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New approaches to corn silage use in beef cattle finishing diets

Dirk Burken
University of Nebraska-Lincoln, dirk_burken@hotmail.com

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NEW APPROACHES TO CORN SILAGE USE IN BEEF CATTLE FINISHING DIETS

by

Dirk Benedict Burken

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NEW APPROACHES TO CORN SILAGE USE IN BEEF CATTLE FINISHING DIETS

Dirk Benedict Burken, Ph.D.

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Adviser: Galen E. Erickson

Cattle feeders are considering alternative feedstuffs to replace expensive corn grain and decrease rations costs. Feeding corn silage allows cattle feeders to take advantage of the entire corn plant at a time of maximum quality and tonnage as well as secure substantial quantities of roughage and grain inventory. Distiller's grains have proven to be economical and are now a commonplace ingredient in feedlot finishing diets. Experiments were conducted to determine the effects of feeding increased concentrations of corn silage in replacement of corn grain in finishing diets containing distillers grains. Feedlot gains and gain:feed ratios were reduced as corn silage increased in the diet. Total tract dry matter digestibility of diets containing 45% corn silage was decreased compared to diets containing 15% corn silage. Although total tract neutral detergent fiber (NDF) concentration was not different across corn silage inclusions, in-situ NDF disappearance of corn bran was greater for diets with increased corn silage inclusion. Whole corn plants were sampled and analyzed for two consecutive years for determination of the effects on whole corn plant yield and quality measurements due to hybrid season length, planting density, and whole plant harvest timing. As whole plants were harvested later in the season, yield increased with minimal changes in whole plant quality measures. The economic factors involved in pricing corn silage were assessed, and different economic scenarios were developed for feeding corn silage in finishing diets containing distillers grains. Feeding increased concentrations of corn silage in finishing diets containing distillers grains was determined economical when corn grain price was above $163.38 per metric tonne. As well, as corn grain price and the inclusion of corn silage in the diet increased, reducing corn silage shrink and harvesting corn silage at higher DM contents became more economically beneficial. These data demonstrate that corn silage can economically replace corn grain in finishing diets containing distillers grains.

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INTRODUCTION

Corn silage has been used for many years in cattle finishing diets. When corn has been relatively expensive, it has been shown that corn silage can economically partially replace corn as an energy source in finishing diets (Goodrich et al., 1974; DiCostanzo 1998a). When corn silage has replaced corn in finishing diets, it has been well documented that G:F decreases as corn silage is increased in the diet (Goodrich et al., 1974; Preston 1975; Erickson et al., 2001). There are many management decisions that can affect quality and yield of corn silage and thus can affect economics of producing and feeding corn silage to finishing cattle. Three of these variables that affect corn silage production are corn plant population density, corn hybrid and season length, and the timing of corn plant harvest.

All of the past cattle performance and economic data with increased concentrations of corn silage in finishing diets were completed prior to the expansion of the ethanol industry and the common inclusion of distillers grains in finishing diets. As well, distillers grains and corn silage could be produced in the same region, and, therefore, the evaluation of increasing corn silage in finishing diets containing distillers grains is logical. Therefore, the objectives of the following studies were to assess the effects of hybrid relative maturity, plant population density, and harvest date on corn plant yield and quality measures, to evaluate animal performance and carcass characteristics of cattle fed increasing concentrations of corn silage and distillers grains in finishing diets, to provide a general outline on the costs associated with corn silage production, and to evaluate the economics of finishing cattle on increased concentrations of corn silage and distillers grains.

REVIEW OF LITERATURE

Corn silage production

Corn silage is a staple of modern dairy operations as well as beef cow/calf, growing, and finishing enterprises. It is a relatively high energy (75% TDN; NRC, 1996), low protein (8% CP; NRC, 1996) feedstuff that is a major forage source in climates that are moderately to well adapted to corn production. According to the 2012 Census of Agriculture (USDA, 2012), corn for silage production was grown on over 113 million acres, up from over 104 million acres in 2007. United States corn silage production usually is produced on 8-10% of the total acres planted for corn (Mahanna, 2005).

The production of corn silage as a forage crop has many benefits. First, it provides large yields of highly digestible and palatable feed in only one harvest a yr. Due to corn silage being harvested before physiological maturity and grain dry-down, corn for corn silage production can be grown in shorter growing seasons compared to dry-corn production. As well, harvesting corn for corn silage is commonly used to "salvage" a corn crop that has been damaged due to weather events, such as drought, hail, and frost, or crop production problems, such as poor pollination and grain fill. Another major advantage outlined by Allen et al. (2003) is that producers have some flexibility in harvesting corn for forage or grain. When market conditions look favorable for feeding cattle, crop producers can harvest more total yield of TDN through corn silage production and market their corn crop through cattle sales. However, when market conditions dictate, crop producers may elect to sell dry grain compared to feeding cattle. In years when the corn crop is high-yielding, excess corn can be harvested for grain; likewise, when corn yields are low, the majority of the crop may need to be harvested as silage.

Although corn silage offers a multitude of advantages for integrated crop and livestock producers, there are some different management considerations that need to be evaluated when producing corn silage in comparison to dry corn grain. Corn silage is a high moisture feedstuff that is usually harvested and ensiled at 35% DM. At relatively low DM content, there are increased transportation costs from field to market (bunker), as well as, potentially higher feedstuff shrink costs if proper storage and management procedures are not followed. Once harvested, corn silage essentially has to be marketed through on-farm livestock as no outside markets are available. With corn silage production compared to dry corn grain production, producers need to be cognizant of nutrient removal and crop rotation. Fertilizer value of stover removed with corn silage was calculated from values determined from the NRC (1996). Corn grain CP, P, and K concentration data (approximately 3,500 samples) were used to calculate the amount of N, P, and K contained in a metric tonne (t; DM) of corn grain. This was also calculated for corn silage nutrient concentration data (approximately 32,000 samples). The amount of fertilizer nutrients removed from harvesting corn silage instead of only corn grain was then assessed using a partial budget approach taking into account only nutrients removed with corn stover. These values were 5.7 kg of N, 0.55 kg of P, and 11.0 kg of K per t of corn silage (DM) removed; to re-emphasize these are calculated nutrients coming from the stover fraction (partial budget approach) of the corn silage. Additionally, corn silage harvest leaves little ground cover on crop surfaces allowing for increased potential for wind and water erosion. As well, harvesting corn for corn silage removes more organic matter for subsequent crops compared to traditional dry corn grain production. The use of cover crops and application of livestock wastes to fields harvested for corn silage are ways of mitigating these agronomic issues.

Effect of harvest date on whole corn plant yield and quality

Corn silage harvest has long been determined by the proximity of the kernel milk line to the placental region of the kernel. Starting at the dent stage of kernel development, the milk line travels down the kernel toward the cob before reaching physiological maturity or black layer formation (Figure 1; Afuakwa and Crookston, 1984). The development and movement of the milk line corresponds to the R5 stages of the growth cycle of the corn plant before R6 or physiological maturity. The kernel milk line has been used as an indicator of the whole plant dry matter content for many years (Afuakwa and Crookston, 1984; Crookston and Kurle, 1988), however actual measurement of whole plant dry matter content should be a better predictor of ensiling potential (Figure 2; Lauer, 1999; Mahanna, 2005). Nonetheless, harvesting corn silage at ½ to ¾ milkline has been widely considered optimum for both yield and quality (Hunt et al., 1989; Wiersma et al., 1993; Moss et al., 2001) but also nutrient preservation. Vetter and VonGlan (1978) stated the importance of harvesting corn silage at correct moisture concentration (recommendation of 30-40% DM) as too wet (<30% DM) corn silage results in poor fermentation patterns and seepage losses while too dry (>50% DM) corn silage increases the risk of heat damage and mold problems.

Yield

Corn silage yield usually increases as harvest is done closer to plant physiological maturity. This is due to the accumulation of growing degree d and the plants ability to maintain photosynthesis for a longer period of time before harvest. This produces a greater amount of total DM, with a majority of the increases in DM yield accounted for in the grain fraction.

Darby and Lauer (2002) stated that stover yield is maximized at the time of reproductive development in corn. These researchers reported no relationship between stover DM yield and growing degree units across silage DM contents of 30 to 42% (Darby and Lauer, 2002). Shinners and Binversie (2007) collected three years of data following the corn plant progress from approximately August 25 to October 20, these researchers reported that the peak of total stover yield was at the start of the experiment and that total stover yield decreased (12.6 to 10.5 Mg/ha) during the experiment. Huang et al. (2012a) also reported maximal stover yield at the initiation of their experiment (August 21st) and a decrease in stover yield as the experiment progressed until the end (November 23rd). Shinners and Binversie (2007) and Huang et al., (2012a) both harvested corn plants slightly before typical silage harvest, however, the end of the experimental data was harvested well past typical silage harvest. For this, the loss of stover over the harvesting period would be overestimating the loss of the stover that would occur when comparing an early corn silage harvest compared to a later corn silage harvest.

Owens (2008) summarized results from Hunt et al. (1989) and reported that stover DM yields were 14.5, 12.9, and 11.6 t/ha at 1/3 milkline, 2/3 milkline, and blacklayer.

Moss et al. (2001) reported stover yields of 21.1, 20.4, and 20.4 t/ha (yr 1) and 23.5, 22.2, and 22.4 t/ha (yr 2) at 1/3 milkline, 2/3 milkline, and blacklayer (respectively). Potential reasons for the loss of stover included senescence and abscission as the stover parts (leaves, husk, and upper stalk) became dry and brittle leading up to and especially after physiological maturity (Shinners and Binversie, 2007), but also stover dry weight would be lost due to translocation of nutrients from the stalk and leaf fractions to grain (Huang et al., 2012a). Contrary to these data, Pordesimo et al. (2004) reported that stover DM yield increased from 13.43 t/ha to a peak of 15.57 t/ha in the two weeks prior to physiological maturity. Although Owens (2008) reported that total sugars decrease during this time which would support a decrease in stover yield, Allen et al. (2003) suggested that total starch plus sugars increased up until physiological maturity, which would replenish some of the sugars being translocated during kernel fill.

As corn silage is harvested later in the growing cycle of the corn plant, corn grain yield is increased. This is due to the corn plant translocating photoassimilate to corn grain for storage as starch. The easiest and most accurate measure of quantifying the increase in corn grain yield across silage DM contents is harvesting and quantifying corn grain (one measurement) separately from the whole plant. The other option would be to measure two variables (corn grain concentration and whole plant yield), however, each variable would be associated with a corresponding measure of error. Huang et al. (2012b) reported that grain yield increased to a plateau when grain moisture content reached 40% and 35% DM in two subsequent years in Illinois. This agrees with Shinners and Binversie (2007; Wisconsin), in which maximum corn grain yield was attained at a corn grain DM content threshold of 35% DM; however, Pordesimo et al. (2004;

Tennessee) reported maximum grain yield once corn grain DM content is between 20 and 30% DM. Differences in hybrids, relative maturities, environment, and growing conditions would undoubtedly affect the DM content at which corn grain reaches physiological maturity or maximal corn grain yield. Although there is substantial range in the ratio between stover moisture and grain moisture (1.5-3:1), Shinners and Binversie (2007) reported that the common rule of thumb is that stover moisture is roughly twice that of corn grain. If this assumption is used, then grain content would reach maximum when corn silage was approximately 40 to 50% DM. This agrees with Daynard and Hunter (1975; Ontario), grain dry matter yield was maximized when the whole corn plant DM content was at least 50%. These whole plant DM contents would be drier than normal corn silage harvest, therefore, when corn silage is harvested prior to physiological maturity, maximal corn grain yield is sacrificed, and there is a harvested grain yield drag.

The amount of grain yield drag that occurs with harvest of corn silage compared to harvesting dry corn grain depends on the DM content of the harvest corn silage or it's relativity to physiological maturity. This yield drag has a substantial effect on the economics of producing corn silage or corn grain. Moss et al. (2001) conducted an experiment with harvesting three corn hybrids at three harvest times (1/3, 2/3, and 100% milkline) over a two yr period. Dry matter content in this experiment for the harvest times were 34.35, 41.52, and 47.74% in yr one and 26.80, 29.04, and 35.58% in yr two. Moss et al. (2001) summarized that increased maturity enhanced grain and whole plant yield. Grain yields (85% DM) for separate harvest times were 4.2, 4.7, and 5.3 t/ha (yr 1) and 6.3, 7.2, and 7.8 t/ha (yr 2). Averaging across both years in this experiment, harvested grain would be approximately 80 and 90% that of potential yield when corn silage was harvested at 1/3 and 2/3 milkline, respectively. In a study conducted by Afuakwa and Crookston (1984), harvested corn grain yield was approximately 61 and 88% that of potential yield when corn plants were harvested at full dent and ½ milkline, respectively. This agrees with data based on harvesting at different grain moisture contents in a study conducted by Daynard and Hunter (1974). This experiment resulted in grain yields that were 81 and 93% that of maximum grain yield when corn grain was harvested at 50% and 40% grain moisture content, respectively (Daynard and Hunter, 1974). When summarizing these experiments, if corn silage is harvested at ½ milkline, the producer is losing approximately 10-15% of potential grain yield due to kernel immaturity at harvest time. An opportunity may exist for capturing increased grain yield with harvesting corn silage at an advanced maturity, however, potential changes in stover yield and whole plant quality need to be considered.

Nutrient Content and Yield

As the corn plant matures before corn silage harvest, nutrient location and quality changes. Allen et al. (2003) summarized these changes as grain development occurring largely at the expense of stover quality. As the corn plant matures there is an increase in grain content as sugars once located within the stover are converted to starch within the corn kernel. However, total starch plus sugars increase during this time (Hunt et al., 1989; Bal et al., 1997), suggesting that plant photosynthesis is continually adding to net sugar production.

Increases in starch content and yield are the most dramatic changes that occur from the R5 to the R6 stages of the corn plant. Many corn silage experiments have documented these changes (Bal et al., 1997; Johnson et al., 2002; Lewis et al., 2004).

Mahanna (2005) stated that starch content will commonly increase 30% or more from ¼ milkline to ¾ milkline. Since starch provides more than 50% of the energy in corn silage (Owens, 2008), this increase in starch content represents a large increase in total energy yields for harvesting corn silage with more maturity.

As corn silage is harvested later in the harvest season with advanced maturity, whole plant NDF decreases (Hunt et al., 1989; Bal et al., 1997; Owens 2008). Since starch is increasing quite dramatically from dent to black layer, a dilution effect has been proposed (Mahanna, 2005). Owens (2008) suggested that NDF is being lost by the plant during this maturation process. Using data from Lewis et al. (2004) and Cox et al. (2005), Owens (2008) suggested that total NDF yield is decreasing but indigestible NDF yield does not change with advancing maturity. This author speculated that NDF is lost with advancing maturity due to a loss in hemicelluloses (Owens, 2008).

Harvesting corn silage later in the season has decreased (Johnson and McClure, 1968; Wiersma et al., 1993; Xu et al., 1995; Sheperd and Kung, 1996) or had no effect (Moss et al., 2001) on crude protein content.

Nutrient Digestibility

Since NDF represents a major component of corn silage (41%; NRC, 1996), digestibility of NDF in corn silage is extremely important in assessing the quality of corn silage. As corn silage maturity is increased, NDF digestibility (**NDFD**) has been shown to slightly decrease (Johnson et al., 1999; Darby and Lauer, 2002; Lewis et al., 2004; Owens, 2008). In the summary by Owens (2008), there was a decrease in NDFD of only 3 percentage points between harvest DM contents of 30 and 40%. Dry matter intake of high producing lactating dairy cows is limited by high NDF content and low NDFD due to rumen bulk fill (Dado and Allen, 1995; Oba and Allen, 1999). Due to this, seed corn companies have been pursuing hybrids with improved NDFD, such as brown midrib (**BMR**) corn mutations, however the genetic variability in non-BMR hybrids for NDFD is small (Mahanna, 2005).

Starch concentration is widely known to increase with advancing plant maturity, however starch digestibility has been shown to somewhat decrease as corn silage DM content increases. Numerous reports have shown a decrease in total tract starch digestibility with more mature corn silage (Harrison et al., 1996; Bal et al., 1997; Johnson et al., 1999; Ferraretto and Shaver, 2012), however, in most experiments, total tract starch digestibility is still above 90% even in the driest of corn silage treatments. Additionally, most of these studies have been conducted with high-producing, lactating dairy cows with high DMI and fast GI tract passage rates. Diet digestibility, including starch digestion, would intuitively be decreased in these situations compared to the GI tract environment found in feedlot cattle. This is in agreement with a summary by Owens and Soderland (2006), where it was suggested that ruminal and total tract starch digestion is lower for lactating cows compared to feedlot cattle albeit there is no known direct treatment comparison between feedlot cattle and lactating dairy cows. Corn grain moisture found in corn silage is greater than that of corn grain moisture found in harvested high-moisture corn (**HMC**) for ensiling. Ruminal and total tract starch digestibilities of HMC in feedlot cattle have been reported as approximately 90 and 97-99%, respectively (Galyean et al., 1976; Huntington et al., 1997; Cooper et al., 2002). Further, Benton et al. (2004) reported that *in situ* dry matter digestibilities increased for high moisture corn as moisture content increased from 24 to 35%. This would potentiate that ruminal starch digestibility would be increased as corn grain moisture content is increased, however Szasz et al. (2007) found no difference in ruminal or total tract starch digestibility for HMC harvested at 28.1, 31.2, or 35.7% moisture. Nonetheless, corn grain found in mature corn silage should be at least equal to HMC in terms of digestibility and feeding value when fed to feedlot cattle.

Kernel processing is a relatively recent development to United States corn silage production. High-capacity corn silage choppers now have the capability to shear the corn kernel on the chopper by the passage of the kernel through two rollers (typically set at 1-5 mm of clearance; Mahanna, 2005) revolving at two different revolutions per minute. Corn silage can also be kernel processed by passing the pre- or post-ensiled material through a recutter screen on a forage harvester or a stationary roller mill (Johnson et al., 1999). Not only is the kernel broken into smaller pieces, but also the cob and other stover portions of corn silage are broken down as well. Therefore in dairy diets, it is common for producers to increase the theoretical length of cut in order to optimize particle size both for nutrient digestibility but also maintenance of ruminal health. Kernel processing has been shown to improve total tract starch digestibility with the benefit of kernel processing on starch digestibility being greater for corn silage harvested later and drier (Owens, 2008). This effect has been incorporated into the corn silage nutrient prediction models used by the University of Wisconsin to assess corn silage hybrids (MILK 2000; Schwab et al., 2003). The effect of kernel processing on digestibility of fiber has been variable (Johnson et al., 1999; Ferraretto and Shaver, 2012). In experiments involving high-producing dairy cows, there has been varying success in modifying the feeding value of corn silage with mechanical processing as summarized by the reviews by Johnson et al. (1999) and Ferraretto and Shaver (2012). In growing beef cattle, variable results have also been reported. Rojas-Bourrillon et al. (1987) reported no performance differences between growing steers fed rolled (3 mm roll clearance) and non-rolled corn silage when the corn silage was harvested at black layer maturity or 40.6% DM. Young et al. (1998) found an increase in ADG (1.46 and 1.42 compared to 1.33 kg/d for cattle fed pre-ensiled rolled corn silage, post-ensiled rolled corn silage, and non-processed corn silage; respectively) and an improvement in G:F (0.152 and 0.156 compared to 0.143 for cattle fed pre-ensiled rolled corn silage, post-ensiled rolled corn silage, and non-processed corn silage; respectively) for kernel processed corn silage. Although animal performance data have been variable with regards to processed corn silage, additional potential benefits from processing corn silage include improved packing density, ensiling characteristics, and reduced shrink losses albeit experimental data validating these improvements are quite limited (Muck et al., 2003).

Energy content

Nutrient movement within the whole corn plant has been characterized and is quite dynamic during advancing maturity of corn silage, however the effects of this in regards to energy values of corn silage differing in maturity is quite variable in the literature. In summary, NDF content, NDF digestibility, and sugar content decreases with advancing corn silage maturity. However, it has been proposed that 55% and 75% of the energy in corn silage comes from starch and the kernel (respectively; Mahanna, 2005). With advancing maturity, starch content and kernel mass increases, with a potential slight decrease in starch digestibility. Owens (2008) summarized these nutrient changes and concluded that between corn silage DM contents of 30 and 40%, digestible sugars decrease 15%, digestible NDF decreases 13%, but digestible starch increases 18%. When each nutrient digestible component was summed by Owens (2008), the total amount of digestible components equaled 70.9% at 30% DM and 70.7% at 40% DM. Owens (2008) concluded very similar energy values across this DM range, however the source of energy is changing with more energy coming from starch and less energy coming from NDF as corn silage maturity is increased. It is important to note this simulation is once again for corn silage when used in dairy cow diets, and the dynamics of rumen fermentation, DMI, passage rate, and nutrient digestibility will change when compared to feedlot cattle (Owens and Soderland, 2006). In one experiment conducted by Buchanan-Smith (1981), steers fed corn silage harvested at 40% DM had 5% increased DMI but similar gains compared to steers fed corn silage harvested at 28% DM. There is no other known data on the effects of corn silage harvest DM content on beef cattle finishing performance.

Effect of hybrid selection and season length on whole corn plant yield and quality

Production of corn grain has steadily been advancing from the 1940's at 1.9% per yr (Owens, 2008). Owens (2008) reported that grain production from today's (2008) hybrids will produce approximately one third more grain compared to hybrids used in 1990. Mahanna (2005) reported that many studies have shown that grain yield is a positive indicator of corn silage yield. Using saved seed that would have been representative of the typical corn genetics of every decade from the 1930's to present-day, University of Wisconsin researchers have noted genetic advancements in corn silage (Lauer et al., 2001). In this analysis, DM yield of ear (+2.4% per yr since 1930), stover (+0.7% per yr), and forage (+1.4% per yr) have increased dramatically with a larger increase in grain yield increase compared to stover yield increase. Owens (2005) agreed with this trend and reported that grain content of many corn silages today often exceeds 55% grain. From the University of Wisconsin dataset, it has been confirmed that cell walls comprise less of the whole corn plant, mainly due to the dilution effect of corn grain (Mahanna, 2005); however stover NDF concentration and digestibility appears to be relatively unchanged.

When planning a corn production yr, producers need to be cognizant of corn hybrids and their relative advantages/disadvantages under each individual scenario. Lauer (1997) suggests that corn hybrid selection is one of the most important management decisions in silage production. Lauer (1997) and Allen et al. (2003) suggests that hybrids should be first selected from a group that is well adapted for maturity, disease and insect resistance, and drought tolerance in the area where they will be grown. Maturity should be selected as the latest relative maturity that will reach harvest maturity by frost (Undersander and Lauer, 2005). This is due to higher yield potential with later maturing hybrids since they can utilize more of the growing season for photosynthate production.

