
Flavor Liking	76	79	77	78	0.728	0.384
Texture Liking	75	77	74	77	0.692	0.132
Toughness	6^{b}	5^{c}	7^{a}	5^{c}	0.184	<0.001
Juiciness	8^{ab}	9^{a}	8^{b}	9^{a}	0.18	0.003
Off-flavor	5	5	5	4	0.199	0.21

^{ab} Different letters within each row denote significant differences

Table 8. Subjective color scores of Steak, Fresh ground, and Bologna meat samples

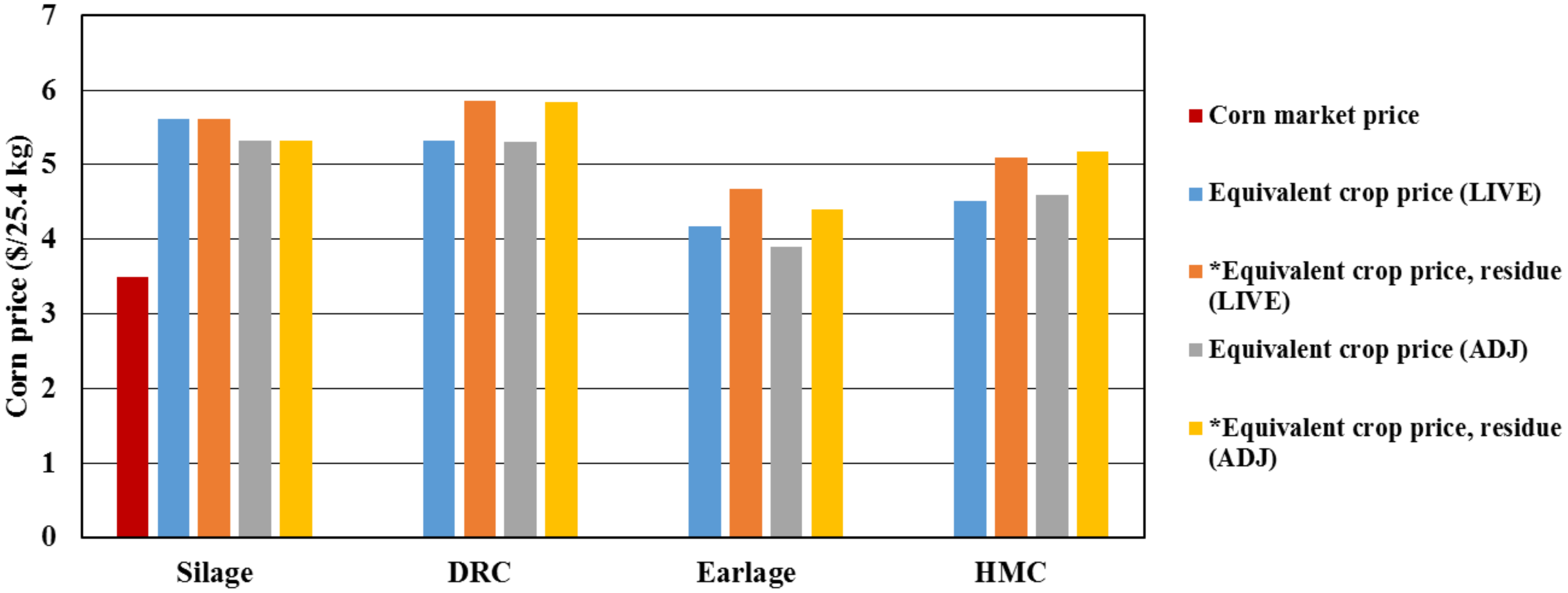
Item	Silage	SE	Earlage	SE	HMC	SE	DRC	SE
Steak								
L*	39.23	±0.83	39.48	±0.88	38.22	±0.87	36.93	±0.80
a*	15.26	±0.45	16.18	±0.47	15.60	±0.48	15.35	±0.43
b*	17.41	±0.41	18.09	±0.43	17.33	±0.44	16.86	±0.40
Fresh Ground								
L*	39.23	±0.83	39.48	±0.88	38.22	±0.87	36.93	±0.80
a*	15.26	±0.45	16.18	±0.47	15.60	±0.48	15.35	±0.43
b*	17.41	±0.41	18.09	±0.43	17.33	±0.44	16.86	±0.40
Bologna								
L*	64.52^a	±0.56	66.07^b	±0.52	63.83^a	±0.63	63.71^a	±0.55
a*	6.00	±0.20	6.11	±0.20	6.12	±0.21	6.50	±0.21
b*	19.41	±0.14	19.53	±0.14	19.14	±0.16	19.37	±0.14