After these initial decisions, thoughts should be geared toward the end goal of corn production. After determination if grain will be potentially produced as well as silage, decisions regarding dual purpose or grain and silage specific hybrids must be made. In the case of silage production, Undersander and Lauer (2005) recommend planting hybrids that mature slightly later (5 to 10 relative maturity units) than those adapted for grain production. Evaluation of hybrids for yield potential is critical. Further, corn silage quality is affected by corn hybrid and needs to be the last characteristic in the selection for the correct corn hybrids. Evaluating corn hybrids on quality characteristics may intuitively seem to be more important and therefore higher in the decision-making hierarchy, however, although there are quality differences across hybrids, many researchers have found relatively narrow ranges in whole plant digestibility and fiber concentrations (Carter et al., 1992; Coors, 1994). Lauer (1997) reported that grain yield is a good general indicator of whole-plant yield; however, within high-yielding (corn grain) hybrids, there are still differences in whole-plant yield and quality. This emphasizes the need for silage yield and quality data on corn hybrids (Lauer, 1997) for the final assessment of each potential corn hybrid.

The University of Wisconsin has developed equations to rank corn silage hybrids according to quality and yield (MILK2000 and MILK2006; Shaver, 2006). These equations predict the amount of milk produced from a 614 kg dairy cow utilizing NDF concentration and digestibility to predict DMI and a modification of the NRC (2001) $\text{TDN}_{\text{maintenance}}$ summative equation to include starch, non-starch non-fibrous carbohydrate components, and a predicted starch digestibility. Hybrids are then characterized as the amount of milk produced per megagram forage, which can be multiplied by forage yield to calculate the amount of milk produced per hectare. Undersander et al. (1993) suggested that milk produced per acre (hectare) should be used to evaluate corn silage hybrids because it combines yield and quality into a single value. Although these equations are beneficial in evaluating corn silage hybrids for use in dairy cow enterprises, rank of hybrids may differ when evaluated for beef feeding programs due to the differences in nutrient needs and digestive capacities of each different class of cattle. Lauer (1997) acknowledged these differences for choosing corn hybrids and declared that the optimum silage composition can vary depending on the type of cattle and the other ration components.

Effect of planting density on whole corn plant yield and quality

Corn grain yield (as well as corn silage yield) typically exhibits a quadratic response to plant density, with a near linear increase in yield across low plant densities, then a decreasing rate of increase in yield across mid-range densities, and finally a plateau and decrease in yields at very high plant densities (Shapiro and Wortman, 2006). Due to hybrid, maturity, and field/growing conditions, optimal plant densities that maximize production will vary. Planting at optimum plant densities maximizes use of soil nutrients, solar radiation, and available moisture within the growing season. However, optimal planting density that maximizes production may not maximize returns to the crop producer mainly due to the quadratic response of yield to planting density. In different economic scenarios, the economic optimal planting density may differ from the planting density that maximizes production due to prices of seed, fertilizer, water, and other variable costs and prices garnered for grain or corn silage. Another risk with increasing corn planting density is lodging potential, or the potential for down cornstalks throughout a field. Corn plants will be smaller in stalk diameter and more prone to stalk lodging at greater planting populations; however, since corn silage is harvested much earlier in the season compared to dry grain, lodging is not as great of an issue for corn silage as it is for corn grain production.

Compared to corn production for dry grain, corn production for silage is recommended to be planted at 7.5-20% greater populations than would be optimal for grain production (Allen et al., 2003). Dry matter yield has been shown to be maximized between 80000 and 100000 plants/ha in many studies in a variety of growing areas and conditions (Fairey, 1982; Pinter et al., 1990, 1994; Graybill et al., 1991; Cox, 1996, 1997; Cusicanqui and Lauer, 1999; Roth et al., 2000; Baron et al., 2006; Stanton et al., 2007).

There is a tradeoff between corn silage yield and quality with increasing plant density. As planting density increased, crude protein content has be shown to decrease (Allen et al., 2003). With increased planting density, measurements of NDF and ADF were reported to linearly increase and in vitro true digestibility to linearly decrease in a study conducted by Cusicanqui and Lauer (1999). Roth et al. (2000) agreed with this quality tradeoff when evaluating corn planted at 59280 to 103740 plants/ha. These researchers reported a decrease in in vitro digestibility of 0.66 units for every additional 14820 plants/ha. Stanton et al. (2007) reported a slight linear decrease in *in vitro* true digestibility from 72.6% to 71.5% and a slight linear decrease in crude protein from 7.0% to 6.6% across population densities of 49000 to 124000 plants/ha. When assessing these quality parameters on an animal performance basis, Cusicanqui and Lauer (1999) calculated a linear reduction in milk per/t of corn silage. However, when based on milk produced per unit of land area, the benefit of additional yield offsets the somewhat lower quality data observed at higher plant densities.

Fiber digestion

Plant cell walls are the major source of fiber in diets for animals. The polysaccharides in cell walls (cellulose, hemicellulose, and pectin) cannot be degraded by mammalian enzymes and therefore must be fermented to volatile fatty acids that can then be utilized by the host via microorganisms (bacteria, fungi, and protozoa) located within the rumen or large intestine of cattle. This ability to harvest energy from fiber is highly valuable to the viability and competiveness of the ruminant animal industries compared to non-ruminant species. Maximal fiber digestion occurs with readily digestible, low-lignified fiber sources, and when the rumen environment is greater than pH of 6.8 (Hoover, 1986). As well, cellulolytic organisms have a requirement for ammonia as a nitrogen source, and Hoover (1986) reported that proteins are superior to urea for maintenance of fiber digestion, partially due to a requirement for the branched chain fatty acids isobutyrate, isovalerate, and 2-methylbutyrate that are formed from the deamination of valine, leucine, and isoleucine.

Fiber polysaccharides and lignin are complex molecules. Cellulose is glucose units linearly linked by β-1,4 linkages and comprises 20-30% of the dry weight of most plant primary cell walls (Chafe, 1970; McNeil et al., 1984). Hemicelluloses are a complex combination of linear and branched-chain polysaccharides with polymers of xylose, arabinose, mannose, galactose, glucose, and uronic acids (Buxton et al. 1996). As well, xylan polymers can be cross-linked to other hemicelluloses backbones or to lignin or to cellulose (Wang and McAllister, 2002). Pectin is formed with a backbone of α-1,4 linked residues of D-galacturonate. The backbone of pectin can be interspersed with rhamnose or galacturonic acid with various sugar side chains. Lignin is a complex polymer that is virtually indigestible, but is important to plant cell rigidity and structure and resistance to diseases, insects, cold temperatures, and other biotic and abiotic stresses (Buxton and Redfearn, 1997). Lignin is usually further characterized as either core or noncore lignin. Core lignin is a highly condensed, high molecular-weight polymer of three closely related phenylpropanoid monomers, p-coumaryl, coniferyl, and sinapyl alcohol (Buxton et al., 1996). Noncore lignin is primarily composed of p-coumaric and ferulic acids attached to either core lignin or to arbinoxylan (Buxton et al., 1996). Lignin and all the polysaccharides within the plant cell wall are complexly cross-linked via ionic-, hydrogen-, or covalent bonding (Wang and McAllister, 2002).

Fiber concentration differs due to plant species, component, and maturity. Grasses contain more fiber than legumes, however in contrast, legumes will usually contain more lignin and the fiber is less digestible. There is increased fiber concentrations (NDF) in stems of plants compared to leaves, this is due in part to stems containing more structural and conducting tissue than leaves, where more mesophyll cells reside (Buxton and Redfearn, 1997). Leaf sheaths are intermediate in fiber concentration to that of stems and leaves. With advancing plant maturity, fiber concentration increases and digestibility decreases within each plant part, with stems decreasing in digestibility at a faster rate than leaves. As well, total plant fiber concentration increases and total plant fiber digestibility decreases due to a decrease in leaf:stem ratio with advancing maturity(Buxton and Redfearn, 1997).

There are many limitations to increasing fiber digestion and improving the harvestable energy that fiber contains. Lignin is a major source of indigestibility and is thought to interfere with microbial degradation of other plant cell wall polysaccharides through physical barriers and cross-linkages with potentially degradable polysaccharides (Buxten and Redfearn, 1997). This interference is mainly due to limiting access of microbial enzymes to substrates trapped within the lignin-polysaccharide complexes. Wang and McAllister (2002) reported that free phenolic acids and soluble phenolic-carbohydrate complexes have both been implicated in the inhibition of rumen microbial activity and potentially in preventing microbial attachment, a critical step in fiber digestion by some fiber-digesting bacteria. Another obstacle to complete fiber digestion is passage rate or limited retention time. The time allotment a feed particle is allowed to stay in the rumen is based on particle size and specific gravity, with larger and less dense particles staying in the rumen for longer retention times compared to smaller, denser particles. Retention time therefore impedes extent of digestion and not rate. Wilson and Mertens (1995) reported that fiber digestion is limited as well by the low surface area:volume ratio of parenchyma and schlerenchyma cells. These researchers also pointed to the toxic effects of phenolic-carbohydrate compounds to fiber-degrading bacteria on a micro-climate level within cells as a limitation to fiber digestion. Hoover (1986) described the reduction in fiber digestibility when readily fermentable carbohydrates are included in the diet, implicating the negative associative effect between starch and fiber digestion.

Negative associative effects of starch and fiber

An associative effect in nutrition is defined by Moe (1981) as the digestibility of a mixed diet being different from that predicted from direct measurement of the individual ingredients separately. Negative associative effects occur when the digestibility of the mixed diet is decreased from the predicted of the individual ingredients. As reported by Merchen and Bourquin (1994), negative associative effects occur with mixed forage-concentrate diets when fed at high intakes.

Joanning et al. (1981) conducted a metabolism experiment with six steers (250 kg) fed each of five diets containing corn silage and/or cracked corn grain *ad libitum*. Dietary treatments, utilizing both immature (19.9% DM) and mature corn silage (31.9% DM), consisted of: all corn silage (90%), all cracked corn grain (90%), or a 30:60 mix of corn silage and cracked corn grain. Steers fed the mixed diet had increased DMI. Dry matter digestibilities were 67.8% for the all silage diets and 84.4% for the all corn diet. The mixed diet DM digestibility was 69.8%, which is 11.3% lower than the 78.6% calculated by linear prediction. This depression in DMD and validation of a negative associative effect between grains and roughages agrees similarly with results found by Byers et al. (1975), in which whole corn and corn silage mixtures were fed. In the experiment by Joanning et al. (1981), starch utilization accounted for 56% of the total DMD depression, with NDF and protein digestion accounting for 31 and 12% of the total DMD depression.

There are many theories as to why the negative associative effect occurs between starch and fiber digestion. According to Joanning et al. (1981), the increased intake of the mixed silage-corn diet expectantly increases rate of passage and thereby potentially decreases starch and fiber digestion in the rumen and starch digestion in the small intestine. Theories by Hoover (1986) to explain the negative effects of dietary non-structural carbohydrates (**NSC**) on fiber digestion include: preference by rumen microorganisms for NSC rather than fiber or structural carbohydrates, decreased ruminal pH caused by rapid NSC digestion, and essential nutrient competition between ruminal microorganisms resulting in the proliferation of NSC digesting microorganisms in place of fiber digesting microorganisms.

Corn silage in corn-based finishing diets

When corn silage is increased in the diet and substituted for corn grain, energy density is decreased. If DMI of cattle fed mixed diets of corn grain and corn silage are similar, the ME intake of cattle fed diets with elevated ratios of corn silage:corn grain is decreased. In the net energy system (NRC, 1996), cattle that have less ME intake have a larger proportion of energy intake that is devoted to maintenance (NEm) and a consequently smaller proportion available for gain (NEg). This leads to the classical depression in ADG and poorer feed efficiencies (Goodrich et al., 1974; Preston 1975; Perry and Beeson, 1976; Danner et al., 1980; Brennan et al., 1987; DiCostanzo et al., 1997, 1998a; Erickson et al., 2001) for cattle fed diets with higher ratios of corn silage:corn grain.

There was a lot of research devoted to finishing cattle on corn silage in the 1970's. Goodrich et al. (1974) summarized much of this early work by looking at the performance and economic effects of corn silage concentration in finishing diets utilizing 17 university experiments involving 878 steers (average initial BW = 232 kg). Corn silage inclusion concentration was studied in increments of 10 percentage units from 10% to 80% of the diet. Daily gains were 1.14, 1.13, 1.10, 1.07, and 1.03 kg/d for 10, 20, 30, 40, and 50% corn silage inclusion concentrations. At higher concentrations of corn silage inclusion, the decline in ADG was greater; at 80% corn silage, ADG was 0.87 kg/d. Due to the slower rates of gain for cattle fed higher proportions of corn silage, DOF markedly increase. For 272 kg of gain, these researchers calculated 238 DOF needed for cattle fed 10% corn silage and up to 314 DOF for cattle fed 80% corn silage. Dry matter intake ranged from 6.85 to 7.35 kg/d with maximum DMI occurring in 40-50% corn silage diets, suggesting that intake was controlled by chemostatic methods at lower concentrations of corn silage and then by gut fill after this threshold. There was a linear decrease in G:F (range from 0.165 to 0.127) as corn silage inclusion was increased in the diet, with 11.8 kg additional feed required per 45.4 kg of gain for each 10 percentage unit increase in corn silage in the diet (Goodrich et al., 1974).

Peterson et al. (1973) fed diets containing 85.71% corn grain, 57.14% corn grain and 28.57% corn silage, 28.57% corn grain and 57.14% corn silage, or 85.71% corn silage. Cattle were fed longer (range of 172 to 227 DOF) as corn silage was increased in the diet due to ADG being linearly decreased (1.48, 1.39, 1.25, and 1.18 kg/d) as corn silage was increased. Gain:feed ratio was also linearly decreased by 31.8% as corn silage was increased in the diet, from 0.198 for cattle fed 85.71% corn grain to 0.135 for cattle fed 85.71% corn silage. A comparison of observed to expected gain was made for all treatments utilizing the net energy values from Lofgreen and Garret (1968). This illustrated the negative associative effect of mixed proportions of corn grain and corn silage mentioned in an earlier section, as cattle fed the 85.71% corn grain or corn silage diets had gains that were 123 and 135% of expected values versus gains that were only 110 and 113% of expected for the mixed diets. This nonlinearity agrees well with conclusions made by Vance et al. (1971) when feeding increasing concentrations of corn silage with corn grain and suggests that net energy values of feedstuffs are not constant across inclusions and diets (Peterson et al., 1973). Brennan et al. (1987) also reported evidence of this negative associative effect for diets above 30% corn silage. In contrast, Danner et al. (1980) reported that the performance-calculated NEg of a diet consisting of 67% corn silage and 33% corn was 6% improved over the linear predicted NEg from diets containing 0% corn silage (93% corn grain) and 0% corn grain (89% corn silage). However, the diet containing 0% corn silage had a performance-calculated NEg value that was 12% lower than NRC (1976) values. This would have decreased the linear predicted NEg for the diet containing 67% corn silage and consequently inflated the observed – predicted response for the 67% corn silage diet.

Gill et al. (1976) fed 96 steers (initial BW = 278 kg) diets containing 14, 30 or 75% corn silage. Cattle fed the 75% corn silage diet were fed for 196 d compared to 168 d for all other cattle to compensate for the classical response of lower ADG (1.10 kg/d for cattle fed 75% corn silage compared to 1.30 and 1.26 kg/d for cattle fed 30 and 14% corn silage, respectively). Gain:feed ratio was considerably poorer for cattle fed 75% corn silage (0.141 compared to 0.179 and 0.188 for cattle fed 30 and 14% corn silage, respectively).

The cattle feeding industry has changed quite dramatically from the 1970's to present-day. Genetic selection for growth and implant programs have allowed for greater growth potential and heavier carcass weights. Feedlot cattle are "pushed" harder to consume greater quantities of ME with smaller proportions of roughage in the diet. Gains compared to the 1970's have been correspondingly increased with the increases in ME intake which has resulted in less DOF compared to cattle fed in the past. Feed conversion has been dramatically improved and is the subject of more intense management focus than in previous decades.

More recent research evaluating elevated concentrations of corn silage replacing corn grain has been conducted by DiCostanzo et al. (1997, 1998a, and 1998b) and Erickson et al. (2001). In the first experiment, DiCostanzo et al. (1997) fed 60 steers finishing diets containing 12, 24, 36, or 48% corn silage. These researchers reported no differences in gains, however there was a linear increase in DMI as corn silage concentration was increased in the diet. Gain:feed ratio was linearly increased as corn silage concentration was increased in the diet and were 0.148, 0.141, 0.134, and 0.122 for the four corn silage concentrations fed. A similar experiment by DiCostanzo et al. (1998a) utilized 96 steers fed either 12, 24, or 36% corn silage. This experiment resulted in no difference in DMI across treatments. Gains were higher for cattle fed 12% corn silage (126 DOF) compared to those fed 30 (126 DOF) or 45% corn silage (142 DOF), and consequently feed conversions were improved as well at lower concentrations of corn silage with cattle fed 12, 24, and 36% corn silage having G:F of 0.149, 0.129, and 0.128, respectively.

Erickson et al. (2001) conducted three experiments evaluating 15, 30, and 45% corn silage in finishing diets. These researchers found a linear decrease in ADG and G:F as corn silage increased in the diet for two of their three experiments (1 with yearling steers and 1 with calf-fed steers). Intake was not different across treatments, but G:F was decreased by 5.6% when comparing 15 to 30% corn silage and by 7.4% when comparing 15 to 45% corn silage for yearling cattle. When feeding calf-fed steers, DMI was improved for cattle fed both 30 and 45% corn silage. Gains were linearly decreased from 1.59 to 1.42 kg/d as corn silage was increased in the diet. Feed efficiency for steers fed 30 and 45% corn silage were 8.8 and 15.4% decreased, respectively, compared to cattle fed 15% corn silage. In the third experiment by Erickson et al. (2001), ADG and feed efficiency responded quadratically as corn silage was increased in the diet. When comparing 15 to 30% corn silage treatments, ADG and feed efficiency were decreased by 13.5%. When these researchers compared 15 to 45% corn silage, there were reductions in ADG and feed efficiency of 9.1 and 7.8%, respectively. Comparatively, the summary by Goodrich et al. (1974) reported approximately a 15% reduction in feed efficiency when corn silage was increased from 15 to 45% of the diet.

When cattle are fed elevated concentrations of corn silage (or roughage), dressing percentage is decreased due to increased gut fill. In the experiment conducted by Peterson et al. (1973), dressing percentage linearly decreased (64.36 to 62.61%) as corn silage was increased from 0% to 85.71% of the diet. This agrees with Gill et al. (1976), when cattle where fed 75, 30, or 14% corn silage, dressing percentages were 62.8, 65.9, and 65.3%, respectively. Danner et al. (1980) also reported a reduction in dressing percentage as corn silage concentration in the diet increased from 16 to 92.5%. These differences in dressing percentage supports the importance of assessing feedlot performance data on a carcass weight basis and not on a live weight basis, thereby removing the bias of variable gut fill between treatments on performance data.

Economic evaluation of feeding elevated concentrations of corn silage has been variable, mainly due to the complexity of pricing corn silage. Due to the variability of corn silage in regards to DM content, grain content, analyzed nutrient content, total plant yield and, perhaps more importantly, a multitude of opportunity costs/returns associated with dry commodity corn production and corresponding harvest costs; there are many ways of calculating a price for corn silage. This calculated price has major implications on the net returns of feeding elevated concentrations of corn silage in substitution of corn to finishing cattle.

In the summary by Goodrich et al. (1974), economic data were favorable for high concentrations of corn silage inclusion based on assumptions of \$3.50/bu corn price (84.5% DM) and \$26.45/ton corn silage (32% DM) price. In the first experiment by

DiCostanzo et al. (1997) and assuming $3.00/bu of corn, the authors concluded that feeding cattle 36% corn silage ($31.50/ton) resulted in the most net return to feeding and most net return per acre of corn. DiCostanzo et al. (1998b) reported that when corn was priced at $3.00/ bu and corn silage at $21.50/ton (cost of production), the most net return to feeding and the most net return per acre occurred when cattle were fed 36% instead of 12 or 24% corn silage. However, when these authors assumed $3.00/bu corn and corn silage priced at $31.50 (including assumed opportunity cost of dry grain), the most net return both to feeding and per acre occurred when corn silage was reduced to the lowest concentration or 12% compared to 24 or 36% corn silage. In general, the economics of feeding elevated concentrations of corn silage in substitution of corn grain is more favorable in periods of high priced corn grain. This is mostly due to the harvesting costs of corn silage being a smaller proportion of the total costs of corn silage compared to the opportunity costs of the dry grain. Economically important as well is the added non-feed costs reported by Goodrich et al. (1974) associated with feeding elevated concentrations of corn silage. Yardage charges are increased due to lower ADG and increased DOF associated with feeding elevated concentrations of corn silage.

Distillers grains production

The United States ethanol industry has experienced exponential growth in the past 30 years due to increasing fuel prices and government policy. In 1980, the United States produced 175 million gallons of ethanol, however in 2013 production was 13.3 billion gallons of ethanol (Renewable Fuels Association, 2014). With this increase in ethanol production, there is a corresponding increase in co-products available to the livestock feeding industries, as with each bushel of grain feedstock fermented in the dry milling production of ethanol, one third of the original cereal grain on a dry weight basis is returned to the animal feed market in the form of distiller's grains with (**DGS**) or without solubles (**DG**) (Erickson et al., 2010). Cereal grains are approximately 2/3 starch. Since the starch is fermented for the production of ethanol, all of the fiber, protein, fat, and minerals are concentrated 3-fold and are returned in the form of co-products (Klopfenstein et al. 2008). Wet distillers grains with solubles (**WDGS**) is the co-product produced when the distillers grains are combined with condensed distillers solubles at the end of the dry milling process on a DM basis. Distillers grains with solubles have a CP content of approximately 30% and a NDF content of 40% according to the NRC (1996). Distillers grains are used as a protein source for finishing cattle when fed at 15-20% of the diet (DM) and can be used as both a protein and an energy source when fed above 15-20% of the diet (DM); consequently, protein and P is fed above animal requirements at these increased dietary concentrations (Klopfenstein et al., 2008).

Distillers grains in high forage diets

Distillers grains have been utilized for supplementing high forage diets. Starch causes a depression in forage intake and is a hindrance to fiber digestion (Fieser and Vanzant, 2004). Comparatively to corn grain, DG and DGS are relatively devoid of starch due to the starch-fermenting ethanol process. Due to the low starch content and elevated concentrations of protein and phosphorous, distillers grains complements forages well. With starch removed, most of the energy in distillers grains comes from the protein, fat, and the highly digestible NDF fractions. Lightweight cattle are grown for a period of time before feedlot entry on high forage diets. Lightweight growing cattle require high concentrations of metabolizable protein (**MP**) in the form of undegradable intake protein (**UIP**; Klopfenstein et al., 1996); DGS meets this protein requirement with 31-34% CP and 63% UIP (Castillo-Lopez et al., 2013).

When studying the nutritional profiles of both corn grain and DGS, DGS should be more complementary to high forage-based diets. Loy et al. (2007) supplemented either dry distillers grains with soluble (**DDGS**), dry-rolled corn (**DRC**), or a blend of DRC and corn gluten meal (BLEND) to heifers consuming low quality grass hay. The blend treatment was formulated to supply similar MP estimates as DDGS. Supplements were offered at either LOW (0.21% of BW) or HIGH (0.79% of BW) levels. At LOW levels of supplementation, DDGS-supplemented heifers had improved ADG and G:F with similar DMI compared to the DRC or BLEND-supplemented heifers. At HIGH levels of supplementation, heifers fed the DDGS and BLEND supplements had improved ADG, but these researchers found no difference in DMI or G:F across supplement type. Loy et al. (2008) calculated a TDN of DDGS that was 118-130% the value of corn in this experiment. Nuttelman et al. (2009) compared WDGS to DRC in a growing diet containing grass hay and sorghum silage. Diets were formulated to be isocaloric (assuming a WDGS energy value of 127% that of corn) with DRC and WDGS fed at 33.6 and 25%, respectively, replacing grass hay. From this study, Nuttelman et al. (2009) concluded that WDGS has 130% the energy of corn in high forage diets.

Nuttelman et al. (2010) conducted a 2 X 3 factorial study with factors of energy source and concentration. A feeding value for WDGS was assumed to be 130% that of corn in order to formulate isocaloric diets within concentrations across energy sources. Wet distillers grains were fed at either 15, 25, or 35% (DM). Dry rolled corn was included at 22, 41, or 60% (DM). The base diet contained 30% sorghum silage with the energy sources replacing grass hay. From this experiment, Nuttelman et al. (2010) concluded that WDGS has an energy value ranging from 142 – 149% that of DRC.

Differences in energy values of DGS across moisture concentrations of DGS have been studied in forage based growing diets. In finishing diets, there appears to be a DGS drying effect on DGS feeding value with WDGS having higher energy values than MDGS than DDGS (Bremer et al., 2011; Nuttelman et al., 2011), this appears to not hold true in high forage growing diets. In a growing study conducted by Ahern et al. (2011), DDGS and WDGS were fed at 15 or 30% (DM) replacing a 60:40 ratio of grass hay and sorghum silage. Dry-rolled corn was also fed at either 22 or 50% (DM) replacing the blend of grass hay and sorghum silage. Diets were formulated to contain equal amounts of energy (TDN of DDGS and WDGS assumed to be 108% or 120% that of corn, respectively). There was no interaction between energy source and concentration, as well as no differences in performance across energy sources. From this experiment, Ahern et al. (2011) concluded that DDGS and WDGS has an energy value of 114% and 120% that of corn, respectively. Jones et al. (2014) conducted a 2 X 3 factorial experiment with factors of DGS type (MDGS or DDGS) and level of supplementation (0.3, 0.7, or 1.1% of BW) in calves grazing corn residue. These researchers agreed with Ahern et al. (2011) that there is no performance difference across type (or moisture content) of DGS in high forage growing programs.

Griffin et al. (2012) conducted a meta-analysis studying the effects of level of DGS supplementation to cattle consuming forage-based diets. These researchers utilized 13 pasture-grazing and 7 confinement-fed experiments in their analysis. In this analysis, ADG and ending BW were linearly improved with increasing supplementation of DGS in pasture studies and quadratically increased in confinement studies. Due to the collection of individual forage intakes in the confinement-fed treatment means, the effect of DGS supplementation level on total DMI and forage intake was quantified. As supplementation of DGS was increased, total DMI was quadratically increased. Additionally, forage intake was quadratically decreased with increasing DGS supplementation (Griffin et al., 2012). These results agree with other researchers suggesting that when cattle are supplemented with DGS, the DGS replaces intake of grazed or harvested forages (MacDonald et al., 2007; Griffin et al., 2012; Watson et al., 2012; Gillespie et al., 2013).

Distillers grains in finishing diets

With the expanding availability of DGS to the cattle feeding industry, it has been the subject of many research experiments in feedlot cattle finishing diets. Bremer et al. (2011) conducted a meta-analysis with feedlot finishing diets where DGS replaced DRC, HMC, or a combination of DRC and HMC. In this meta-analysis, these researchers found that DMI increased quadratically at a decreasing rate as DGS increased in the diet. In MDGS and WDGS diets, ADG and G:F increased quadratically with maximum ADG occurring at 30% of diet (DM) and maximum G:F occurring at 40% of the diet (DM). In DDGS diets, ADG and G:F linearly increased as DDGS increased in the diet (Bremer et al., 2011). In this meta-analysis by Bremer et al. (2011), a feeding value relative to corn was calculated for WDGS, MDGS, and DDGS at each inclusion. Feeding value for each inclusion of DGS was calculated as the increase in G:F of the diet containing DGS compared with the control diet containing no DGS divided by the level of inclusion of DGS that substituted the corn in the diet (Bremer et al., 2011). The calculated feeding values were 150, 143, 136, and 130% that of corn for WDGS fed at 10, 20, 30, and 40% of the diet (DM; respectively). For MDGS, the calculated feeding values were 128, 124, 120, and 117% that of corn for MDGS fed at 10, 20, 30, and 40% of the diet (DM; respectively). These authors noted that G:F values did not decrease at the higher inclusion concentrations, but feeding values decreased due to accounting for increased DGS inclusion in the feeding value calculation. The feeding value of DDGS did not change with increases in inclusion and was 112% that of corn when fed at 10 to 40% of the diet (DM; Bremer et al., 2011). When comparing the meta-analyses (across experiments), there is an increase in feeding value for WDGS compared to MDGS compared to DDGS. Nuttelman et al. (2011) agreed with this drying effect on feedlot performance in a study comparing WDGS, MDGS, and DDGS in a corn-based finishing diet, however the reason for this drying effect has largely been unexplainable (Nuttelman et al., 2011).

Roughage concentration and source in finishing diets containing distillers grains

The inclusion of DGS in finishing diets increases NDF concentration and decreases starch concentration. Due to this, roughage source and concentration in finishing diets containing DGS has been studied. Benton et al. (2007) evaluated the effect of roughage source utilizing alfalfa, cornstalks, and corn silage on an equal NDF basis (with corn silage NDF calculated from the whole plant and not just stover fraction) in diets containing 30% WDGS. Roughage concentration was also assessed, with treatments of no roughage, roughage concentration equivalent to 4% alfalfa, and roughage concentration equivalent to 8% alfalfa. Intake and ADG were lowest for steers fed no roughage diets, suggesting that the NDF concentration of WDGS does not supply adequate effective roughage. These researchers reported no differences in G:F across roughage sources (Benton et al., 2007). Benton et al. (2007) suggested that roughages can be exchanged on an equal NDF basis in finishing diets containing WDGS, as DMI were similar across roughage sources within roughage concentrations. In steam flaked corn (SFC) based finishing diets containing 0 or 25% DDGS, Uwituze et al. (2009) reported greater DMI for cattle fed corn silage (11% of diet on DM basis) compared to alfalfa hay (6% of diet on DM basis), which was explained by greater roughage NDF in corn silage diets. Uwituze et al. (2009) reported no differences in ADG, G:F, or final BW due to roughage source. The results by Quinn et al. (2011) when utilizing alfalfa, bermudagrass hay, and sorghum silage in SFC based finishing diets containing 15 or 30% WDGS suggest that roughage sources cannot be exchanged on an equal roughage NDF basis. These researchers reported inclusion of sorghum silage with 15% WDGS resulted in greater DMI and ADG, but decreased G:F (Quinn et al., 2011). Quinn et al. (2011) also reported that alfalfa reduced ADG and final BW.

Hales et al. (2013) fed 2, 6, 10, and 14% alfalfa hay in DRC based finishing diets containing 25% WDGS. Intake was linearly increased as alfalfa increased in the diet. Gains responded quadratically with increases in ADG from 2 to 6% alfalfa then decreasing at higher concentrations of alfalfa (Hales et al., 2013). Solving for the first derivative, ADG and G:F were optimized at alfalfa inclusions of 3 and 7%, respectively (Hales et al., 2013). May et al. (2011) reported improved G:F when 7.5% alfalfa hay was fed compared to 10 or 12% alfalfa in SFC based finishing diets containing either 15 or 30% WDGS. May et al. (2010) fed 5 or 15% corn silage in DRC or SFC based finishing diets containing 25% DDGS. In the first experiment, there was no differences in DMI, ADG, or G:F due to corn silage inclusion. However, in the second experiment, DMI and ADG were decreased (7.2 and 7.0%, respectively) as corn silage inclusion was decreased in diet with no differences in G:F (May et al., 2010). From the literature, adequate roughage concentrations in finishing diets containing DGS are relatively close to the industry standard roughage concentration of 8-9% (DM; Hales et al., 2013).

Conclusions

Due to the competition from ethanol production and worldwide feed grain consumption, the price and volatility of corn grain have made cattle feeders source alternate feedstuffs to finish cattle. Corn silage was widely fed as a major energy source in finishing diets in the 1970's. However, due to the overproduction of corn and consequential inexpensive corn grain prices (1980's until approximately 2008); cattle feeders decreased corn silage concentrations due to corn grain being more energy-dense and more economical on an energy basis. Distillers grains with solubles have been shown to be an excellent source of protein and energy for feedlot cattle and subsequently have been widely adopted in present-day feedlot diets. Corn silage production and feeding at elevated concentrations to feedlot cattle have been shown to be economical in times of high-priced corn. Limited work has been done evaluating increasing concentrations of corn silage as an energy source in present-day feedlot diets containing distillers grains with solubles. As well, there is a need for recent regional research on the effects of corn hybrid selection and production practices on corn silage quality and yield. The economics of replacing corn with corn silage in feedlot diets is largely determined by corn silage price compared to corn grain price. The complexity of pricing corn silage compared to corn grain remains significant, with many unknowns surrounding input pricing variables. Therefore additional work needs to be conducted evaluating corn silage production and pricing scenarios for feedlot cattle, as well as, nutrient metabolism, cattle performance, and carcass characteristics when cattle are fed increased concentrations of corn silage in finishing diets containing distillers grains with solubles.

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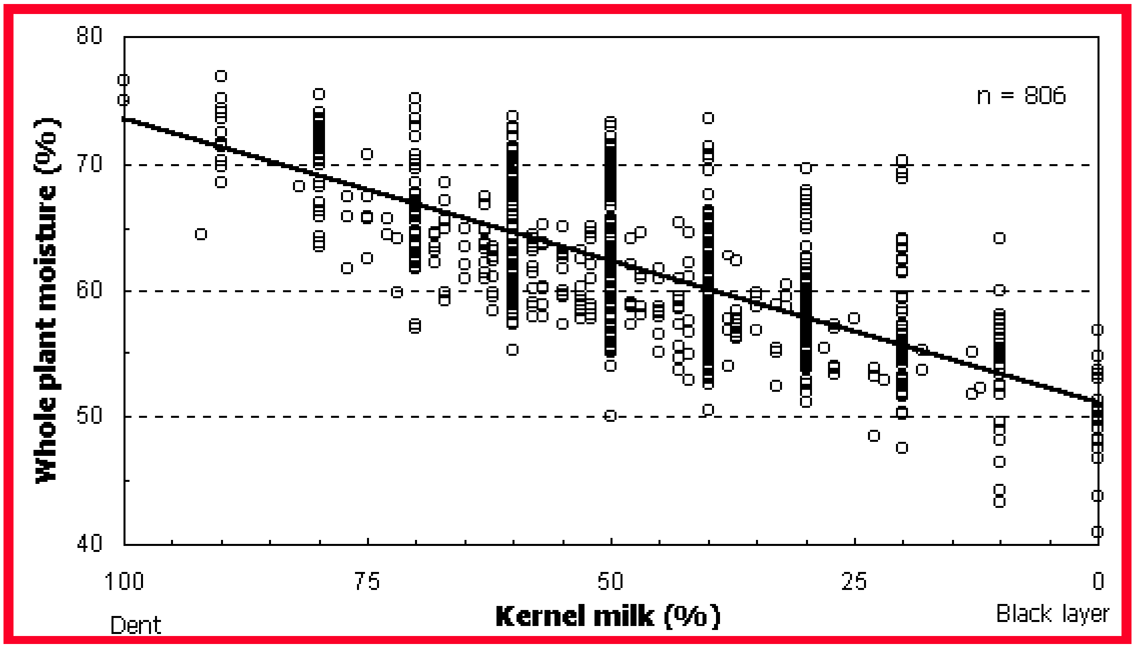
Figure I-1. Diagram of kernel milkline.

Fig. 1. When an ear of maize is broken in half, the tip half (on the left) contains kernels with their smooth or endosperm sides exposed. The butt half (on the right) contains kernels with their embryo sides exposed. If the kernels are approaching maturity, a "line" (arrow) can be seen on the smooth side of the kernels. This line is called the milk line.

Adapted from Afuakwa and Crookston, 1984.

Figure I-2. Relationship between kernel milkline and corn silage DM content. Each datapoint is one hybrid in an environment.



Adapted from Lauer, 1999.

Running Header: Corn silage and distillers grains for finishing cattle

CHAPTER II. Digestibility and performance of steers fed corn silage and modified distillers grains with solubles to partially replace corn in finishing diets[1]

D. B. Burken, B. L. Nuttelman, M. J. Jolly-Briethaupt, J. L. Harding, S. E. Gardine, T. J. Klopfenstein, J. C. MacDonald, and G.E. Erickson[2]

Department of Animal Science, University of Nebraska, Lincoln 68583

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[2] Corresponding author: gerickson4@unl.edu

ABSTRACT

Two finishing and one digestibility experiments evaluated the partial substitution of corn with corn silage (CS) and corn modified distillers grains with solubles (MDGS). Steers were used in Exp. 1 (n = 295; 467 ± 52 kg) and Exp. 2 (n = 225; BW = 348 ± 27 kg) in a 2 x 2 + 1 factorial arrangement of treatments with factors including CS (15 or 45%) and MDGS (20 or 40%) (15:20 – 15% CS, 20% MDGS; 15:40 – 15% CS, 40% MDGS; 45:20 – 45% CS, 20% MDGS; 45:40 – 45% CS, 40% MDGS) plus a control diet consisting of 5% cornstalks and 40% MDGS. In Exp. 1, there were tendencies for a CS X MDGS interaction for ADG, final BW, and G:F ($P \leq 0.08$). In the overall F-test for G:F, there were no differences between the control treatment and 15:20, 15:40, or 45:40 ($P \geq 0.15$), however, steers fed the control treatment had increased G:F compared to steers fed 45:20 treatment diets ($P = 0.03$). In Exp. 2, there were no CS x MDGS interactions ($P \geq 0.12$). As CS increased in the diet, ADG, final BW, and G:F decreased ($P \leq 0.01$). As MDGS increased from 20 to 40%, ADG and G:F tended to improve ($P \leq 0.07$). In the overall F-test, the control was not different for G:F from 15:20, 45:20, or 45:40 ($P \geq 0.15$), but had a 4.8% poorer G:F compared to 15:40 ($P < 0.01$). In Exp. 3, ruminally fistulated steers (n = 6) were used in a 5 x 6 Latin rectangle design 15 or 45% CS and 20 or 40% MDGS as a 2 X 2 factorial in addition to a +1 consisting of 95% CS and 5% supplement. There were no CS x MDGS interactions for nutrient intake, total tract digestibility, ruminal pH measurements, acetate: propionate ratio (A:P), or in-situ disappearance data ($P \geq 0.31$) for the 2 X 2 factorial. As CS increased in the diet, DMI, NDF intake, ruminal pH, A:P, in-situ NDF disappearance of corn bran, and DM disappearance of corn increased ($P \leq 0.09$) with decreases in DM and OM digestibility (*P*

≤ 0.03). As MDGS increased in the diet, there was an increase in NDF intake, total volatile fatty acid concentration, and NDF disappearance of corn bran (*P* ≤ 0.03) with no differences for any other tested variables (*P* ≥ 0.13). In general, increasing CS in place of corn in finishing diets containing MDGS results in a modest reduction in ADG and G:F with increases in ruminal pH, and replacing corn with MDGS in CS diets improved ADG and G:F.

Key Words: corn silage, distillers grains with solubles, roughage, feedlot

INTRODUCTION

The amount of U.S. corn production used for alcohol fuel has increased from 0.89 to 128 million t since 1980 (ERS, 2014). Because of the resultant increased competition for corn, alternative feedstuffs have been sought after to replace high-priced corn for cattle finishing diets. The use of corn silage in partial substitution of corn grain in beef finishing diets has been shown to be economical in times of expensive corn (Goodrich et al., 1974; DiCostanzo et al., 1998a). Feeding corn silage allows cattle feeders to take advantage of the entire corn plant at a time of maximum quality and tonnage as well as secure substantial quantities of roughage/grain inventory. Past research (Goodrich et al., 1974; Gill et al., 1976; Erickson et al., 2001) with corn silage partially replacing corn in finishing diets has resulted in reductions in G:F as corn silage inclusion is increased; however, this research was completed prior to the expansion of the ethanol industry and the common use of distillers grains in finishing diets. Distillers grains are a source of highly digestible fiber and minimal starch (Klopfenstein et al., 2008). Due to higher concentrations of highly digestible fiber and a decrease in total dietary starch concentration, there are potential benefits of adding elevated concentrations of corn silage in finishing diets containing distillers grains in terms of rumen environment, fiber digestion, and cattle performance. Distillers grains are commonly used in feedlot diets throughout the ethanol belt as an economical protein source, however when market conditions dictate, distillers grains may be fed as an energy source at dietary concentrations of 30-50% (DM; Klopfenstein et al., 2008). Therefore the objectives of these experiments were to determine the effects on digestibility and rumen metabolism, cattle performance, and carcass characteristics of feeding elevated concentrations of both corn silage and MDGS as a partial replacement of corn in finishing diets.

MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Exp. 1 and 2

Upon arrival at the research feedlot, all steers on Exp. 1 were individually identified and processed with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza$_3$, and bovine respiratory syncytial virus (Bovi-Shield Gold 5, Pfizer Animal Health, New York, NY), a *Haemophilus somnus* bacterin (Somubac, Pfizer Animal Health), and an injectable anthelmintic (Dectomax, Pfizer Animal Health). All steers on Exp. 1 were revaccinated approximately 14-28 d after initial processing with Bovi-Shield Gold 5 (Pfizer Animal Health), a killed viral vaccine for clostridial infections (Vision 7 Somnus with SPUR, Merck Animal Health, Summit, NJ), and a killed viral vaccine for pinkeye prevention (Piliguard Pinkeye TriView, Merck Animal Health). At initial processing all steers on Exp. 2 were individually identified and processed with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I & II, parainfluenza$_3$, bovine respiratory syncytial virus, and bacterins for *Mannheimia haemolytica* and *Pasteurella multocida* (Vista Once SQ, Merck Animal Health), an injectable anthelmintic (Cydectin Injectable, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), and an oral drench for internal parasites (Safe-Guard, Merck Animal Health). All steers on Exp. 2 were revaccinated approximately 12-28 d after initial processing with a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza$_3$, and bovine respiratory syncytial virus (Vista 5 SQ, Merck Animal Health) and Vision 7 Somnus with SPUR (Merck Animal Health). Steers were limit fed (Watson et al., 2012) to equalize gastro-intestinal fill a diet containing 47.5% sweet bran 47.5% alfalfa hay, and 5.0% supplement (DM basis), at 2.0% of projected BW for 5 d, prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). All these procedures on both experiments were performed prior to experiment initiation.

In Exp. 1, crossbred yearling steers (n = 295; BW = 467 ± 52 kg) were utilized in a randomized complete block design with six BW blocks and 30 pens (9 or 10 steers/pen). For Exp. 2, crossbred steer calves (n = 225; BW = 348 ± 27 kg) were separated into three BW blocks (randomized block design) and assigned randomly to one of 25 pens (9 steers/pen). Treatment design was the same in both Exp. 1 and 2. Treatments were designed as a 2 x 2 + 1 factorial arrangement consisting of 15% or 45% corn silage and 20% or 40% MDGS (15:20 - 15% corn silage, 20% MDGS; 15:40 - 15%

corn silage, 40% MDGS; 45:20 - 45% corn silage, 20% MDGS; and 45:40 - 45% corn silage, 40% MDGS; DM basis) and a control diet consisting of 5% cornstalks and 40% MDGS (control; Tables II-1 and II-2). Elevated concentrations of corn silage and MDGS replaced a 1:1 blend of dry-rolled corn (DRC): high moisture corn (HMC) on a DM basis. All steers were fed a supplement formulated to provide 33 mg/kg of DM monensin (Elanco Animal Health, Indianapolis, IN) and a targeted intake of 90 mg/steer daily of tylosin (Elanco Animal Health). Thiamine (International Nutrition, Inc., Omaha, NE) was included at a targeted intake of 150 mg/steer daily in Exp. 1. There was no supplemental thiamine included in the diet for Exp. 2. Steers were implanted with Revalor-200 (Merck Animal Health) on d 1 in Exp. 1. For Exp. 2, steers were implanted with Revalor-XS (Merck Animal Health) on d 1. In both experiments, feedbunks were assessed at approximately 0530 h with the goal of trace amounts of feed at the time of feeding. All diets were fed once daily. Feed refusals were removed from feedbunks when needed, weighed, and subsampled. All feed refusal subsamples were dried for 48 h in a 60ºC forced-air oven for determination of DM (AOAC, 1999 method 4.1.03) and calculation of refusal DM weight. Dietary ingredients were sampled weekly for determination of DM by aforementioned method with dietary as-fed ingredient proportions adjusted weekly. Dietary ingredient samples were analyzed for CP (AOAC, 1990 method 990.06; TrueSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), and ether extract (Bremer, 2010; Tables II-1 and II-2). Weekly dietary ingredient samples were composited and then analyzed by a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) for Ca, P, K, and S concentration. Dietary mineral concentration was then calculated utilizing ingredient mineral concentration and dietary inclusion of ingredients. Steers in both experiments were harvested at a commercial abattoir (Greater Omaha Pack, Omaha, NE). One block of steers were harvested after 91 DOF in Exp. 1, with the remaining five blocks harvested after 98 DOF. For Exp. 2, one block of steers were harvested after 134 DOF and the other two blocks were harvested after 148 DOF. On the day of shipping to the commercial abattoir, pens of steers were fed 50% of the previous day's DM offer at regular feeding time. Pens of steers were then weighed on a platform scale at 1500 h prior to being loaded for shipping. A 4% pencil shrink was applied to this weight for final live BW and calculation of dressing percentage. Hot carcass weight and liver scores were obtained the d of harvest. Liver abscesses were categorized from 0 (no abscesses), A-, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were then combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in calculation of ADG and G:F, was calculated from HCW and a common dressing percentage of 63%. Marbling score, 12th rib fat thickness, and LM area were recorded after a 48 h (block 1, Exp. 1; Exp. 2) and 144 h (block 2-6; Exp. 1) carcass chill. Yield grade was calculated according to Boggs and Merkel (1993) using carcass measurements (assuming a common 2.5% KPH) and the following formula: (YG = (2.50 + (0.0017 x HCW, kg) + (0.2 x KPH, %) + (6.35 x 12th rib fat, cm) - (2.06 x LM area, cm2)).

The feeding value of corn silage and MDGS relative to the corn blend on a DM basis was calculated by the following equation for each inclusion level: [1 – ((G:F of higher inclusion diet – G:F of lower inclusion diet) ÷ G:F of lower inclusion diet) ÷

amount of inclusion level substitution] x 100 + 100. The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Performance, carcass data, and energy values were analyzed using the Mixed procedure of SAS (SAS Inst., Inc., Cary, NC). Pen was the experimental unit, and BW block was included as a fixed effect. Main effects of corn silage and MDGS inclusion were tested as well as the interaction of corn silage x MDGS. For Exp. 2, there were no corn silage x MDGS interactions for any of the tested variables; therefore, the interaction term was taken out of the statistical model for Exp. 2. The control was included in the analysis using an overall F-test across all treatments. Prevalence of liver abscesses was analyzed using the GLIMMIX procedure of SAS (SAS Inst., Inc.) using a binomial distribution. Treatment differences were evaluated when overall significance was $P \leq 0.05$.