[ab] Different letters within each row denote significant differences

Table 9. Retail shelf life panel scores for evaluation of color, discoloration, and overall desirability of steak, fresh ground, and bologna sample

Item	Silage	SE	Earlage	SE	HMC	SE	DRC	SE
Steak								
Color	6.37	±0.16	6.48	±0.17	6.35	±0.17	6.23	±0.16
Discoloration	9.68	±0.17	9.77	±0.18	9.71	±0.18	9.85	±0.18
Desirability	6.25	±0.19	6.37	±0.20	6.33	±0.21	6.27	±0.18
Fresh Ground								
Color	4.91	±0.19	4.87	±0.19	5.14	±0.19	5.19	±0.18
Discoloration	7.69	±0.25	7.71	±0.25	8.07	±0.25	8.19	±0.25
Desirability	4.78	±0.18	4.79	±0.18	5.07	±0.18	5.20	±0.18
Bologna								
Color	3.54	±0.07	3.61	±0.06	3.47	±0.07	3.42	±0.07
Discoloration	7.75	±0.12	7.73	±0.12	7.67	±0.12	7.60	±0.12
Desirability	4.12	±0.08	4.16	±0.08	4.06	±0.08	3.99	±0.08

Figure 1. [1]Equivalent price of corn crop marketed at reference dry corn price [2] ($3.50 / 25.4 kg) with or without residue on a live and carcass basis.