Exp. 3

Six ruminally fistulated steers were used in a 5 X 6 Latin rectangle experiment to determine diet digestibility of 5 diets. Steers were assigned randomly to each dietary treatment for five, 21-d periods, with a 15-d adaptation period and a 6-d fecal sample collection period. Treatments were designed as a 2 x 2 + 1 factorial arrangement. The 2 x 2 treatment design was the same as in Exp. 1 and 2; however, the +1 diet in Exp. 3 consisted of 95% corn silage and 5% supplement (95:0; Table II-3). Elevated levels of corn silage and/or MDGS replaced DRC. Diets were mixed twice weekly and stored in a cooler (0ºC) to ensure fresh feed. All steers were fed a supplement formulated for 33 g/kg monensin (DM basis; Elanco Animal Health) and a targeted intake of 90 mg/steer daily of tylosin (DM basis; Elanco Animal Health). Urea was included at 1.66% of the diet in the 95:0 treatment, at 0.50% of the diet in diets containing 20% MDGS, and no urea was included in the supplement for diets containing 40% MDGS.

Titanium dioxide was ruminally dosed at 5 g/steer twice daily at 0800 and 1600 h for seven d prior to and for the duration of the collection period. Fecal grab samples (approximately 300 g) were collected at 0800, 1200, and 1600 h during d 16-20 of each period. Fecal samples were composited on a wet basis into daily composites and then lyophilized (Virtis Freezemobile 25ES, SP Industries, Warminster, PA). From daily composites, a steer within period fecal sample composite was prepared and subsequently analyzed for NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), OM (600ºC for 6 h), and Ti concentration (Spectra MAX 250, Molecular Devices, LLC , Sunnyvale, CA; Myers, 2004). Ruminal pH was recorded every minute using wireless pH probes (Dascor Inc.; Escondido, CA) from d 16 to d 20 of each period. Rumen fluid samples were collected at 0800, 1100, 1400, 1600, and 1900 h on d 21 of each period and were analyzed for ruminal volatile fatty acids (**VFA**; Trace 1300, Thermo Fisher Scientific, Waltham, MA) using the procedures outlined by Ehrlich et al. (1981). Feeds offered and refused were analyzed for DM, OM, and NDF concentration using the procedures mentioned above. Dry matter of feed ingredients and orts were determined using a forced-air oven set at 60ºC for 48 h.

An in-situ study was conducted concurrently to the digestibility experiment utilizing the same experiment steers and treatments. Dacron bags (5 cm x 10 cm Ankom *in situ* bags (R510) with a 50 µm pore size; Ankom Techology, Macedon, NY) were filled with 1.25 g of dry corn bran, DRC, or corn silage. The DRC and corn silage utilized for the in-situ experiment was from the same source as experimental diets. Dry corn bran and DRC were oven-dried using the methodology above, and corn silage was lyophilized (Virtis Freezemobile 25ES, SP Industries). Dry corn bran, DRC, and corn silage were ground through a 2 mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) prior to being weighed into the dacron bags. Four bags per feedstuff were placed in mesh bags and incubated in the ventral rumen of each of the 6 steers for incubation time periods of 24 and 36 h. Bags were incubated at different times and all bags were removed at the same time (0800 h on d 6 of the collection period). Two nonincubated bags (0 h) were also prepared for each sample. In-situ bags were rinsed five times in a washing machine (39ºC water) utilizing one minute agitation and two minute spin cycles (Whittet et al., 2003). All in-situ bags were then rinsed with distilled water. In-situ bags containing DRC were then dried at 60ºC for 48 h and then weighed for determination of DM disappearance. Neutral detergent fiber disappearance was determined for in-situ bags containing corn bran and corn silage by refluxing bags in neutral detergent solution using the ANKOM ^{200} Fiber Analyzer (Ankom Technology). Samples were agitated in NDF solution for 1 hour at 100° C then rinsed with distilled water for five minutes four separate times. Dry matter disappearance of DRC and NDF disappearance of corn bran and corn silage within each dietary treatment was calculated by subtracting remaining residue of each sample (24 and 36 h) from the initial value (0 h; non-incubated bags) and then dividing by the original DM (DRC) or NDF percentage (corn bran and corn silage) of the feedstuff.

Total tract nutrient intake and digestibility data were analyzed using the Mixed procedure of SAS (SAS Inst., Inc.) with period and treatment as fixed effects. Steer was included as a random effect. Main effects of corn silage and MDGS inclusion and the interaction between corn silage and MDGS inclusion were also tested for the 2 x 2 factorial. The interaction was removed from the model due to lack of significance ($P > 0.10$). The Mixed procedure of SAS (SAS Inst., Inc.) was used for analysis of ruminal VFA data with fixed effects of treatment, time of incubation (24 or 36 h), and period. Treatment x time was included as a fixed effect in the analysis of ruminal VFA data but was removed from the model due to lack of significance ($P > 0.10$). The same model was used in the analysis of in-situ data, but the treatment x time interaction was included in the model when significant ($P < 0.10$). In-situ bag was the experimental unit. Steer was used as a random effect in the in-situ analysis. Period was removed from the model in the analysis of in-situ data due to variability across periods and the inaccurate statistical prediction of least square means relative to observed means. Ruminal pH data were analyzed as a repeated measure using the GLIMMIX procedure (SAS Inst., Inc.) with d as the repeated measure. An autoregressive covariance structure was used for pH variables (Littell et al., 1998). Treatment was the fixed effect, and steer was utilized as a random effect. Period was removed from the model due to missing datapoints within period and the subsequent inaccurate statistical prediction of least square means relative to observed means. An autoregressive covariance structure was utilized for pH repeated measures analysis. Main effects of corn silage and MDGS inclusion and the interaction between corn silage and MDGS inclusion were also tested. Treatment differences were evaluated when overall significance was less than $P = 0.10$.

RESULTS AND DISCUSSION

Due to the similar treatment designs between Exp. 1 and 2, the experiment x corn silage x MDGS interaction was tested for pooling of experiments. There was an experiment x corn silage x MDGS interaction for ADG (*P* = 0.04) and tendencies for experiment x corn silage x MDGS interactions for HCW (*P* = 0.06) and G:F (*P* = 0.07). Therefore experiment 1 and 2 were analyzed and will be presented separately.

Exp. 1

There was no interaction between corn silage and MDGS for DMI (*P* = 0.24; Table II-4), and therefore the main effects of corn silage and MDGS will be presented. There was no difference in DMI as corn silage increased from 15 to 45% of the diet (*P* = 0.34). There was also no difference in DMI due to concentration of MDGS (*P* = 0.47). There was a tendency for a corn silage x MDGS interaction for ADG (*P* = 0.08), and therefore the simple effects will be presented. For diets containing 20% MDGS, ADG decreased by 13.6% (*P* = 0.01) as corn silage increased from 15 to 45% of the diet. In diets containing 40% MDGS diets, there was no difference in ADG (*P* = 0.87). When steers were fed 40% MDGS compared to 20% MDGS in diets containing 15% corn silage, there was an 8.3% numerical decrease in ADG from 1.69 kg/d to 1.55 kg/d (*P* = 0.11). In 45% corn silage diets, there was a 4.8% numerical increase in ADG as MDGS increased from 20 to 40% of the diet (1.46 kg/d for 45:20 compared to 1.53 kg/d for 45:40; *P* = 0.36).

There was a tendency for a corn silage x MDGS interaction for G:F (*P* = 0.07), and thus the simple effects will be discussed. In diets containing 20% MDGS, G:F decreased from 0.126 to 0.109 as corn silage increased from 15 to 45% of the diet ($P < 0.01$). However in 40% MDGS diets, there was a slight numerical decrease in G:F as corn silage increased from 15 to 45% of the diet (0.118 compared to 0.114; $P = 0.38$). For diets containing 15% corn silage, there was a numerical decrease in G:F from 0.126 to 0.118 as MDGS increased from 20 to 40% of the diet ($P = 0.12$). Conversely, in 45% corn silage diets, there was a numerical increase in G:F as MDGS increased from 20 to 40% of the diet (0.109 for 45:20 compared to 0.114 for 45:40; $P = 0.30$). Feeding values relative to the corn blend (1:1 blend of HMC and DRC on a DM basis) were calculated as the decrease in G:F of the diet containing 45% corn silage compared with the diet containing 15% corn silage divided by the level of inclusion of corn silage (30%) that substituted the corn blend in the diet. For the 30% replacement of corn by corn silage, the feeding value of corn silage was 56% in 20% MDGS diets and 88% in 40% MDGS diets. Using the same feeding value calculation methodology mentioned above, the 20% replacement of the corn blend by MDGS resulted in the feeding value of MDGS being 70% in 15% corn silage diets and 122% in 45% corn silage diets.

There was a tendency for a corn silage x MDGS interaction for HCW ($P = 0.09$). For diets containing 20% MDGS, HCW was decreased (398 compared to 384 kg; $P = 0.02$) as corn silage increased from 15 to 45% of the diet. In 40% MDGS diets, there was no difference in HCW ($P = 1.00$). With diets containing 15% corn silage, HCW numerically decreased from 398 to 389 kg when MDGS increased from 20 to 40% of the diet ($P = 0.11$). In 45% corn silage diets, there was a numerical increase of 5 kg of HCW as MDGS was increased from 20 to 40% of the diet ($P = 0.38$). A tendency was also observed for the interaction between corn silage and MDGS for LM area ($P = 0.09$).

There was a tendency for LM area to decrease as corn silage increased from 15 to 45% in 20% MDGS diets (*P* = 0.05). There was no difference in LM area in 40% MDGS diets (*P* = 0.66). Comparing steers fed 20% MDGS to steers fed 40% MDGS, there was a decrease in LM area (*P* = 0.03) in 15% corn silage diets, however in 45% corn silage diets, there was no difference in LM area across MDGS inclusions (*P* = 0.94).

There was no corn silage x MDGS interaction for all other carcass characteristics ($P \geq 0.37$). Dressing percentage for steers fed 45% corn silage compared to 15% corn silage was less (60.3 compared to 59.4%; $P < 0.01$). There was no difference in dressing percentage due to MDGS inclusion (*P* = 0.40). There was no effect of corn silage or MDGS concentration on 12th rib fat thickness or calculated yield grade ($P \geq 0.15$). Marbling scores were improved from 443 for steers fed 45% corn silage to 466 for steers fed 15% corn silage (*P* = 0.05). As MDGS increased in the diet from 20 to 40%, marbling scores decreased from 469 to 440 (*P* = 0.02).

Comparing the control to all other treatments with an overall F-test (Table II-4), no differences in DMI was observed across treatments (*P* = 0.48). There was a tendency for steers fed 15:20 to have greater ADG than steers fed 15:40, 45:20, or 45:40 (*P* = 0.08), with the control ADG not different from any other treatment ($P \geq 0.15$). For G:F, there were no differences between the control treatment and 15:20, 15:40, or 45:40 ($P \geq 0.15$), however, steers fed the control treatment had increased G:F compared to steers fed 45:20 treatment diets (*P* = 0.03).

There was no difference in carcass-adjusted final BW, live final BW, or HCW across treatments according to the overall F-test ($P \geq 0.11$). These steers were finished during an unseasonably warm and wet winter and consequently went to slaughter with a high degree of mud and tag on the cattle, but these should be equal across all treatments. Dressing percentage for the control (60.3%) was not different from that of 15:20 (60.3%) or 15:40 (60.3%; $P \geq 0.96$). There was a tendency for cattle fed the control diet to have increased dressing percentage compared to 45:40 (59.6%; $P = 0.07$). Dressing percentage for the control, 15:20, and 15:40 treatments were all greater than 45:20 (59.1%; $P < 0.01$). Cattle that are finished on higher concentrations of roughage usually have decreased dressing percentages compared to cattle fed lower concentrations of roughage, and this has been reported when corn silage has replaced corn grain in finishing diets (Peterson et al., 1973; Danner et al., 1980). This is due to a slower rate of passage for roughage compared to concentrate and consequently greater gastro-intestinal tract fill in cattle fed higher roughage diets (Danner et al., 1980). Control steers had greater LM area compared to 15:40 steers ($P = 0.03$) and tended to have greater LM area compared to 45:20 and 45:40 steers ($P \leq 0.08$). There was no difference in LM area for the control and 15:20 steers ($P = 0.72$). Steers on 15:20 had greater marbling scores compared to the steers on the control, 15:40, and 45:40 ($P \leq 0.03$). Steers on 15:20 tended to have greater marbling scores compared to 45:20 ($P = 0.07$). There were no other differences between treatments for marbling score ($P \geq 0.17$). There were no differences across treatments for 12th rib fat thickness or calculated yield grade ($P \geq 0.38$). There were no differences in liver abscess prevalence due to dietary treatment ($P \geq 0.74$; data not presented).

Exp. 2

There were no interactions between corn silage and MDGS inclusion for any of the tested variables ($P \geq 0.12$; Table II-5). For the main effect of corn silage inclusion, steers fed 45% corn silage instead of 15% tended to have slightly greater DMI (12.2 vs. 12.0 kg/d; *P* = 0.07) and decreased ADG (1.91 vs. 1.96 kg/d; *P* = 0.01). This translated to steers fed 45% corn silage being 5.2% less efficient in comparison to steers fed 15% corn silage (0.157 G:F for steers fed 45% corn silage compared to 0.165 for steers fed 15% corn silage; $P < 0.01$). The 30% substitution of corn silage for corn (1:1 blend of HMC:DRC) in this experiment resulted in a calculated feeding value for corn silage of 84% that of the corn blend. In previous research with corn silage replacing corn grain in diets containing no distillers grains, G:F was linearly decreased due to the lower energy content of corn silage compared to corn grain (Preston et al., 1975; NRC, 1996). In diets containing increased concentrations of corn silage, G:F decreased due to an increase in DMI and constant ADG across corn silage inclusion (DiCostanzo et al., 1997), constant DMI with decreased ADG (DiCostanzo et al., 1998a; Exp. 1 and 2 - Erickson et al., 2001), or both DMI and ADG decreases (Exp. 3 - Erickson et al., 2001). When calculating feeding values of corn silage from past data, the study by DiCostanzo et al. (1997) results in feeding values of 61%, 61%, and 51% that of corn (for the 12, 24, and 36% substitution of corn by corn silage, respectively). In the experiments conducted by Erickson et al. (2001), the calculated feeding value of corn silage would be 60 to 75% that of a HMC:DRC blend in yearling steers (Exp. 1 and 2 - Erickson et al., 2001) and 42 to 48% in calf-fed steers (Exp. 3 - Erickson et al., 2001).

Burken et al. (2013) compared 15, 30, 45, and 55% corn silage in diets containing 40% MDGS. Dry matter intake and ADG linearly decreased as corn silage was increased in the diet. Gain:feed also decreased linearly with increasing corn silage in the diet. In this experiment, steers on the 15% corn silage treatment were 1.5%, 5.0%, and 7.7%

more efficient than steers on treatments containing 30, 45, or 55% corn silage, respectively. This resulted in feeding values of 91, 83, and 81% that of corn for the 15, 30, and 40% replacement of corn (Burken et al., 2014).

For the purpose of comparing the present Exp. 1 and 2, the feeding value of corn silage was 85% that of the corn blend in 20% MDGS diets and 83% in 40% MDGS diets in Exp. 2. This feeding value for corn silage in 20% MDGS diets calculated from Exp. 2 differs from that of Exp. 1 (56%). There are differences in cattle types across experiments with long yearling cattle fed through the winter used in Exp. 1 and short yearling cattle fed through the summer used in Exp. 2. Further, the different feeding period weather may have affected feedlot performance and calculated feeding values (warm, wet winter; 2012-2013) in Exp. 1 compared to normal, dry summer (2013) in Exp. 2). Performance data were considerably worse compared to the historical data for the cattle type utilized in Exp. 1, but performance data was normal to improved compared to historical data for Exp. 2. Regardless, these environment factors should have affected all treatments equally. The feeding value for corn silage in 40% MDGS diets are quite similar across experiments (88% for Exp. 1 and 83% for Exp. 2), which further complicates the reasoning for the discrepancy in corn silage feeding values in 20% MDGS diets across experiments. In the experiment conducted by Burken et al. (2013) with calf-fed steers finished during the time period of November to May, the reported feeding value for corn silage was 83% that of a corn blend (1:1 blend of HMC:DRC) for the 30% replacement of corn (15 compared to 45% corn silage) in finishing diets containing 40% MDGS. The feeding value of corn silage in finishing diets containing distillers grains are greater compared to past experiments (DiCostanzo et al., 1997, 1998;

Erickson et al., 2001), which may be attributed to improved digestibility when increased concentrations of corn silage are fed with distillers grains or there are differences in nutrient content of the dietary ingredients across experiments, however, the lack of reported feedstuff nutrient values limit these comparisons.

For Exp. 2, carcass-adjusted final BW (*P* = 0.01) and HCW (*P* = 0.01) were 8.8 and 5.5 kg less, respectively, for steers fed 45% corn silage compared to steers fed 15% corn silage. Unexpectedly and not agreeing with results in Exp. 1 or previous research with increased dietary concentrations of corn silage (Peterson et al., 1973; Danner et al., 1980), dressing percentage was not different between corn silage inclusions (*P* = 0.51) suggesting equal gastro-intestinal tract fill and fatness across treatments. All other carcass characteristics were not different across corn silage dietary concentrations ($P \geq 0.25$).

For the main effect of MDGS in Exp. 2, there was no difference in DMI when steers were fed 20 or 40% MDGS (*P* = 0.86). When MDGS was increased in the diet from 20% to 40%, ADG tended to increase from 1.91 to 1.97 kg/d (*P* = 0.06). For G:F, there was a tendency for steers fed 40% MDGS compared to 20% MDGS to be 2.3% more efficient, with steers fed 40% MDGS having a G:F of 0.165 in comparison to a G:F of 0.157 for steers fed 20% MDGS (*P* = 0.07). When calculating a feeding value relative to the corn blend for the 20% substitution of MDGS for corn (1:1 blend of HMC:DRC) in this experiment, the resultant feeding value was 110% of corn for MDGS. This feeding value for MDGS agrees well with the 109% calculated feeding value for MDGS for the 20% substitution of corn between dietary inclusion concentrations of 20% and 40% MDGS reported in the meta-analysis conducted by Bremer et al. (2011). There was no difference in carcass-adjusted final BW ($P = 0.12$) between MDGS concentrations, however, there was a numerical increase of 5.2 kg for cattle fed 40% in comparison to 20% MDGS. There was a tendency for a slight increase in dressing percentage and calculated yield grade for cattle fed 40% MDGS in comparison to 20% MDGS ($P = 0.08$ and 0.09, respectively). There were no differences in LM area, 12th rib fat thickness, or marbling score for cattle fed either 20 or 40% MDGS ($P \geq 0.15$).

The control treatment, which consisted of 5% cornstalks and 40% MDGS, was compared with all other treatments in the analysis of the overall F-test. There were no differences in DMI, ADG, or final BW across all treatments in Exp. 2 ($P \geq 0.11$). Using the overall F-test statistics, steers fed the 15:20 and 15:40 treatment diets were not different for G:F ($P = 0.13$). Although G:F of steers fed the control diet were not different from 15:20, 45:20, and 45:40 treatments ($P \geq 0.15$), steers fed the control had 4.8% poorer G:F compared to steers fed the 15:40 treatment ($P < 0.01$). The control and 15:40 diets both contained 40% MDGS with the control containing 5% cornstalks compared to the 15% corn silage used as the roughage source in 15:40. This difference in G:F between roughage sources in Exp. 2 disagrees with results in Exp. 1 as well as previous research evaluating roughage source in diets containing wet distillers grains with solubles (WDGS; Benton et al., 2007). Benton et al. (2007) evaluated the effect of roughage source utilizing alfalfa, cornstalks, and corn silage on an equal NDF basis (with corn silage NDF calculated from the whole plant and not just stover fraction) in diets containing 30% WDGS. Contrary to the Exp. 2 results, these researchers reported no differences in G:F across roughage sources (Benton et al., 2007). In Exp. 1, the roughage NDF percentage was 4.2% in the control diet compared to 8.6% in the 15:40 diet, and in

Exp. 2 the roughage NDF percentage was 4.4% compared to 7.1% for the control and 15:40 diets, respectively. This compares to 4.6% for the 6% cornstalk diet and 5.3% for the 12% corn silage diet reported in the experiment conducted by Benton et al. (2007). There were no differences across treatments in Exp. 2 for HCW, dressing percentage, LM area, 12th rib fat thickness, calculated YG, or marbling score according to the overall F-test ($P \geq 0.18$). There were also no differences in liver abscess prevalence either due to dietary treatment ($P \geq 0.53$).

Exp. 3

There were no corn silage x MDGS interactions for intake and total tract digestibility data ($P \geq 0.31$; Table II-6). For the main effect of corn silage, there was a increase in DMI from 9.9 kg/d to 11.0 kg/d ($P = 0.09$) and a tendency for a increase in organic matter intake (OMI; $P = 0.12$) when corn silage was increased from 15 to 45% of the diet. For diets containing 15% corn silage compared to 45% corn silage, there was greater DM digestibility (73.4% to 69.3%; DMD; $P = 0.03$) and OM digestibility (75.3 to 71.5%; OMD; $P = 0.03$). There was an increase in NDF intake from 2.2 kg/d to 3.4 kg/d as corn silage increased in the diet ($P < 0.01$), however, there was no difference across corn silage concentration for NDF digestibility (53.3% for 15% corn silage diets compared to 56.4% for 45% corn silage diets; NDFD; $P = 0.15$). The increase in DMI with increased corn silage in the diet has been reported by DiCostanzo et al. (1997). Vance and Preston (1971) conducted a digestibility experiment and reported that OMD decreased from 85.0 to 76.7% and from 87.1 to 80.7% in whole corn and crimped corn diets (respectively) when corn silage was increased from approximately 2 to 61% of the diet. The difference in OMD in this experiment was 3.8% units for a replacement of 30%

corn grain, compared to the 8.3 and 6.4% units difference in OMD reported in the study by Vance and Preston (1971) for the approximately 60% replacement of corn grain.

For the main effect of MDGS inclusion, there was no difference in DMI or OMI (*P* ≥ 0.94). There was also no difference in DMD (*P* = 0.27) or OMD (*P* = 0.44) across MDGS concentrations, but there was a numerical decrease in DMD (72.2% compared to 70.5%) and OMD (74.0% compared to 72.8%) as MDGS increased from 20 to 40% of the diet. The numerical decrease in DMD observed in this experiment as MDGS increased from 20 to 40% agrees with Corrigan et al. (2009), Vander Pol et al. (2009), and Bremer (2010) who reported DM digestibility of WDGS diets to be at least numerically less than DM digestibility of corn control diets. As MDGS increased from 20 to 40% of the diet in the present experiment, NDF intake (NDFI) increased from 2.58 to 3.01 kg/d (*P* = 0.02), but there was no difference in NDFD (54.2% for 20% MDGS diets compared to 55.5% for 40% MDGS diets; *P* = 0.54) across MDGS concentrations. Corrigan et al. (2009), Vander Pol et al. (2009), and Bremer (2010) have all reported WDGS diet NDF digestibility to be numerically greater than corn diet NDF digestibility. Total tract digestibility of NDF was reported by Ham et al. (1994) to be significantly greater for a diet containing 40% wet distillers grains (69.6%) compared to a corn control finishing diet (62.5%).

When cattle were fed the 95:0 diet (95% corn silage), DMI and OMI were substantially decreased (7.5 and 7.0 kg/d, respectively; *P* < 0.01) compared to all other treatments. According to the overall F-test, steers fed 45:20 had greater DMI (*P* =0.05) and OMI (*P* = 0.07) compared to 15:20. For DMI and OMI, there was no difference between 45:20 and 15:40 or 45:40, as well, there was no differences between 15:20 and

15:40 or 45:40 ($P \geq 0.13$). For DMD, the 95:0 treatment had the lowest DMD across all treatments ($P = 0.03$). The 95:0 treatment also had lower OMD compared to 15:20, 15:40, and 45:20 ($P \geq 0.08$) but was not different from 45:40 for OMD ($P = 0.12$). Steers fed 45:20 and 45:40 were not different for NDFI ($P = 0.14$), but 45:40 had greater NDFI compared to 95:0, 15:20, and 15:40 ($P < 0.01$). The 95:0 treatment was not different from 45:20 for NDFI ($P = 0.12$), but 95:0 had greater NDFI compared to 15:20 or 15:40 ($P \leq 0.04$). Steers fed 15:20 had the least NDFI ($P \leq 0.03$). There was no difference in NDFD across treatments according to the overall F-test ($P = 0.33$), however the 95:0 treatment had the numerically lowest total tract NDFD (50.9%).

There was no interaction between corn silage and MDGS concentration for any of the measured ruminal pH variables ($P \geq 0.35$; Table II-7). As corn silage was increased in the diet from 15 to 45%, there was an increase in average (5.69 for 15% corn silage diets compared to 6.10 for 45% corn silage diets; $P = 0.01$) and maximum pH (6.62 and 6.90 for 15 and 45% corn silage diets, respectively; $P = 0.04$). Minimum pH also increased as corn silage was increased in the diet (5.04 for 15% corn silage diets compared to 5.29 for 45% corn silage diets; $P = 0.03$). There was no difference across corn silage concentrations for magnitude of pH change or ruminal pH variance ($P \geq 0.70$). Time spent below a ruminal pH of 5.60 ($P < 0.01$) was greater for steers fed 15% corn silage compared to steers fed 45% corn silage. Area below a ruminal pH of 5.60 was also greater for steers fed 15% compared to 45% corn silage ($P = 0.06$).

When MDGS was increased in the diet from 20 to 40% in diets containing 15 or 45% corn silage, there was no difference in minimum, average, or maximum ruminal pH ($P \geq 0.31$). The replacement of corn by distillers grains has been reported to numerically increase (Bremer et al., 2010) or numerically decrease (Ham et al., 1994; Corrigan et al., 2009; VanderPol et al., 2009) average ruminal pH. In this experiment, the increase in MDGS from 20 to 40% of the diet numerically increased minimum (5.12 vs. 5.21; $P = 0.31$), average (5.86 vs. 5.94; $P = 0.41$)), and maximum pH (6.71 vs. 6.80; $P = 0.88$). There was no difference across MDGS concentrations for magnitude of pH change or ruminal pH variance ($P \geq 0.13$). There was also no difference in time or area below a ruminal pH of 5.60 across MDGS concentrations ($P \geq 0.42$).

When comparing the 95:0 treatment to all other treatments using the overall F-test, the 95:0 treatment had the highest average, minimum, and maximum ruminal pH ($P < 0.01$). The 95:0 treatment had less magnitude of pH change compared to all other treatments ($P = 0.02$). There was no difference in ruminal pH variance across treatments when using the overall F-test ($P = 0.20$). For time spent below a ruminal pH of 5.60, the 95:0 treatment was not different from 45:40 ($P = 0.32$), however steers fed 95:0 spent less time with a ruminal pH below 5.60 compared to 15:20, 15:40, or 45:20 ($P \leq 0.06$). There was no difference between 95:0, 45:20, or 45:40 for area spent below a pH of 5.60 ($P \geq 0.24$), but 95:0 had less area below a ruminal pH of 5.60 compared to 15:20 or 15:40 ($P \leq 0.03$).

There were no interactions between corn silage and MDGS inclusion for total ruminal VFA concentration or molar proportions of acetate or propionate ($P \geq 0.11$; Table II-7). As corn silage was increased from 15 to 45% of the diet, total ruminal VFA concentration decreased from 107.7 mM to 100.8 mM ($P = 0.01$). There was an increase in the VFA profile proportion of acetate ($P < 0.01$) and a corresponding decrease in the proportion of propionate (*P* < 0.01) as corn silage was increased from 15 to 45% of the diet.

There was a decrease in total ruminal VFA concentration as MDGS increased from 20 to 40% of the diet (*P* = 0.03). There was no difference in VFA profile proportions of acetate and propionate across MDGS inclusions (*P* ≥ 0.54).

There was a corn silage x MDGS interaction for the VFA profile proportion of butyrate (*P* < 0.01). In 15% corn silage diets, the molar proportion of butyrate decreased from 11.6 to 10.4% (*P* = 0.06) when MDGS increased from 20 to 40% of the diet, however, when 45% corn silage diets were fed, the molar proportion of butyrate increased from 11.3 to 12.9% when MDGS increased from 20 to 40% of the diet (*P* < 0.01). In 20% MDGS diets, there was no difference in proportion of butyrate due to corn silage concentration (*P* = 0.26). When 40% MDGS diets were fed, proportion of butyrate increased from 10.4 to 12.9% (*P* < 0.01) as corn silage increased from 15 to 45% of the diet. There was no corn silage x MDGS interaction for acetate to propionate ratio (A:P; *P* = 0.95). As corn silage increased in the diet, the acetate to propionate ratio increased (1.47 to 1.86; *P* = 0.01). For the main effect of MDGS, there was no difference in the acetate to propionate ratio (*P* = 0.31). Ham et al. (1994) reported that distillers grains replacing corn in finishing diets results in no differences in molar proportions of VFA. In contrast, the addition of distillers grains resulted in an increase in the molar proportion of propionate and a decrease in acetate in an experiment conducted by Vander Pol et al. (2009).

In the overall F-test analysis, 15:20 had the greatest concentration of total VFA, with 15:40, 45:20, and 45:40 being intermediate, and 45:40 and 95:0 having the least total concentration of VFA (*P* <0.01). Steers fed the 95:0 treatment had the greatest ruminal VFA profile proportion of acetate (59.2%; *P* < 0.01). When evaluating the ruminal VFA profile proportion of propionate, steers fed diets containing 15% corn silage had the greatest proportion of propionate, followed by treatments 45:20 and 45:40 (*P* < 0.01). The 95:0 treatment was not different from 45:40 (*P* = 0.15) but had a lower proportion of propionate compared to all other treatments (*P* < 0.01). The 95:0 treatment also had the greatest A:P compared to all other treatments (2.26; *P* < 0.01). The lowest A:P was calculated for steers consuming 15% corn silage diets, with steers fed 45% corn silage diets being intermediate according to the overall F-test (*P* < 0.01). Corn silage contains a greater concentration of NDF compared to corn (41 compared to 9%; NRC, 1996), and therefore the reduction in total VFA and the proportional shift towards greater proportions of acetate compared to propionate was expected due to the change in dietary substrate (Firkins et al., 2006) and ruminal pH (Esdale and Satter, 1972).

There was no corn silage x MDGS interaction for ruminal NDF disappearance for corn bran (*P* = 0.30; Table II-8). For the main effect of dietary corn silage, there was an increase in ruminal NDF disappearance of corn bran (40.39% compared to 49.68%; *P* < 0.01) as corn silage increased from 15 to 45% of the diet. As MDGS increased from 20 to 40% of the diet, there was an increase in ruminal NDF disappearance of corn bran (42.97% compared to 47.10; *P* < 0.01). Bremer (2010) reported numerically lower ruminal NDF disappearance of corn bran for WDGS (56% of the diet; 19.1 and 24.7% for 24 and 48 h, respectively) compared to a corn control diet (22.6 and 31.6% for 24 and 48 h, respectively). Conversely and agreeing with the current experiment, Corrigan et al. (2009) reported an increase in in-situ NDF disappearance of WDGS and corn bran in a

40% WDGS diet (35.6% NDF disappearance) compared to a corn control diet (32.5% NDF disappearance).

For the overall F-test, a treatment x time interaction was observed for NDF disappearance of corn bran ($P = 0.03$). At an incubation period of 24 h, the greatest NDF disappearance of corn bran was observed in steers fed 45:40 ($P \leq 0.07$). Incubating corn bran in steers fed 95:0, 15:40, and 45:20 resulted in no difference in NDF disappearance at 24 h ($P \geq 0.31$) . Incubating corn bran (24 h) in steers fed 15:20 resulted in lower NDF disappearance than 45:40 and 45:20 ($P \leq 0.05$), but there was no difference in NDF disappearance from corn bran between 95:0, 15:20, and 15:40 ($P \geq 0.13$).

There was no interaction between corn silage and MDGS for NDF disappearance from corn silage ($P = 0.48$). As well, there was no effect from corn silage ($P = 0.24$) or MDGS ($P = 0.24$) inclusion on NDF disappearance from corn silage. In the evaluation of the overall F-test for NDF disappearance of corn silage, there was no interaction between treatment and time ($P = 0.98$), as well as, no effect of treatment ($P = 0.42$). The lack of significance in the evaluation of NDF disappearance of corn silage was most likely due to the increased variability, as shown in the standard error of the mean, associated with NDF disappearance from corn silage in an *in situ* procedure. Corn silage is not a homogenous feedstuff, but is made up of many parts of the corn plant that vary widely in digestibility (McGee, 2013). Due to this heterogeneity, corn silage is not a good indicator of NDF digestibility across treatment diets utilizing the *in situ* disappearance methodology.

There was no corn silage x MDGS interaction for ruminal DM disappearance of corn ($P = 0.79$). For the main effect of corn silage, there was an increase in ruminal DM disappearance of corn (77.39 to 81.45%; $P < 0.01$) as corn silage increased from 15 to

45% of the diet. There was no difference across MDGS concentrations for ruminal DM disappearance of corn (*P* = 0.86). In the overall F-test evaluation, there was not a treatment x time interaction (*P* = 0.37) for DM disappearance of corn. The greatest DM disappearance of corn was observed in diets 45:20 and 45:40; intermediate for diets 15:20, and 15:40; and least for 95:0 (*P* < 0.01).

The increases in ruminal pH as corn silage increases in the diet in the present study show the classical response of added roughage in high-grain diets. Ruminal pH results from the balance of acid production by fermentation of organic matter, absorption of these acids from the rumen, and the neutralization of these acids by salivary bicarbonate and phosphate buffers (Allen, 1997). As forage:concentrate ratio is increased, ruminal pH is usually increased due to less fermentable substrate, and increases in mastication time and production of salivary buffers (Galyean and Defoor, 2003). Allen (1997) reported that although dietary NDF alone is not related to ruminal pH, forage NDF as a percentage of the DM was significantly correlated to ruminal pH. This explains the ruminal pH results in Exp. 3 when corn silage and MDGS were added to the diet. Corn silage is a source of roughage NDF. Distillers grains increases the dietary concentration of NDF, however, distillers grains have a fine particle size and are not stimulating maxication time (Clark and Armentano, 1997; Penner et al., 2009; Zhang et al., 2010) and subsequent saliva secretion. The results of Ham et al. (1994), Vander Pol et al. (2009) and Bremer et al. (2010) agree with the present results in that the addition of distillers grains to finishing diets have little effect on ruminal pH.

As ruminal pH is decreased, fiber digestibility is decreased (Terry et al., 1969; Hoover, 1986). In the present study, there was no difference in dietary total tract NDFD across treatments. However, ruminal pH was increased as corn silage increased in the diet, suggesting less inhibition of fiber digestion. Our lack of difference in NDFD across diets may be explained by the differences between sources of NDF. Corn and corn silage NDF would differ substantially in terms of NDF components and particle size, and therefore passage rate and digestibility of NDF would likely be different. The in-situ digestibility data utilizing NDF from corn bran is a better indicator of the ruminal fiber fermentation environment across treatment diets. These results suggest that ruminal NDF digestion is improved as corn silage is increased in diet. In the assessment of the corn DMD data, there was an improvement in corn DMD as corn silage increased from 15 to 45% of the diet. This may be a function of ruminal pH. Diets containing 15% corn silage in comparison to 45% corn silage had lower ruminal pH and over two times greater time and area below a ruminal pH of 5.6. The reduction in corn bran NDFD as corn silage is decreased from 45 to 15% of the diet would explain a 0.8 percentage unit decrease in corn DMD assuming corn is 9% NDF (NRC, 1996). The rest of the difference in DMD between corn silage concentrations is unexplainable. When 95% corn silage was fed, corn DMD decreased substantially. The change in microbial community due to change in substrate may have caused the substantial decline in corn DMD when the 95:0 treatment diet was fed.

CONCLUSIONS

Although feedlot performance was variable across experiments, corn silage and MDGS can replace corn in finishing diets. Data from these experiments suggest that feeding greater concentrations of corn silage (45% instead of 15%) in finishing diets containing distillers grains results in decreases in ADG and G:F. Increasing the concentration of corn silage in distillers grains diets results in increased ruminal pH and improvements in the rumen environment for enhanced fiber digestion.

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Table II-1. Diet composition (DM basis) in Exp. 1.

	Treatment[1]				
	Control	15:20	45:20	15:40	45:40
Dry-rolled corn	25.0	30.0	15.0	20.0	5.0
High-moisture corn	25.0	30.0	15.0	20.0	5.0
Corn Silage	0.0	15.0	45.0	15.0	45.0
Cornstalks	5.0	0.0	0.0	0.0	0.0
MDGS[2]	40.0	20.0	20.0	40.0	40.0
Dry supplement[3]					
Fine-ground corn	...	...	3.0077	...	...
Limestone	...	...	1.4660	...	...
Salt	...	...	0.3000	...	...
Tallow	...	...	0.1250	...	...
Trace Mineral premix[4]	...	...	0.0500	...	...
Vitamine ADE premix[5]	...	...	0.0150	...	...
Thiamine[6]	...	...	0.0116	...	...
Rumensin 90[7]	...	...	0.0167	...	...
Tylan 40[8]	...	...	0.0080	...	...
Nutrient Composition[9]					
Crude Protein, %	17.4	13.2	13.3	17.6	17.7
NDF, %	25.7	23.7	37.4	29.0	42.7
Ether Extract, %	6.2	4.8	4.5	6.2	5.9
Ca, %	0.62	0.65	0.73	0.65	0.73
P, %	0.53	0.42	0.40	0.54	0.52
K, %	0.62	0.62	0.98	0.76	1.13
S, %	0.32	0.23	0.24	0.33	0.34

[1] 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] MDGS= Modified distillers grains with solubles.

[3] Supplement formulated to be fed at 5.0% of diet DM.

[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

[5] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.
[6] Premix contained 88 g/kg of thiamine.
[7] Premix contained 198 g/kg monensin.
[8] Premix contained 88 g/kg tylosin.
[9] Based on analyzed nutrients for each ingredient.

Table II-2. Diet composition (DM basis) in Exp. 2.

	Treatment[1]				
	Control	15:20	45:20	15:40	45:40
Dry-rolled corn	25.5	30.5	15.5	20.5	5.5
High-moisture corn	25.5	30.5	15.5	20.5	5.5
Corn Silage	0.0	15.0	45.0	15.0	45.0
Cornstalks	5.0	0.0	0.0	0.0	0.0
MDGS[2]	40.0	20.0	20.0	40.0	40.0
Dry supplement[3]					
Fine-ground corn	...	...	2.0438	...	...
Limestone	...	...	1.4660	...	...
Salt	...	...	0.3000	...	...
Tallow	...	...	0.1000	...	...
Trace Mineral premix[4]	...	...	0.0500	...	...
Vitamine ADE premix[5]	...	...	0.0150	...	...
Rumensin 90[6]	...	...	0.0165	...	...
Tylan 40[7]	...	...	0.0087	...	...
Nutrient Composition[8]					
Crude Protein, %	19.2	14.2	13.8	19.2	18.8
NDF, %	24.6	21.4	32.2	26.2	37.0
Ether Extract, %	5.5	4.7	4.4	5.1	5.2
Ca, %	0.62	0.63	0.70	0.64	0.70
P, %	0.61	0.45	0.42	0.60	0.57
K, %	0.73	0.59	0.81	0.80	1.02
S, %	0.31	0.21	0.22	0.31	0.31

[1] 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] MDGS= Modified distillers grains with solubles.

[3] Supplement formulated to be fed at 4.0% of diet DM.

[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

[5] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.

[6] Premix contained 198 g/kg monensin.
[7] Premix contained 88 g/kg tylosin.
[8] Based on analyzed nutrients for each ingredient.

Table II-3. Diet composition (DM basis) in Exp. 3.

	Treatment[1]				
	Control	15:20	45:20	15:40	45:40
Dry-rolled corn	0.0	60.0	30.0	40.0	10.0
Corn Silage	95.0	15.0	45.0	15.0	45.0
MDGS[2]	0.0	20.0	20.0	40.0	40.0
Dry supplement[3]					
Fine-ground corn	1.6582	2.3222	2.3222	2.8222	2.8222
Limestone	1.1650	1.6610	1.6610	1.6610	1.6610
Urea	1.6600	0.5000	0.5000	0.0000	0.0000
Salt	0.3000	0.3000	0.3000	0.3000	0.3000
Tallow	0.1250	0.1250	0.1250	0.1250	0.1250
Trace Mineral premix[4]	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamine ADE premix[5]	0.0150	0.0150	0.0150	0.0150	0.0150
Rumensin 90[6]	0.0165	0.0165	0.0165	0.0165	0.0165
Tylan 40[7]	0.0102	0.0102	0.0102	0.0102	0.0102
Nutrient Composition[8]					
Crude Protein, %	13.8	15.7	15.7	19.4	19.3
NDF, %	38.6	20.5	28.8	24.6	32.8
Ether Extract, %	3.0	4.7	4.4	5.7	5.5
Ca, %	0.68	0.71	0.77	0.71	0.78
P, %	0.25	0.38	0.38	0.51	0.52
K, %	0.80	0.50	0.67	0.66	0.83
S, %	0.09	0.26	0.26	0.43	0.43

[1] 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] MDGS= Modified distillers grains with solubles.

[3] Supplement formulated to be fed at 5.0% of diet DM.

[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

[5] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.

[6] Premix contained 198 g/kg monensin.

[7] Premix contained 88 g/kg tylosin.
[8] Based on analyzed nutrients for each ingredient.

Table II-4. Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on cattle performance and carcass characteristics (Exp. 1).

	Treatment[1]						*P*-value[2]			
Item	Control	15:20	45:20	15:40	45:40	SEM	F-test	Int.	Silage	MDGS
Performance										
Initial BW, kg	470	468	469	468	469	1	0.17	0.30	0.09	0.72
Final BW, kg[3]	622	631	610	618	618	5	0.11	0.08	0.08	0.61
Live final BW, kg	650	660	650	645	653	6	0.48	0.18	0.84	0.34
DMI, kg/d	13.2	13.4	13.4	13.0	13.5	0.2	0.48	0.24	0.34	0.47
ADG, kg[3]	1.57	1.69	1.46	1.55	1.53	0.05	0.08	0.08	0.05	0.59
G:F[3]	0.119^{ab}	0.126^{a}	0.109^{c}	0.118^{ab}	0.114^{bc}	0.003	0.01	0.07	<0.01	0.69
NEm[4]	1.64^{ab}	1.69^{a}	1.56^{c}	1.64^{ab}	1.60^{bc}	0.02	<0.01	0.09	<0.01	0.83
NEg[4]	1.03^{ab}	1.07^{a}	0.96^{c}	1.03^{ab}	0.99^{bc}	0.02	<0.01	0.09	<0.01	0.83
Carcass Characteristics										
HCW, kg	392	398	384	389	389	3	0.12	0.09	0.08	0.57
Dressing %	60.3^{a}	60.3^{a}	59.1^{b}	60.3^{a}	59.6^{ab}	0.3	0.01	0.37	<0.01	0.40
LM area, cm^{2}	89.7^{b}	90.2^{a}	87.2^{bc}	86.7^{c}	87.3^{bc}	0.9	0.04	0.09	0.27	0.11
12th-rib fat, cm	1.19	1.19	1.18	1.26	1.23	0.04	0.65	0.82	0.65	0.20
Calculated YG[5]	3.01	3.03	3.06	3.20	3.14	0.08	0.38	0.58	0.84	0.15
Marbling Score[6]	440^{b}	483^{a}	454^{ab}	448^{b}	432^{b}	11	0.03	0.54	0.05	0.02

[1] 15:40 = 15% Corn Silage, 40% MDGS; 30:40= 30% Corn Silage, 40% MDGS; 45:40= 45% Corn Silage, 40% MDGS; 55:40= 55% Corn Silage, 40% MDGS; 30:65= 30% Corn Silage, 65% MDGS; 45:0= 45% Corn Silage, 0% MDGS.

[2] F-test = *P*-value for the overall F-test of all diets. Int. = *P*-value for the interaction of corn silage x MDGS. Silage = *P*-value for the main effect of corn silage inclusion. MDGS = *P*-value for the main effect of MDGS inclusion.

[3] Calculated from hot carcass weight, adjusted to a common 63% dressing percentage.

[4] NEm and NEg calculated using methodology by Galyean (2009).

[5] Calculated YG (yield grade) = [2.5 + (6.35 x fat thickness, cm) + (0.2 x 2.5% KPH) + (0.0017 x HCW, kg) – (2.06 x LM area, cm2)]; (Boggs and Merkel, 1993).

[6] Marbling Score: 400 = Small00, 500 = Modest00.

[abc] Within a row, values lacking common superscripts differ when F-test was significant ($P < 0.05$).

Table II-5. Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on cattle performance and carcass characteristics (Exp. 2).