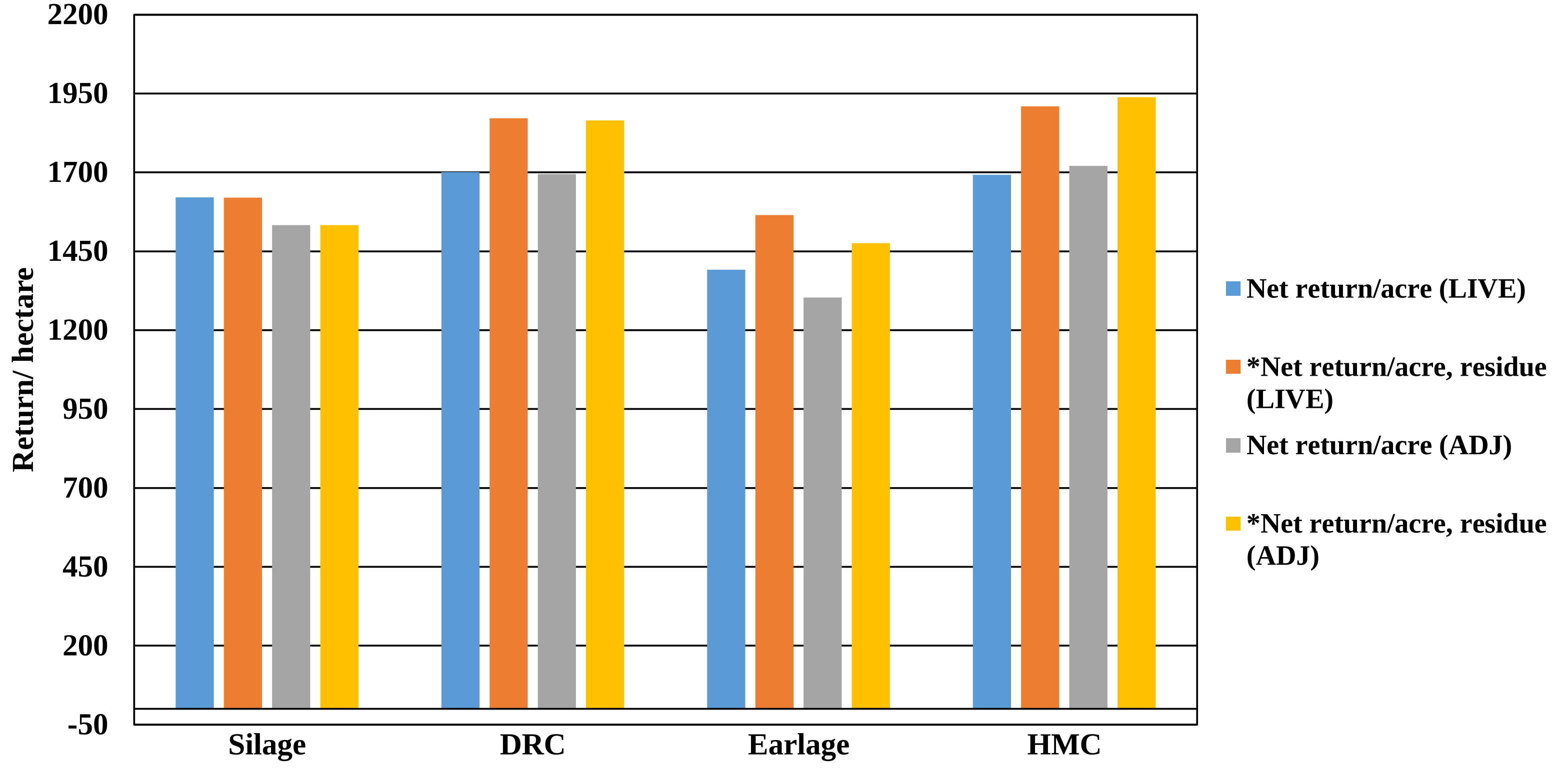


[1] Price of corn set per 25.4 kg

[2] Reference price of $3.50 / 25.4 kg of corn grain represents corn marketed through a local elevator

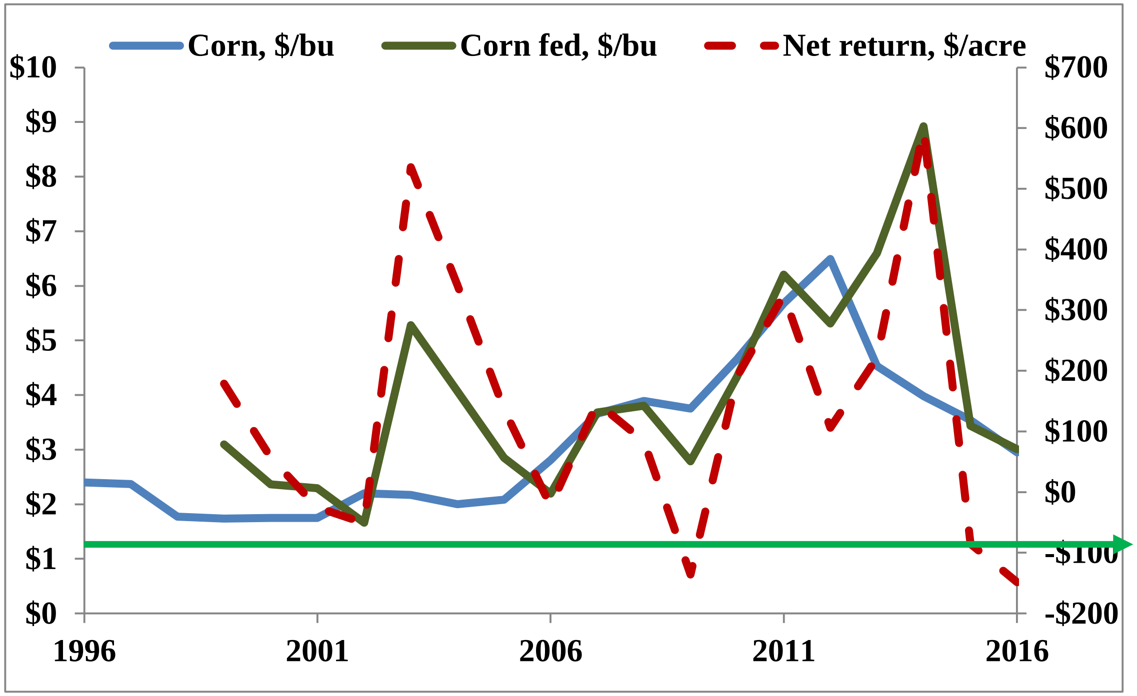
* Adjusted for common bedding need of steers subtracted from amount of corn residue after harvest of particular crop

Figure 2. Net return to corn hectares when corn crop is harvested as Silage, Earlage, HMC, or DRC



*Adjusted for common bedding need of steers subtracted from amount of corn residue after harvest of particular

Figure 3. Equivalent value of corn fed to cattle in relation to market value corn and net return/ 0.4 hectare



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