	Treatment[1]						*P*-value[2]			
Item	Control	15:20	45:20	15:40	45:40	SEM	F-test	Int.	Silage	MDGS
Performance										
Initial BW, kg	348	348	347	346	348	1	0.51	0.18	0.85	0.40
Final BW, kg[3]	633	629	623	637	626	4	0.18	0.41	0.01	0.12
Live final BW, kg	645	646	643	652	640	4	0.35	0.20	0.04	0.75
DMI, kg/d	12.3	11.9	12.2	12.0	12.1	0.1	0.13	0.41	0.07	0.86
ADG, kg[3]	1.96	1.93	1.90	2.00	1.92	0.03	0.11	0.18	0.01	0.06
G:F[3]	0.159^{bc}	0.163^{ab}	0.156^{c}	0.167^{a}	0.158^{c}	0.002	<0.01	0.61	<0.01	0.07
NEm[4]	1.85^{c}	1.89^{ab}	1.83^{c}	1.92^{a}	1.86^{bc}	0.01	<0.01	0.81	<0.01	0.06
NEg[4]	1.21^{c}	1.25^{ab}	1.19^{c}	1.27^{a}	1.22^{bc}	0.01	<0.01	0.81	<0.01	0.06
Carcass Characteristics										
HCW, kg	399	396	393	401	394	3	0.18	0.41	0.01	0.12
Dressing %	61.9	61.3	61.1	61.6	61.6	0.2	0.22	0.54	0.51	0.08
LM area, cm^2	84.1	84.3	84.3	83.7	81.8	1.4	0.62	0.39	0.38	0.15
12th-rib fat, cm	1.66	1.61	1.60	1.77	1.61	0.07	0.43	0.27	0.25	0.26
Calculated YG[5]	3.81	3.72	3.69	3.96	3.83	0.12	0.54	0.66	0.43	0.09
Marbling Score[6]	451	437	455	459	432	17	0.74	0.12	0.74	0.99

[1] 15:40= 15% Corn Silage, 40% MDGS; 30:40= 30% Corn Silage, 40% MDGS; 45:40= 45% Corn Silage, 40% MDGS; 55:40= 55% Corn Silage, 40% MDGS; 30:65= 30% Corn Silage, 65% MDGS; 45:0= 45% Corn Silage, 0% MDGS.

[2] F-test= *P*-value for the overall F-test of all diets. Int. = *P*-value for the interaction of corn silage x MDGS. Silage = *P*-value for the main effect of corn silage inclusion. MDGS = *P*-value for the main effect of MDGS inclusion.

[3] Calculated from hot carcass weight, adjusted to a common 63% dressing percentage.

[4] NEm and NEg calculated using methodology by Galyean (2009).

[5] Calculated YG (yield grade) = [2.5 + (6.35 x fat thickness, cm) + (0.2 x 2.5% KPH) + (0.0017 x HCW, kg) – (2.06 x LM area, cm2)]; (Boggs and Merkel, 1993).

[6] Marbling Score: 400 = Small00, 500 = Modest00.

[abc] Within a row, values lacking common superscripts differ when F-test was significant ($P < 0.05$).

Table II-6. Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on intake and digestibility of nutrients (Exp. 3).

	Treatment[1]						*P*-value[2]			
Item	95:0	15:20	45:20	15:40	45:40	SEM	F-test	Int.	Silage	MDGS
DM intake, kg/d	7.5^{c}	9.6^{b}	11.2^{a}	10.2^{ab}	10.8^{ab}	0.8	<0.01	0.48	0.09	0.94
DM excretion, kg/d	2.54^{b}	2.52^{b}	3.33^{a}	2.76^{ab}	3.42^{a}	3.13	0.08	0.71	0.03	0.56
DM digestibility, %	65.2^{b}	74.3^{a}	70.1^{a}	72.5^{a}	68.4^{a}	1.9	0.03	0.72	0.03	0.27
OM intake, kg/d	7.0^{c}	9.2^{b}	10.6^{a}	9.6^{ab}	10.1^{ab}	0.7	<0.01	0.48	0.12	0.96
OM excretion, kg/d	2.18	2.26	2.94	2.41	2.95	2.82	0.10	0.73	0.04	0.76
OM digestibility, %	68.0^{b}	75.8^{a}	72.1^{a}	74.7^{a}	70.9^{ab}	1.8	0.06	0.76	0.03	0.44
NDF intake, kg/d	2.94^{b}	1.97^{d}	3.19^{ab}	2.48^{c}	3.54^{a}	0.21	<0.01	0.56	<0.01	0.02
NDF excretion, kg/d	1.38^{ab}	0.91^{c}	1.45^{a}	1.16^{bc}	1.46^{ab}	1.21	0.01	0.27	<0.01	0.28
NDF digestibility, %	50.9	54.3	54.1	52.3	58.7	3.6	0.53	0.31	0.15	0.54

[1] 95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] F-test= *P*-value for the overall F-test of all diets. Int. = *P*-value for the interaction of corn silage x MDGS. Silage = *P*-value for the main effect of corn silage inclusion. MDGS = *P*-value for the main effect of MDGS inclusion.

[abcd] Within a row, values lacking common superscripts differ when F-test was significant ($P < 0.10$).

Table II-7. Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on pH and ruminal volatile fatty acid measurements (Exp. 3).

	Treatment[1]						*P*-value[2]			
Item	95:0	15:20	45:20	15:40	45:40	SEM	F-test	Int.	Silage	MDGS
Ruminal pH										
Maximum pH	7.24^{a}	6.65^{bc}	6.77^{b}	6.58^{c}	7.02^{b}	0.18	<0.01	0.49	0.04	0.88
Average pH	6.69^{a}	5.72^{cd}	5.99^{bc}	5.67^{d}	6.20^{b}	0.18	<0.01	0.35	0.01	0.41
Minimum pH	5.94^{a}	5.01^{c}	5.22^{bc}	5.06^{c}	5.36^{b}	0.14	<0.01	0.55	0.03	0.31
Magnitude	1.30^{b}	1.64^{a}	1.55^{a}	1.52^{a}	1.67^{a}	0.15	0.02	0.98	0.70	0.16
Variance	0.12	0.22	0.18	0.13	0.16	0.06	0.20	0.80	0.95	0.13
Time < 5.6, min/d	7^{c}	690^{a}	335^{b}	752^{a}	212^{bc}	149	<0.01	0.61	<0.01	0.57
Area < 5.6[3]	1^{b}	247^{a}	92^{ab}	215^{a}	39^{b}	84	0.04	0.81	0.06	0.42
Ruminal VFA[4]										
Total, mM	91.3^{c}	113.2^{a}	106.6^{b}	102.1^{b}	95.0^{bc}	6.5	<0.01	0.61	0.01	0.03
Acetate[5]	59.2^{a}	50.1^{c}	54.0^{b}	48.3^{c}	53.0^{b}	1.7	<0.01	0.31	<0.01	0.54
Propionate[5]	28.5^{c}	35.3^{a}	31.5^{b}	38.2^{a}	30.4^{bc}	2.3	<0.01	0.11	<0.01	0.68
Butyrate[5]	9.4^{bc}	11.6^{ab}	11.3^{bc}	10.4^{c}	12.9^{a}	1.7	<0.01	<0.01	0.07	0.51
A:P[6]	2.26^{a}	1.53^{c}	1.86^{b}	1.40^{c}	1.85^{b}	0.16	<0.01	0.95	0.01	0.31

[1] 95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] F-test= *P*-value for the overall F-test of all diets. Int. = *P*-value for the interaction of corn silage x MDGS. Silage = *P*-value for the main effect of corn silage inclusion. MDGS = *P*-value for the main effect of MDGS inclusion.

[3] Area < 5.6 = ruminal pH units below 5.6 by minute.

[4] Ruminal volatile fatty acids (VFA).

[5] VFA concentraton in mol/100 mol.

[6] Acetate:Propionate.

[abcd] Within a row, values lacking common superscripts differ when F-test was significant ($P < 0.10$).

Table II-8. Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on NDF disappearance from corn bran and corn silage and DM disappearance from corn (Exp. 3).

	Treatment[1]						*P*-value[2]			
Item	95:0	15:20	45:20	15:40	45:40	SEM	F-test	Int.	Silage	MDGS
Corn bran, % NDFD[3]										
24 h	41.36^{de}	36.12^{e}	42.77^{d}	39.52^{de}	48.60^{bc}	2.91	<0.01	0.30	<0.01	<0.01
36 h	59.81^{a}	42.17^{d}	50.82^{b}	43.74^{cd}	56.52^{a}					
Corn silage, % NDFD[4]										
24 h	41.03	39.25	37.82	38.07	45.53	6.38	0.42	0.48	0.24	0.24
36 h	51.16	41.57	44.33	44.55	53.61					
Corn, % DMD[5]										
24 h	62.05^{c}	73.78^{b}	77.72^{a}	74.06^{b}	79.52^{a}	1.79	<0.01	0.92	<0.01	0.86
36 h	71.95	81.11	85.43	80.60	83.14					

[1] 95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS

[2] F-test= *P*-value for the overall F-test of all diets. Int. = *P*-value for the interaction of corn silage x MDGS. Silage = *P*-value for the main effect of corn silage inclusion. MDGS = *P*-value for the main effect of MDGS inclusion.

[3] Interaction between treatment and time point ($P = 0.03$).

[4] Interaction between treatment and time point ($P = 0.98$).

[5] Interaction between treatment and time point ($P = 0.37$).

[abcde] Within a row and column, values lacking common superscripts differ when F-test was significant ($P < 0.10$).

Running Header: Economics of corn silage for finishing cattle

CHAPTER III. Assessment of economic results from feeding increased concentrations of corn silage in finishing diets containing distillers grains[1]

D. B. Burken*, B. L. Nuttelman*, J. L. Harding*, A. L. McGee*, K. M. Sudbeck*, S. E. Gardine*, T. C. Hoegemeyer†, T. J. Klopfenstein*, and G.E. Erickson*[2]

*Department of Animal Science, University of Nebraska, Lincoln 68583

†Department of Agronomy, University of Nebraska, Lincoln 68583

ABSTRACT

Corn plants were sampled over two consecutive years to assess the effects of corn hybrid season length, plant density, and harvest time on whole corn plant quality and yield in Nebraska. A finishing experiment evaluated the substitution of corn with corn silage in diets with corn modified distillers grains with solubles (MDGS). Economic data were compiled for use in pricing corn silage. Corn silage pricing scenarios were then applied to the cattle performance results to assess the economics of feeding elevated concentrations of corn silage in finishing diets containing distillers grains. Whole plant yields increased as harvest time progressed (yr 1 quadratic $P < 0.01$; yr 2 linear $P < 0.01$). However, differences in TDN concentration in both years were quite minimal across harvest time, although grain percentage increased and residue NDF in-situ disappearance decreased as harvest time was delayed. In the finishing experiment, as corn silage inclusion increased from 15 to 55% (DM basis) in diets containing 40% MDGS, DMI, ADG, and G:F linearly decreased ($P \leq 0.01$), with the steers on the 15% corn silage treatment being 1.5%, 5.0%, and 7.7% more efficient than steers on treatments containing 30%, 45%, and 55% corn silage, respectively. As corn price increased above $155.50 per t in the economic analysis, feeding elevated concentrations of corn silage was more economical. The economic importance of shrink and harvest moisture content were assessed. As corn price and the inclusion of corn silage in finishing diets increase, corn silage management decisions have greater economic importance.

Key words: corn silage, distillers grains with solubles, feedlot cattle, harvest time, yield

INTRODUCTION

Corn silage can partially replace corn as an energy source in finishing diets during periods of high-priced corn (Goodrich et al., 1974; DiCostanzo 1998). However, the price of corn silage has major implications on these economics. Corn silage pricing is complex due to the variability of corn silage in regards to nutrient content and plant yield, which can be affected by corn production management decisions (such as hybrid selection and planting density), growing conditions, and harvest timing. Pricing corn silage must also take into account the opportunity costs/returns associated with dry commodity corn production and corresponding grain and silage harvest costs.

Gain and G:F decrease as corn silage increases in the diet in replacement of corn grain (Goodrich et al., 1974; Preston 1975; Erickson et al., 2001), and days on feed (**DOF**) need to be increased to compensate for lower ADG. With additional DOF, non-feed costs increase, and diet cost savings from feeding elevated concentrations of corn silage in finishing diets must offset additional days. However, all of the cattle performance data with increased concentrations of corn silage was completed prior to the expansion of the ethanol industry and inclusion of distillers grains in finishing diets. Distillers grains and corn silage potentially would be produced in the same region, and, therefore, the evaluation of increased corn silage in finishing diets containing distillers grains is warranted. Therefore, the objectives of these experiments were 1) to assess the effects of hybrid relative maturity (**RM**), plant population density, and harvest date on whole corn plant yield and quality measures, 2) to evaluate animal performance and carcass characteristics of cattle fed increasing concentrations of corn silage in finishing diets containing distillers grains, 3) to provide a general outline on the costs associated with corn silage production and management, and 4) to discuss the potential economic gain from feeding increased concentrations of corn silage to finishing cattle based on accurately pricing corn silage and accounting for cattle performance.

MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Corn plant sampling

Whole corn plants were harvested from an irrigated yield plot located near York, NE. Moderately early maturity corn hybrids (**MEM**; 107 to 111 d RM; n = 5, yr 1; n = 3, yr 2) and moderately late maturity corn hybrids (**MLM**; 112 to 117 d RM; n = 5, yr 1; n = 3, yr 2) were planted at four populations (49,421, 64,247, 79,073, and 93,900 plants/ha in yr 1; 49,421, 69,189, 88,958, and 108,726 plants/ha in yr 2) in a completely randomized design with 3 replications per hybrid x population combination. Hybrids that were used in yr 1 for MEM hybrids included HPT 7616 Hx/LL/RR, 7726 3000GT, HPT 7998 Hx/LL/RR, HPT 8041 Hx/LL/RR, and P1151 HR. For yr 1, MLM hybrids included 8360 3111, HPT 8345 Hx/LL/RR, 6203 VT/RR, HPT 8505 Hx/LL/RR, and HPT 8803 Hx/LL/RR. In yr 2, MEM hybrids were HPT 7616 Hx/LL/RR, HPT 8041 Hx/LL/RR, and HP1153 Hx/LL/RR; MLM hybrids in yr 2 were 8359 3000 GT, HPT 8345 Hx/LL/RR, and HPT 8803 Hx/LL/RR. Plots were arranged throughout a cornfield as four rows (76 cm) that were 6 m in length. The outside two rows were sampled for this experiment, with the inside two rows utilized in commercial grain yield research trials.

Five competitive corn plants were cut 15.2 cm above ground level and collected at three harvest dates to simulate corn silage harvest at half starch milkline (**EH**), late corn silage harvest (**LH**), and grain and stover harvest (**GH**). In yr one, harvest dates were September 1 (EH), September 15 (LH), and September 29 (GH). In yr two, harvest dates were August 23 (EH), September 6 (LH), and September 24 (GH). Hand harvest, subsequent handling, and sample analyses methods were performed similarly across years except for harvest three in yr 1. For yr 1 (harvest 1 and 2) and yr 2, ear and husk fractions were separated and weighed at time of harvest. The remaining plant parts (stem, leaf, and shank) were ground through a wood chipper (Model 24A-414B711; Troy-Bilt LLC, Cleveland, OH), collected into one sample, and weighed at the time of harvest. A subsample from the stem, leaf, and shank sample, as well as grain, husk, and cob samples were dried in a 60º C forced-air oven and weighed for DM determination (AOAC, 1999 method 4.1.03) and yield/ha calculations (sample DM weight x actual population per ha). Another subsample of the stem, leaf, and shank sample was lyophilized (Virtis Freezemobile 25ES, SP Industries, Warminster, PA) and ground through a 2-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) for laboratory analysis. Harvest three of yr 1 was performed by procedures outlined by McGee (2013) in an attempt to assess the yield and quality of the different corn plant parts at typical grain harvest. For this harvest, five competitive plants were cut from the field as outlined above. After being removed from the field; leaf blade, leaf sheath, and ear were removed from the stalk. Stalks were then bundled together. Stalk bundles and individual plant parts were left to air dry for approximately one month. Stalks were then chopped into more manageable pieces (approximately 2.5 cm in length). Plant parts were separated into leaf blade, leaf sheath, husk, cob, grain, and shank, placed into individual bags by plant fraction and allowed to continue to dry. Once all the fractions were air-dry, DM determination on each individual plant part was established using the procedures mentioned above.

After DM determination, husk and cob were ground through a 2-mm screen for laboratory analysis. Concentration of NDF was analyzed by refluxing bags in neutral detergent solution using the ANKOM ^{200} Fiber Analyzer (Ankom Technology, Macedon, NY). Dacron bags (Ankom Techology) were filled with 1.25 g of as-is sample for analysis of in-situ NDF disappearance. Two bags per feedstuff per steer were placed in mesh bags and incubated in the ventral rumen of two steers for an incubation time period of 28 h. The steers were fed a diet consisting of 70.5% grass hay, 23.3% dry distillers grains with solubles, 5.8% DRC, and 0.4% trace minerals/vitamins. Two nonincubated bags (0 h) were also prepared for each sample. Neutral detergent fiber was determined for incubated in-situ bags containing husk, cob, and the stem, leaf, and shank sample by refluxing bags in neutral detergent solution using the methodology given above. Disappearance of NDF was calculated by subtracting remaining residue of each sample (after 28 h incubation period) from the initial value (0 h). Plant part data were combined utilizing plant part proportions of the whole plant to get to original plant fractions that were separated in harvest 1 and 2. Due to the differences in procedures, a plant as-is weight at the time of harvest was not measured for harvest 3 in yr 1. Therefore, there is no whole plant DM concentration for harvest three of yr 1.

A value for plant residue digestible NDF was calculated using plant part DM percentage of the whole plant, NDF concentration, and in-situ NDF digestibility (NDFD) for husk, cob, and the stem, leaf, and shank sample. Total plant residue cell soluble concentration was determined summing (1-NDF x respective plant part DM percentage of the whole plant) for husk, cob, and the stem, leaf, and shank sample. Addition of plant residue digestible NDF and total plant residue cell soluble concentration resulted in a value for true digestibility, with TDN of residue calculated from this true digestibility – 12% (metabolic loss assumption; Minson, 1990). Percentage TDN of plant residue multiplied by the residue DM percentage of the whole plant (sum of all plant residue components or 1 – percent corn grain) resulted in a value for digestible plant residue. Digestible grain content was calculated as corn grain percentage of the whole plant multiplied by 0.9 (NRC, 1996). A final TDN for each hybrid x density x harvest x repetition corn plant sample was calculated as digestible plant residue + digestible grain content. Yield of TDN/ha was then calculated as TDN concentration x whole plant yield/ha.

Yield and nutritive value data were analyzed using the Mixed procedure of SAS (SAS Inst., Inc., Cary, N.C.). The experimental unit consisted of a composite of 5 corn plants per each hybrid x harvest time x plant density x repetition combination. There were three replications per hybrid x harvest time x plant density sample. Season length (MEM or MLM), plant density, and harvest timing were fixed effects. Orthogonal contrasts were used to test the effects of harvest timing and plant density. The IML procedure of SAS (SAS Inst., Inc.) was used in yr 2 to calculate harvest timing orthogonal contrast statement coefficients due to unequal spacing between harvest dates. Statistical interactions between fixed effects were also tested and will be presented when significant ($P \leq 0.05$).

Cattle finishing experiment

For the cattle finishing experiment, crossbred steer calves (n = 324; BW = 324 ± 17 kg) were separated into two BW blocks and assigned randomly to one of 36 pens (9 steers/pen; 2 repetitions in heavy BW block, 4 repetitions in light BW block). Prior to initiation of the experiment, all steers were individually identified and processed at arrival to the research feedlot with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza$_3$, and bovine respiratory syncytial virus (Bovi-Shield Gold 5, Pfizer Animal Health, New York, NY), a *Haemophilus somnus* bacterin (Somubac, Pfizer Animal Health), and an injectable anthelmintic (Dectomax, Pfizer Animal Health). All steers were revaccinated approximately 14-28 d after initial processing with Bovi-Shield Gold 5 (Pfizer Animal Health), a killed viral vaccine for clostridial infections (Vision 7 Somnus with SPUR, Merck Animal Health, Summit, NJ), and a killed viral vaccine for pinkeye prevention (Piliguard Pinkeye TriView, Merck Animal Health). All these procedures were performed prior to experiment initiation. Steers were limit fed (Watson et al., 2012) to equalize gastro-intestinal fill a diet containing 47.5% sweet bran, 47.5% alfalfa hay, and 5.0% supplement (DM basis) at 2.0% of projected BW for 5 d prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). Treatments (Table III-1) consisted of 15, 30, 45, and 55% corn silage with 40% MDGS (15:40, 30:40, 45:40, and 55:40; respectively) as well as one treatment with 30% corn silage and 65% MDGS (30:65) and another treatment with 45% corn silage and 0% MDGS (45:0; DM basis). As inclusion changed, corn silage and MDGS replaced a 1:1 blend of dry-rolled corn (**DRC**): high moisture corn (**HMC**) on a DM basis. All steers were fed a supplement formulated for 33 mg/kg monensin (Elanco Animal Health, Greenfield, IN) and a targeted intake of 90 mg/steer daily of tylosin (Elanco Animal Health). Steers consuming 45:0 treatment diets were supplemented with Soypass (LignoTech USA, Inc., Rothschild, WI) for the first 84 d to meet metabolizable protein requirements (NRC, 1996). Pens were fed once daily at approximately 0930 h. Steers were implanted with Revalor-IS (Merck Animal Health, Summit, NJ) on d 1 and re-implanted with Revalor-S (Merck Animal Health) on d 83. Feedbunks were assessed at approximately 0530 h with the goal of trace amounts of feed at time of feeding. All diets were fed once daily, and feed refusals were removed from feedbunks when needed, weighed, and subsampled. All feed refusals were subsampled and dried for 48h in a 60ºC forced-air oven for determination of DM and calculation of refusal DM weight. Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly. Dietary ingredient samples were analyzed for CP (AOAC, 1990 method 990.06; TrueSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), and ether extract (Bremer, 2010; Table III-1). Weekly dietary ingredient samples were composited and then analyzed by a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) for Ca, P, K, and S concentration. Dietary mineral concentration was then calculated utilizing ingredient mineral concentration and dietary inclusion of ingredients. All steers were on feed for 173 d and were harvested at a commercial abattoir (Greater Omaha Pack, Omaha, NE). On the day of shipping to the commercial abattoir, pens of steers were fed 50% of the previous day’s DM offer at regular feeding time. Pens of steers were then weighed on a platform scale at 1500 h prior to being loaded for shipping. A

4% pencil shrink was applied to this BW for final live BW and calculation of dressing percentage. Hot carcass weight and liver scores were obtained the d of harvest. Liver abscesses were categorized from 0 (no abscesses), A-, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were then combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in calculation of ADG and G:F, was calculated from HCW and a 63% common dressing percentage. Marbling score, 12th rib fat thickness, and LM area were recorded after a 48 h carcass chill. Yield grade was calculated as [2.5 + (6.35 x fat thickness, cm) + (0.2 x 2.5% KPH) + (0.0017 x HCW, kg) – (2.06 x LM area, cm2); Boggs and Merkel, 1993].

The feeding value of corn silage and MDGS relative to the corn blend on a DM basis was calculated by the following equation for each inclusion level: [1 – ((G:F of higher inclusion diet – G:F of lower inclusion diet) ÷ G:F of lower inclusion diet) ÷ amount of inclusion level substitution] x 100 + 100. The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Performance and carcass data were analyzed using the Mixed procedure of SAS (SAS Inst., Inc.). Pen was the experimental unit, and BW block was included as a fixed effect. Orthogonal contrasts were used to test the effects of corn silage concentration within diets containing 40% MDGS. The IML procedure of SAS (SAS Inst., Inc.) was used to calculate orthogonal contrast statement coefficients due to unequal spacing between corn silage dietary treatment concentrations. Preplanned pairwise contrasts were used to test treatments containing 45% corn silage with and without MDGS as well as treatments containing 30% corn silage with 40 or 60% MDGS. Prevalence of liver abscesses was analyzed using the GLIMMIX procedure of SAS (SAS Inst., Inc.) using a binomial distribution. Significance of effects was determined at $P \leq 0.05$.

Economic Analyses

Corn grain and corn silage harvesting costs were based on data from the 2014 Nebraska Farm Custom Rates publication (Wilson, 2014). Combining corn charges (including tractor and auger cart) were assumed at $89.68/ha and a yield of 12.56 t/ha corn for a calculated harvesting costs of $7.14/t. Transportation charges from field to feedyard storage location were assumed at $4.33/t (average distance = 21 km). Drying grain for storage was assumed to be needed to remove two percentage points of moisture. Drying charges were $1.969/t per point of moisture removed for a total drying cost of $3.938/t. It was assumed that harvest and drying losses were 2.5%. When all harvest, transportation, and drying costs were removed from the per t price of corn at the feedyard, a value of corn grain standing in the field was calculated. Harvesting and transportation costs remained constant as corn price changed. We also assumed purchase of the grain by the feedyard at harvest time, and consequently, no storage costs of the grain. Corn silage chopping, hauling, filling, and packing bunker charges were assumed at the rate of $10.86/as-is t of corn silage (up from $8.96/as-is t in 2012). The DM content of the corn silage would affect the dry matter harvesting costs of corn silage. When harvesting corn silage at 32% DM, $10.86/as-is t would equate to $33.93/t of corn silage on a DM basis; however, if corn silage were harvested at a greater DM content, the harvest cost per DM ton of corn silage would decrease. Harvesting at 42% DM corn silage, the harvest cost would calculate to $25.85/t of corn silage on a DM basis.

Fertilizer value of stover removed with corn silage was calculated from values determined from the NRC (1996). Corn grain CP, P, and K concentration data (approximately 3,500 samples) were used to calculate the amount of N, P, and K contained in a t (DM) of corn grain. This was also calculated for corn silage nutrient concentration data (approximately 32,000 samples). The amount of fertilizer nutrients removed from harvesting corn silage instead of corn grain was then assessed using a partial budget approach taking into account only nutrients removed with corn stover. These values were 5.2 kg of N, 0.49 kg of P, and 10.0 kg of K per t of corn silage (DM) removed; to re-emphasize these are calculated nutrients coming from the stover fraction (partial budget approach) of the corn silage and would not be representative of the total amount of nutrients removed from corn silage harvest. These potential fertilizer sources were then valued at $0.81/kg of N (assuming $662/t for anhydrous ammonia), $2.29/kg of P [assuming $606/t for diammonium phosphate (DAP) and valuing the 18% N contained in DAP at $0.81/kg of N], and $0/kg of K2O (assuming adequate soil K concentrations in Nebraska; Shapiro et al., 2008). When calculated on a per ha basis, the stover removed from corn silage harvesting would remove $100.57 per ha in fertilizer value using calculations based on 12.56 t/ha assumed corn grain yields. Although in these calculations this fertilizer value was charged against the cost of the corn silage, in an integrated feedlot/crop system that applies cattle manure onto corn silage ground, the value of this nutrient removal would be a lower charge against the corn silage price and even potentially a benefit as more manure nutrients would be allowed to be applied back in the system.

The corn kernel has not reached physiological maturity or maximum DM accumulation at the time of most corn silage harvest. Due to this, the yield of corn grain has not been maximized at the time of corn silage harvest. To account for this "yield drag" with corn silage harvest, corn silage was separated into grain and stover fractions. The corn grain fraction within corn silage was determined from corn grain yield in t/ha x "yield drag constant" [i.e. 12.56 t/ha x (1- 15.9% "yield drag constant for harvesting at 35% corn silage DM content") x 1000 kg/t x 84.5% grain DM; this scenario would yield 8820 DM kg of corn grain at corn silage harvest time from 12.56 t/ha corn at corn grain harvest time]. Data from the hand-harvested commercial corn grain yield trials (corn plant plot sampling experiment; Figure 3) were compiled for determination of a regression line and yield drag constants between corn silage DM content and corn grain yield drag from harvesting immature corn kernels. From these data, it was assumed at a corn silage harvest DM of 32, 35, and 42%; the corn grain yield drag would be 21.0, 15.9, and 6.8%. The stover fraction yield was assumed to stay a constant amount across harvest DM concentrations. The stover fraction yield was equal to the amount of corn stover in corn silage from corn silage harvested at 35% DM (utilizing a 15.9% grain yield drag) and containing 51.86% corn grain [(i.e. 12.56 t/ha x (1- 15.9% "yield drag constant for harvesting at 35% corn silage DM content") x 1000 kg/t x 84.5% grain DM) / (51.86% grain to stover ratio or harvest index) – (12.56 t/ha – (12.56 t/ha x (1 - 15.9% "yield drag constant for harvesting at 35% corn silage DM content" x 1000 kg/t x 84.5%

grain DM)))]. In the scenarios presented, corn that would yield 12.56 t/ha at grain harvest, would yield 8187 DM kg of corn stover regardless of harvest time.

Corn silage price per t on a DM basis was calculated, and these values were then utilized to calculate returns per fed steer based off feedlot performance results from the finishing experiment. Feedlot performance data were adjusted in the analysis for different corn silage harvest DM and thus corn grain percentage. This was done by regressing the original performance data against the amount of corn silage roughage in the diet (assuming the corn silage fed in the performance study contained a stover concentration of 48.14%). As the harvest DM content of the corn silage increased, the proportion of corn grain contained in that silage increased (thereby increasing the amount of corn grain in the diet) and the feedlot performance improved by that difference in corn concentration in the diet. Due to the effect of variable carcass weight across treatments, DOF were adjusted on a pen basis so that all pens were fed to a constant average carcass weight of 393 kg (DOFc). Initial purchase cost was calculated using average initial weight of a pen multiplied by an initial price/kg determined to achieve a breakeven or net return of $0/steer for the 15% corn silage control treatment at the different corn prices evaluated. Cattle interest charges were calculated as 7.5% interest x (purchase price-$200/steer for down payment) x (DOFc/365). Corn (1:1 blend of DRC and HMC) was charged an additional $3.14/t (DM; Macken et al., 2006) for the cost of corn processing. Corn silage was priced at methods outlined above. Modified distillers grains with solubles feed costs were calculated as 90% the price of corn on a DM basis delivered to the feedyard. Supplement was assumed to be equal to the price of corn on a DM basis. A pencil shrink was applied to all ingredients; 1% was used for corn and supplement, 5%

for MDGS, and 10% for corn silage in the economic models assessing the effects of corn grain price on returns per steer and the effects of harvest moisture on returns per steer. Feed costs were determined by using diet DM costs x DMI x DOFc. A feed interest charge of 7.5% for one half of total feed charges was used. Processing and medicine charges were assumed at \$20/steer. Yardage was calculated as \$0.45/steer/daily utilizing DOFc. Cost of gain calculations included yardage, processing and medicine, and total feed costs (feed and feed interest charges). A sale price of \$4.96/kg x 393 kg or \$1952.50/steer was used for all cattle. Profit per head was calculated as sales price - initial purchase cost (including cattle interest charges) - total feed costs - processing and medicine - yardage - 1% calculated death loss.

Grain yield drag data was analyzed using the Reg procedure of SAS (SAS Inst., Inc.) with harvest DM content as the independent variable and grain yield relative to harvest 3 grain yield as the dependent variable for the linear response analysis. Harvest DM content was the independent variable and (grain yield relative to harvest 3 grain yield)^2 and (grain yield relative to harvest 3 grain yield) were used as dependent variables for the quadratic response analysis. Significance of effects was determined at $P \leq 0.05$.

RESULTS AND DISCUSSION

Corn plant sampling

Season length x harvest time interactions

There was a tendency ($P = 0.09$) for a season length x plant density x harvest time interaction for residue NDFD in yr 2, however there were no season length x plant density x harvest time interactions for all other tested variables ($P \geq 0.28$). For data clarity purposes, three-way interactions were ignored and will not be discussed. Whole corn plant DM was 35.8% (harvest 1) and 42.4% (harvest 2) for yr 1 (harvest 3 DM not available). For yr 2, whole corn plant DM was 37.4, 47.8, and 59.2% for harvest 1, 2, and 3, respectively.

For actual population, there was an effect of season length for yr 1 ($P < 0.01$; Table III-2) with MEM hybrids (107 – 111 d RM; 62134 plants/ha) having less population compared to MLM hybrids (112 – 117 d RM; 63454 plants/ha). This agrees with a tendency for a decrease in actual population for MEM hybrids compared to MLM hybrids in yr 2 (66975 compared with 67961 plants/ha; $P = 0.09$; Table III-3).

Moderately late maturity hybrids had greater harvested grain yield compared to MEM hybrids in both yr 1 (12.50 t/ha compared to 11.87 t/ha; $P < 0.01$) and yr 2 (15.28 t/ha compared to 13.95 t/ha; $P < 0.01$). Norwood (2001) compared 75, 92, 98, 106, and 110 d RM and reported greater grain yield in longer season hybrids compared to shorter season hybrids in dryland corn production in western Kansas if soil moisture was not limiting. Farnham (2001) reported greater grain yields in Iowa by planting longer season (110-114 d RM) hybrids compared to shorter season (94-102 d RM) hybrids. Farnham (2001) also acknowledged the commonly held assumption that longer season hybrids generally produce larger plants (leaves and stalks) and are more sensitive to higher plant densities; however, this was not observed in the present experiment. Steggenborg et al. (1999) also reported that if the growing season is not limiting, a full season hybrid generally produces more grain compared to shorter season hybrids. Undersander and Lauer (2005) recognized this response and recommend that maturity of hybrids should be selected as the latest RM that will reach harvest maturity by frost. These responses are due to higher grain yield potential with later maturing hybrids since they can utilize more of the growing season for photosynthate production and accumulation.

There was no interaction between season length and harvest time for corn stover yield or whole plant yield ($P \geq 0.10$) in yr 1. For the main effect of season length, there was an increase in corn stover yield (11.32 compared to 10.30 t/ha for MLM and MEM, respectively; $P < 0.01$) and whole plant yield (23.54 compared to 22.14 t/ha for MLM and MEM, respectively; $P < 0.01$) for MLM hybrids compared to MEM hybrids.

For the main effect of harvest time, there was a quadratic effect on corn stover yields ($P < 0.01$) in yr 1 with stover yields increasing between the first two harvest times (10.00 t/ha to 10.99 t/ha) and then decreasing at harvest three (10.90 t/ha). There was also a quadratic effect for the main effect of harvest time on whole plant yields ($P < 0.01$) in yr 1. Between the first two harvests, there was an increase of 2.29 t/ha (21.61 t/ha for harvest one compared to 23.17 t/ha for harvest two). From harvest two to harvest three in yr 1, corn plant yield slightly decreased to 23.03 t/ha. In yr 2, there was a season length x harvest time interaction for corn stover yield ($P = 0.04$). In MEM hybrids, there was no difference across harvest time for corn stover yield ($P \geq 0.53$). However in MLM hybrids, there was a linear ($P < 0.01$) decrease in corn stover yield as harvest time was later in the season (10.72 t/ha compared to 10.08 t/ha compared to 9.62 t/ha). Darby and Lauer (2002) stated that stover yield is maximized at the time of reproductive development in corn. These researchers reported no relationship between stover DM yield and growing degree units across silage DM contents of 30 to 42% (Darby and Lauer, 2002). Shinners and Binversie (2007) collected three years of data following the corn plant progress from approximately August 25 to October 20, and reported that the peak of total stover yield was at the start of the experiment and that total stover yield decreased (12.6 to 10.5 t/ha) during the experiment. Huang et al. (2012a) also reported maximal stover yield at the initiation of their experiment (August 21st) and a decrease in stover yield as the experiment progressed until the end (November 23rd). Owens (2008) summarized results from Hunt et al. (1989) and reported that stover DM yields were 14.5, 12.9, and 11.6 t/ha at 1/3 milkline, 2/3 milkline, and blacklayer. Moss et al. (2001) reported stover yields of 21.1, 20.4, and 20.4 t/ha (35% DM; yr 1) and 23.5, 22.2, and 22.4 t/ha (35% DM; yr 2) at 1/3 milkline, 2/3 milkline, and blacklayer (respectively). Potential reasons for the loss of stover include senescence and abscission as the stover parts (leaves, husk, and upper stalk) become dry and brittle leading up to and especially after physiological maturity (Shinners and Binversie, 2007), but also stover dry weight would be lost before physiological maturity due to translocation of nutrients from the stalk and leaf fractions to grain (Huang et al., 2012a). Conversely, Pordesimo et al. (2004) reported that stover DM yield increased from 13.43 t/ha to a peak of 15.57 t/ha in the two weeks prior to physiological maturity. Although Owens (2008) reported that total sugars decrease during this time, which would support a decrease in stover yield, Allen et al. (2003) suggested that total starch plus sugars increase up until physiological maturity, which would replenish some of the sugars being translocated during kernel fill.

For yr 2, there was no season x harvest time interaction for whole plant yield (P = 0.92). For the main effect of season, MLM hybrids outyielded (P = 0.03) MEM hybrids (22.98 t/ha compared to 22.22 t/ha), which agrees with yr 1 results. Raymond et al. (2009) reported greater biomass at physiological maturity in four of five experiments for a later RM hybrid compared to an earlier RM hybrid. Raymond et al. (2009) acknowledged this is due to the increased portion of the growing season that longer season hybrids have to accumulate biomass. Raymond et al. (2009) sampled plants at the R6 stage, which would have been consistent across all RMs tested. In the current experiment, MLM and MEM were harvested the same d and therefore had the same number of growing degree days. It would be expected that MEM would have been in a more advanced stage at each harvest time (Afuakwa and Crookston, 1984). Schwab et al. (2003) observed greater corn silage yield, even though it was less mature, for mid (18.0 t/ha; 105 d RM) and later season hybrids (17.6 t/ha; 113 d RM) compared to earlier (14.6 t/ha; 98 d RM) season hybrids when harvested at the same timepoint, which agrees with these experiments.

For the main effect of harvest time in yr 2, there was a linear ($P < 0.01$) increase in whole plant yield as harvest time increased. Moss et al. (2001) conducted experiments harvesting corn silage at DM contents of 34.35, 41.52, and 47.74% in yr 1 and 26.80, 29.04, and 35.58% in yr 2. From this, Moss et al. (2001) suggested that increased maturity enhanced grain and whole plant yield. Grain yields (85% DM) for separate harvest times were 4.2, 4.7, and 5.3 t/ha (85% DM; yr 1) and 6.3, 7.2, and 7.8 t/ha (85% DM; yr 2). Whole plant yields were 32.3, 32.9 and 36.1 t/ha (35% DM; Moss et al., 2001). Whole corn plant yield was maximized at 39% DM in Ontario (Daynard and Hunter, 1974). Owens (2008) reported that whole plant corn silage yield is maximized at 37% DM and starch yield continued to increase across DM contents of 29 and 41%. Bolinger et al. (2014) reported that whole plant and starch peaked at 41% DM in Iowa. Corn silage harvested at 28, 35, and 42% DM yielded 13.2, 13.6,and 14.1 t/ha (respectively) in an experiment conducted in New York (Lewis et al., 2004). In contrast, Wiersma et al. (1993) reported that corn silage yield is maximized at ½ to ¾ milkline based on three years of data in Wisconsin; however, in one of the years, frost damaged yield at ¾ milkline and blacklayer sampling times which would have affected the across yr average yields for those stages of maturity.

There was an interaction between season length and harvest time for grain percent or harvest index in yr 1 ($P < 0.01$) and yr 2 ($P < 0.01$). In yr 1 for MEM hybrids, there was a quadratic response to harvest time ($P < 0.05$) with grain percent for MEM hybrids equal (52.96% to 52.84%, harvest 1 and 2, respectively) then increasing to 54.57% (harvest 3). For MLM hybrids in yr 1, there was a linear increase in grain percent due to harvest time (49.71, 51.96, and 53.96% for harvest 1, 2, and 3, respectively; $P < 0.01$). In yr 2 for MEM hybrids, there was a linear increase in grain percent as harvest time was later in the season (54.79, 55.86, and 57.03% for harvest 1, 2, and 3, respectively; $P < 0.01$). In yr 2 for MLM hybrids, there was a quadratic response for grain percent due to harvest time, with grain percent increasing from 51.49% to 56.96% to 58.91% ($P < 0.01$). In general across years, grain percentage increased as harvest time progressed later in the season. As well, except for harvest 2 and 3 in yr 2, MEM hybrids had greater grain percent compared to MLM hybrids. Allen (2003) stated that later-maturing hybrids tend to have lower grain/stover ratios and consequently increased total fiber concentration.

There was no interaction between season length and harvest time for residue NDF concentration in yr 1 ($P = 0.76$) or yr 2 ($P = 0.55$). This agrees with Darby and Lauer (2002) who did not observe a season length x harvest time interaction for unfermented forage and concluded that hybrid quality varied similarly across harvest times. In the present experiment for the main effect of season length, there was an increase in residue NDF concentration for MLM (65.77%) compared to MEM (64.14%; $P < 0.01$) in yr 1. As well in yr 2, MLM hybrids (67.15%) had greater NDF concentration compared to MEM hybrids (62.90%; $P < 0.01$). This would agree with Schwab et al (2003) who reported greater whole plant NDF content for longer season corn compared to shorter season corn. In the present experiment, there was a quadratic response for residue NDF concentration due to harvest time in both years ($P < 0.01$). In yr 1, as harvest time increased from harvest 1 to harvest 2, NDF concentration decreased from 65.78% to 62.78% ($P < 0.01$) then increased to 66.28% ($P < 0.01$) for harvest 3. In yr 2, there was an increase between the first two harvests (63.34% to 66.21%; $P < 0.01$) and then no difference in NDF concentration between the second and third harvests (66.21% compared to 65.54%; $P = 0.17$). In the experiment by Darby and Lauer (2002), NDF concentration of stover increased as the harvest season progressed (range of approximately 66% to 69%). This increase in NDF concentration as plant maturity increased is a classical response. The decrease in NDF concentration in yr 1 between the first two harvests is not consistent with other studies.

An interaction between season length and harvest time was observed for residue NDFD in both yr 1 ($P = 0.02$) and yr 2 ($P < 0.01$). For yr 1, in both MEM (34.83, 35.25, and 24.73% for harvest 1, 2, and 3, respectively; $P < 0.01$) and MLM (38.87, 36.83, and 25.59% for harvest 1, 2, and 3, respectively; $P < 0.01$) hybrids, the response to harvest time was quadratic for residue NDFD. For yr 2, both MEM ($P < 0.01$) and MLM ($P < 0.01$) hybrids linearly decreased in NDFD as harvest time increased. In the summary by Owens (2008), whole plant NDF digestibility linearly decreased by only 2.9 percentage units (47.2 to 44.3%) between corn silage DM concentrations of 30 and 40%. When assessing *in vitro* true digestibility of only the stover portion, Darby and Lauer (2002) reported a linear decrease in stover quality as growing degree days accumulated.

There were no interactions between season length and harvest time for either TDN concentration of the residue, TDN concentration of the whole plant, or TDN yield/ha ($P \geq 0.10$) for yr 1. There was no difference in residue TDN concentration across season length ($P = 0.37$) in yr 1. As well, there was only a very slight decrease in whole plant TDN concentration for MLM (69.42%) compared to MEM (70.20%; $P < 0.01$). When calculating yield of TDN/ha, there was an increase in TDN yield/ha for MLM (16.30 t/ha) compared to MEM hybrids (15.56 t/ha; $P < 0.01$) due to the increased whole plant yield for MLM compared to MEM hybrids. For the main effect of harvest time on TDN concentration (yr 1), there was a quadratic response for both residue ($P < 0.01$) and whole plant TDN ($P < 0.01$). For both residue and whole plant TDN concentration, there was an increase in TDN between the first two harvests and then a decrease to the third harvest. Residue TDN concentrations for the three harvests were 49.22%, 50.71%, and 41.55% (harvest 1, 2, and 3; respectively). Whole plant TDN concentration was 70.24%, 71.34%, and 67.84% for harvest 1, 2, and 3; respectively. For TDN yield/ha, there was a quadratic response to harvest time with TDN yield/ha increasing from 15.10 t/ha to 17.05 t/ha and then decreasing to 15.15 t/ha ($P < 0.01$).

For yr 2, there was a tendency ($P = 0.08$) for an interaction between season length and harvest timing for residue TDN concentration. In both MEM and MLM ($P < 0.01$), there was a linear decrease in residue TDN concentration as harvest time increased. There was an interaction between season length and harvest time for whole plant TDN concentration in yr 2 (*P* < 0.01). In MEM hybrids, there was no significant differences across the three harvest times for whole plant TDN (*P* = 0.13). In MLM hybrids, there was a quadratic (*P* = 0.04) response of whole plant TDN to harvest time, however numerically the differences were slight across harvest time (69.72, 70.86, and 70.74% for harvest 1, 2, and 3; respectively). There were no interactions between season length and harvest timing for yield of TDN/ha (*P* = 0.74). Yield of TDN/ha was not different between MLM and MEM hybrids (*P* = 0.23) in yr 2, although numerically MLM hybrids had greater TDN yield/ha (16.2 t/ha) compared to MEM hybrids (15.9 t/ha). For the main effect of harvest timing on yield of TDN/ha, there was a linear increase in TDN yield/ha as harvest timing was delayed (15.42 t/ha to 16.34 t/ha; *P* < 0.01). By delaying harvest of the whole corn plant from harvest 1 to harvest 3, TDN yield/ha increased by 6.0% in yr 2.

Differences in both years for whole plant TDN were quite minimal and would suggest whole plant quality does not change across the three harvest times tested in these experiments. However, the source of whole plant TDN is changing, with greater amounts of grain in later harvests with less digestible NDF. Amounts of digestible corn silage components were near identical (70.9% at 30% DM compared to 70.7% at 40% DM) across corn silage DM content in the summary by Owens (2008). Harvesting corn silage at 28, 35, or 42% DM in the experiment by Lewis et al. (2004) resulted in whole plant *in vitro* true digestibilities being not different across harvest time (86.4, 86.6, and 86.1%; respectively).

<u>Season length x plant density interactions</u>

There were differences in plant density treatments applied to the corn field across years. In yr 1, there was a tendency for a season length by plant density interaction for actual population ($P = 0.08$; Table III-4). The increases in actual population were quadratic responses for MEM hybrids ($P = 0.05$) as well as for MLM hybrids ($P = 0.01$). In yr 2, there was also an interaction between season length and plant density for actual population ($P = 0.02$; Table III-5). The increase in actual population was a quadratic response due to plant density treatments for MEM hybrids ($P < 0.01$). For MLM hybrids in yr 2, there was a linear increase for actual population due to plant density treatments ($P < 0.01$).

In the analysis of harvested grain yield, there was a season length by plant density interaction ($P < 0.01$) in yr 1. Grain yield increased linearly across plant density treatments for MEM hybrids in yr 1 (10.15, 11.39, 12.71, and 13.26 t/ha for the four plant density treatments; $P < 0.01$). However, the grain yield response was quadratic across the plant density treatments for MLM (10.74, 13.17, 12.87, and 13.24 t/ha across the four plant density treatments; $P < 0.01$). In yr 2, there was no interaction between plant density and season length for grain yield ($P = 0.49$). As plant density increased in yr 2, grain yield linearly ($P < 0.01$) increased from 14.20 t/ha for the lowest plant density to 14.99 t/ha at highest plant density. Shapiro and Wortman (2006) stated that corn grain yield typically exhibits a quadratic response to plant density, with a near linear increase in yield across low plant densities, then a decreasing rate of increase in yield across mid-range densities, and finally a plateau and decrease in yields at very high plant densities. However, Raymond et al. (2009) described that research has often produced maximum yield at or near the highest densities studied. Corn hybrids are being developed with increasing stress tolerance including stress from interplant competition. According to the present experiment across both years, the peak of corn grain yield may have not been reached within the plant densities tested.

There was no season length by plant density interaction for corn stover yield or whole plant yield for yr 1 ($P \geq 0.16$) or yr 2 ($P \geq 0.18$). Raymond et al. (2009) stated that many growers and practitioners believe that a significant interaction between season length and plant density exist; however, controlled research experiments (Alessi and Power, 1974; Thomison and Jordan, 1995) have reported little to no relative maturity by plant density interactions. For the main effect of plant density in yr 1, corn stover yield was quadratically increased ($P = 0.05$) across plant density treatments. Corn stover yield was 9.91, 10.70, 11.23, and 11.41 t/ha for the four plant density treatments (from 49,421 to 93,900 plants/ha, respectively). In yr 2, corn stover yield was linearly increased ($P < 0.01$) from 9.34 to 10.46 t/ha for the plant density treatments of 49,421 to 108,726 plants/ha. For whole plant yield in yr 1, there was a quadratic increase as plant density increased ($P < 0.01$). Whole plant yield increased at a decreasing rate as plant density was increased, with whole plant yield increasing by 12.6% between the lowest two plant densities, 6.5% between the middle two plant densities, and by only 1.1% between the two greatest plant densities for yr 1. In yr 2, there was also a quadratic response for whole plant yield due to plant density treatments ($P < 0.01$). In yr 2, whole plant yield increased by 12.7% between the lowest two plant densities, 3.9% between the middle two plant densities, and by 2.6% between the highest two plant densities. Whole plant yield has been shown to be maximized between 80000 and 100000 plants/ha in many studies in a variety of growing areas and conditions (Fairey, 1982; Cusicanqui and Lauer, 1999; Stanton et al., 2007).

For grain percent (harvest index), there was no season length by plant density interaction in yr 1 ($P = 0.27$), however there was an interaction for grain percent in yr 2 ($P = 0.02$). For the main effect of plant density in yr 1, there was a quadratic response ($P < 0.01$) for grain percent due to imposed plant density treatments. Actual grain percentage of the whole corn plant were 50.90, 52.93, 53.59, and 53.28% for the plant density treatments of 43,017; 56,183; 69,501; and 79,835 plants/ha, respectively. For yr 2, in both MEM and MLM hybrids, grain percent responded quadratically ($P \leq 0.04$) to plant density treatments. Grain percent was 53.18, 55.12, 57.86, and 57.41% (MEM hybrids) and 53.84, 56.45, 56.99, 55.88% (MLM hybrids) for the plant density treatments of 49,421; 69,189; 88,958; and 108,726 plants/ha; respectively. Plant density did not affect grain content in the experiment by Cox et al. (1998). Conversely, Stanton et al. (2007) reported a decrease from 47 to 38% in the cob to stover ratio (% of the whole plant) as plant density increased from 49,000 to 124,000 plants/ha in Alberta. Sanderson et al. (1995) also reported decreases in grain content as plant density increased. Our results differ compared to these researchers.

There was not a season length x plant density interaction ($P = 0.34$) for residue NDF concentration in yr 1. For the main effect of plant density, there was a linear ($P < 0.01$) increase in NDF concentration as plant density increased (62.90%, 64.12%, 66.01%, and 66.83% for plant densities of 43,017; 56,183; 69,501; and 79,835 plants/ha; respectively). In yr 2, there was a season length x plant density interaction ($P = 0.02$) for residue NDF concentration. In MEM hybrids, there was a linear increase ($P < 0.01$) in

NDF concentration from 60.29 to 66.34% as plant density increased. In MLM hybrids, there was a quadratic increase in NDF concentration as plant density increased (64.17, 67.39, 68.08, and 68.97%; $P = 0.05$). Previous research has shown an increase in NDF as plant density increases (Cox et al., 1998; Cusicanqui and Lauer, 2002; Stanton et al., 2007). There was no interactions between season length and plant density for residue NDFD in either yr 1 ($P = 0.17$) or yr 2 ($P = 0.25$). There was a quadratic effect to NDFD ($P < 0.01$, yr 1; $P = 0.02$, yr 2) due to plant density treatments imposed (34.22%, 32.26%, 31.87%, and 32.47% for yr 1 and 33.05, 31.88, 30.78, and 32.15% for yr 2 as plant density increased, respectively). Cusicanqui and Lauer (2002) reported a decrease in cell wall digestibility in only one of their three zones tested. Increases in plant density (from 44,479 to 103,784 plants/ha) resulted in a negative quadratic response for NDF digestibility in the experiment by Cox et al. (1998).

In both years, there was no interaction between season length and plant density for TDN concentration of the residue ($P \geq 0.22$), whole plant TDN concentration ($P \geq 0.13$), or yield of TDN/ha ($P \geq 0.12$). As plant density increased, there was a linear ($P < 0.01$) decrease in TDN concentration of the residue from 48.52% at the lowest plant density to 46.15% at the highest plant density in yr 1. This agreed with yr 2 results as TDN concentration of the residue linearly decreased from 47.94 to 45.34% as plant density increased ($P < 0.01$). However, when assessing the TDN concentration of the whole plant, there was a tendency for a quadratic response ($P = 0.07$) as plant density increased, but numerically across plant densities, there is a range of only 0.45 percentage units (69.61 to 70.06%). There was no significant effect ($P \geq 0.30$) for whole plant TDN concentration across plant densities in yr 2. These results would suggest that whole plant quality is minimally affected by planting density. These results are in contrast to findings by other researchers; generally *in vitro* true DM digestibility decreases as plant density increases. In the Cusicanqui and Lauer (1999) experiment with planting densities ranging from 44,500 to 104,500 plants/ha, in vitro true DM digestibility decreased by 0.035% for each 1000 plants/ha increase in plant density. Stanton et al. (2007) reported a more gradual decrease in *in vitro* true DM digestibilities of 72.6 to 71.5% as plant density increased from 49,421 to 123,553 plants/ha. However, there are differences in grain percent between the present experiment (generally increased as plant density increased) and the experiments conducted by Stanton et al. (2007; decrease in cob:stover as plant density increased), Cox et al. (1998; no differences across plant density), and Sanderson et al. (1995; decreased grain content as plant density increased). In yr 1, yield of TDN/ha was quadratically increased as plant density increased (from 14.01 to 17.04 t TDN/ha; $P < 0.01$). As well in yr 2, the response to increases in plant density was a quadratic increase in yield of TDN/ha from 14.21 to 17.08 t of TDN/ha ($P < 0.01$).

Generally, the current experiment results agree with previous research. Timing of harvest has a major impact on grain and whole plant yields. If the whole plant is harvested early, total DM yield of both grain and whole plant is decreased. However, whole plant quality remains consistent as harvest is progressed (at least across the harvest window tested in these experiments). The selection of longer compared to shorter hybrid season length (RM) results in increased yields with minimal changes in whole plant quality. As well, increasing planting densities allow for generally greater yield potential with insignificant changes in quality of the whole plant.

Cattle Finishing Experiment

As corn silage inclusion increased, final BW, ADG, and DMI linearly decreased ($P \leq 0.01$; Table III-6). Gain:feed decreased linearly ($P < 0.01$) with increasing corn silage in the diet, with the steers on the 15:40 treatment being 1.5%, 5.0%, and 7.7% more efficient than steers on treatments 30:40, 45:40, and 55:40, respectively. This resulted in feeding values of 91, 83, and 81% that of corn for the 15, 30, and 40% replacement of corn. Performance-calculated dietary NEm and NEg concentrations were linearly decreased as corn silage inclusion increased in the diet ($P < 0.01$). Previous research has documented a depression in ADG and G:F (Goodrich et al., 1974; Danner et al., 1980; DiCostanzo et al., 1997, 1998; Erickson et al., 2001) for cattle fed diets with higher ratios of corn silage:corn grain. Erickson et al. (2001) conducted three experiments evaluating 15, 30, and 45% corn silage in finishing diets containing no distillers grains. These researchers reported a linear decrease in ADG and G:F as corn silage increased in the diet for two of their three experiments (1 with calf-fed steers and 1 with yearling steers). When feeding calf-fed steers, which would be the same class of cattle as fed in the current experiment, DMI was increased for cattle fed both 30 and 45% corn silage. However, gains were linearly decreased from 1.59 to 1.42 kg/d as corn silage was increased in the diet (Erickson et al., 2001). Gain:feed for steers fed 30 and 45% corn silage decreased 8.8 and 15.4%, respectively, compared to cattle fed 15% corn silage. For the yearling steer experiment conducted by Erickson et al. (2001), intake was not different across treatments, but G:F was decreased by 5.6% when comparing 15 to 30% corn silage and by 7.4% when comparing 15 to 45% corn silage. In the third experiment by Erickson et al. (2001), ADG and G:F responded quadratically as corn silage was increased in the diet. When comparing 15 to 30% corn silage treatments, ADG and G:F were decreased by 13.5%. When these researchers compared 15 to 45% corn silage, there were reductions in ADG and G:F of 9.1 and 7.8%, respectively. A summary by Goodrich et al. (1974) of experiments replacing corn with corn silage reported approximately a 15% reduction in G:F when corn silage was increased from 15 to 45% of the diet. Comparing the present experiment to the previous research with increased concentrations of corn silage in diets without distillers grains, there is agreement that ADG and G:F decreases as corn silage concentration is increased in the diet. In the current experiment with distillers grain, G:F was decreased by 5.0% from increasing corn silage from 15 to 45% of the diet compared to the approximately 15% reduction reported by Goodrich et al. (1974) and Erickson et al. (2001) from increasing corn silage from 15 to 45% of the diet. These differences may be partially attributed to differences in corn silage quality across experiments; however, this is unknown due to lack of common analyses across experiments. Distillers grains are a source of highly digestible fiber with minimal starch concentration (Klopfenstein et al., 2008). It could be hypothesized that finishing diets containing distillers grains with increased concentrations of corn silage may improve fiber digestion of both corn silage and MDGS compared to these ingredients being fed individually in typical high grain diets due to the reduction in dietary starch concentration and the potential negative associative effects between starch and fiber digestion outlined by Hoover (1986).

When comparing the two treatments fed 45% corn silage, there was no difference in DMI (*P* = 0.30). Steers fed 45% corn silage with 40% MDGS instead of 0% MDGS had increased ADG (*P* = 0.02) and a 16 kg increase in final BW (*P* = 0.02). Gain:Feed was improved ($P = 0.04$) from 0.160 to 0.166 for steers on 45:40 compared to 45:0. There was a numerical increase in NEm (1.90 to 1.94 Mcal/kg) and NEg (1.26 to 1.29 Mcal/kg) as MDGS was increased ($P = 0.13$) in 45% corn silage diets. The improvement in G:F for cattle fed 45:40 compared to 45:0 results in a calculated feeding value of 110% for the 40% substitution of the DRC and HMC blend by MDGS. This feeding value would be within 6 percentage units of the 116% predicted feeding value from a meta-analysis for diets containing MDGS (Bremer et al., 2011).

Within diets containing 30% corn silage, steers fed 65% MDGS compared to 40% MDGS resulted in decreased DMI (10.3 compared to 9.8 kg/d, respectively; $P = 0.01$). Gain was also decreased from 1.78 kg/d for steers fed 40% MDGS to 1.64 kg/d for steers fed 65% MDGS in 30% corn silage diets ($P < 0.01$). There was no difference in G:F or calculated NEm or NEg for steers fed 30% corn silage with 40 or 65% MDGS ($P \geq 0.12$). The reduction in ADG resulted in a 23 kg decrease in final BW ($P < 0.01$) for steers fed 30:65 compared to 30:40. Feeding distillers grains at levels above 30-40% of the diet has been reported to decrease DMI and ADG with a slight improvement in G:F (Klopfenstein et al., 2008; Bremer et al., 2011). Klopfenstein et al. (2008) stated that decreasing DMI at DGS inclusion levels above 30 to 40% may be partially explained by S concentration, lipid concentration, or both contained in the DGS.

Hot carcass weight decreased linearly as corn silage increased in the diet ($P < 0.01$). As corn silage was increased in the diet, dressing percentage linearly decreased ($P < 0.01$). The linear reduction in dressing percentage was expected, as this agrees with previous reports feeding increased concentrations of corn silage (Peterson et al., 1973; Danner et al., 1980). Cattle that have less carcass fatness exhibit lower dressing percentages. In this experiment, 12th rib fat ($P < 0.01$) and calculated yield grade ($P = 0.05$) were linearly decreased with increased corn silage in the diet. All treatments in this experiment were harvested after 173 DOF, and the yield grade results would suggest that cattle fed the higher concentrations of corn silage may have benefited from additional DOF. However, there were no differences in marbling score ($P \geq 0.13$) due to inclusion of corn silage. There was no difference in LM area ($P \geq 0.13$) across corn silage concentrations. There were no differences in liver abscess prevalence due to dietary treatment ($P \leq 0.80$; data not presented).

Comparing steers fed 30% corn silage with 40% MDGS instead of 65% MDGS, HCW was 15 kg greater ($P < 0.01$), with no differences ($P \geq 0.19$) in other carcass characteristics. There also was an improvement in HCW (10 kg; $P = 0.02$) for steers fed 40% MDGS instead of 0% MDGS in diets containing 45% corn silage. There were no other differences ($P \geq 0.07$) in carcass characteristics for steers consuming diets containing 45% corn silage.

Corn silage in combination with MDGS can be utilized to partially replace corn in finishing diets; however a linear reduction in ADG and G:F as corn silage is increased should be expected in diets containing 40% MDGS. With this and the reported linear reduction in calculated yield grade with increased concentrations of corn silage, cattle fed increased concentrations of corn silage may benefit from additional DOF. When 45% corn silage is fed in finishing diets, the addition of MDGS in substitution of corn improved cattle ADG and G:F.

Economic Analyses

In order to better outline the cost of corn silage production, some of the assumptions used in the economic analysis will be presented in more detail. As corn silage is harvested later in the growing cycle of the corn plant, corn grain yield is increased. This is due to the corn plant translocating photoassimilate to corn grain for storage as starch. Huang et al. (2012b) reported that grain yield increased to a plateau when grain reached 40% and 35% DM in two subsequent years in Illinois. This was in agreement to the corn grain DM content threshold of 35% DM for maximal corn grain yield reported by Shinners and Binversie (2007) in Wisconsin, however, Pordesimo et al. (2004) reported maximum grain yield once corn grain DM content is between 20 and 30% DM in Tennessee. Differences in hybrids, relative maturities, environment, and growing conditions would undoubtedly affect the DM content at which corn grain reaches physiological maturity or maximal corn grain yield. Although there is substantial range in the ratio between stover moisture and grain moisture (1.5-3:1), Shinners and Binversie (2007) reported that the common rule of thumb is that stover moisture is roughly twice that of corn grain. If this assumption is used as well as the assumption that the stover to grain ratio is roughly 1:1 on a DM basis, then grain content would reach maximum when corn silage was approximately 40 to 50% DM. This agrees with Daynard and Hunter (1975) where grain DM yield was maximized when the whole corn plant DM content was at least 50%. These whole plant DM contents would be drier than normal corn silage harvest, therefore, when corn silage is harvested prior to physiological maturity, maximal corn grain yield is reduced, and there is a harvested grain yield drag. For the economic analysis, scenarios were set up for harvesting corn silage at 32%, 35%, and 42% DM with corresponding corn grain yield drags of 21.0%, 15.9%, and 6.8% based on the data from yr 2 of the corn plant plot experiments (Figure 3).

In the current corn plant plot experiments, the stover yield response was quadratic due to harvest time in yr 1(P < 0.01), with harvest 2 and harvest 3 yielding 108% and 100% of harvest 1, respectively. For yr 2, there was an interaction for season length and harvest date for stover yield (P = 0.03, yr 2). For MEM in yr 2, stover yield increased from harvest 1 to harvest 2 and then decreased to harvest 3, with the relative stover yield of harvest 2 and 3 being 102 and 101% that of harvest 1. In MLM corn for yr 2, stover yield decreased from harvest 1 to harvest 3. Relative yields for harvest 2 and 3 were 94 and 90% that of harvest 1 in MEM corn. In summary of the current results, stover yield remained constant across harvest time in 3 of 4 comparisons. Most of the literature presented above would suggest that stover yield remains constant or decreases. With the variability in the literature presented in the discussion of the corn plant plot experiments as well as the data presented in the current corn plant plot experiments in regards to stover yield increasing, decreasing, or staying constant leading up until black layer, stover yield was assumed constant in the economic analysis across corn silage DM concentrations of 32, 35, and 42% DM. Keeping all other economic assumptions constant and a corn grain price of $177.16 per t (84.5% DM), if a stover yield drag of 10% was imposed on corn silage harvested at 42% DM, the effect would be an increase in corn silage price of $4.71 per t (from $141 to $145.71 per t; DM) and a decrease in per steer returns of $0.67 and $1.36 at 30 and 45% corn silage, respectively.

The effect of corn price on per steer returns from feeding elevated concentrations of corn silage in 40% MDGS finishing diets are presented in Figure 4. As corn price increased, feeding more corn silage in the diet becomes more economically appealing for cattle feeders. Utilizing corn silage pricing assumptions outlined above and corn priced at $137.79, $177.16, or $216.53 per t (84.5% DM; leaving all other cost assumptions the same across corn price levels), corn silage would be priced into the bunker (i.e. breakeven for the crop producer producing either corn grain or corn silage and without corn silage shrink) at $39.26 per as-is (35%DM) t, $48.16 per as-is t, and $57.05 per as-is t, respectively. The breakeven amount for the crop producer selling corn silage standing in the field (feedyard pays harvesting costs) to the feedyard would be $29.41 per as-is (35% DM) t, $38.31 per as-is t, and $47.20 per as-is t when corn is priced at $137.79, $177.16, and $216.53 per t (84.5% DM), respectively. The corn grain price level that would allow for breakeven returns across corn silage concentrations is $155.50 per t (84.5% DM) suggesting that if corn price goes above $155.50 per t (84.5% DM), then feeding elevated concentrations of corn silage is profitable when harvested at 35% DM with 10% shrink losses. The increased value from corn silage as corn price is increased is mainly due to corn silage harvest costs being a lesser proportion and the actual feed value being a larger proportion of the total costs of corn silage.

The effects of corn silage shrink on per steer returns from feeding elevated concentrations of corn silage in 40% MDGS finishing diets are presented in Figure 5. Reducing shrink from 20% to 10% would save $5.56, $11.43, and $17.69 per finished steer when corn is priced at $177.16 per t (84.5% DM) and corn silage is fed at 15%, 30%, or 45% of the diet, respectively. Shrink was held constant at 10% across corn silage harvest DM content, however, it has been reported that packing density decreases and shrink slightly increases as maturity increases in corn silage stored in 122 cm high x

122 cm diameter tubes (Johnson et al., 2002). No data are available to document these shrink changes on a feedlot bunker scale, where there is a lower surface area: volume ration, so shrink was assumed at a constant value across corn silage harvest DM concentrations. Controlling shrink of corn silage via proper harvest moisture and packing density, incorporating sealing strategies, and appropriate feedout management is strongly recommended based on economic outcomes.

Calculated net returns per steer for harvesting corn silage at 35% instead of 32% DM were $2.47, $5.12, and $7.95 at corn silage inclusions of 15%, 30%, or 45% of the diet, respectively (Figure 6). These economic data emphasize the importance of not harvesting corn silage too early resulting in reduced corn silage yield with the potential of harvesting corn silage at higher DM content if shrink can be managed. If shrink can be minimized when harvesting corn silage at 42% DM by proper packing, sealing, and oxygen exclusion strategies, then the price point of corn grain that it becomes economical to feed increased concentrations of corn silage is approximately $96.85 per t (84.5% DM) based on the cattle performance experiment results. Goodrich et al. (1974) conducted an economic analysis on feeding increased concentrations of corn silage in finishing diets based on performance from a summary of 17 university experiments. In this analysis, corn silage was priced at $29.16 per t (32% DM) and corn grain was priced at $177.16 per t (84.5% DM). These researchers reported that when corn is priced at $76.77 per t (84.5% DM), it is economical for producers that only feed one lot a yr to increase corn silage in the diet from 20 to 30% of diet DM. When corn price is above this, Goodrich et al. (1974) reported that it is economical to feed even greater inclusions of corn silage. When producers feed cattle continuously throughout the yr, the economics of increasing corn silage in diet depends on profitability. It may be more profitable for continuous feeding producers to maximize throughput and total profit versus increasing corn silage and trying to maximize profit per head (Goodrich et al., 1974). DiCostanzo et al. (1997) fed 15, 24, or 36% corn silage and reported favorable economics when feeding increased concentrations of corn silage. With corn priced at $118.10 per t (84.5% DM) and corn silage priced at $34.72 per t (42.6% DM), these researchers calculated similar net returns across corn silage inclusion concentrations. When corn silage was priced at the cost of production ($22.31 per t; 42.6% DM), returns to feeding and per ha were maximized when corn silage was fed at 36% of the diet. In a subsequent analysis done by DiCostanzo et al. (1998), feeding increased concentrations of corn silage was economical when corn was priced above $128.73 per t (84.5% DM).

These data suggest that there is an economic incentive to feeding increased concentrations of corn silage in finishing diets containing distillers grains. The economic incentives are increased when corn price is elevated. These data emphasize the economic importance of proper harvesting and storage of corn silage to minimize shrink, as well as the economic consequence of harvesting corn silage at lower DM concentrations. As corn price is increased and the inclusion of corn silage is increased in finishing diets, corn silage management decisions and managing shrink losses have greater economic importance.

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Table III-1. Diet composition (DM basis) for cattle finishing experiment.

	Treatment[1]					
Item	15:40	30:40	45:40	55:40	30:65	45:0
DRC[2]	20.0	12.5	5.0	0.0	0.0	25.0
HMC[3]	20.0	12.5	5.0	0.0	0.0	25.0
Corn Silage	15.0	30.0	45.0	55.0	30.0	45.0
MDGS[4]	40.0	40.0	40.0	40.0	65.0	0.0
Supplement[5]	5.0	5.0	5.0	5.0	5.0	5.0
Fine-Ground Corn	3.2676	3.2676	3.2676	3.2676	2.7066	1.7466
Urea	---	---	---	---	---	1.4900
Limestone	1.1990	1.1990	1.1990	1.1990	1.7600	1.2300
Salt	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Tallow	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250
Trace Mineral Premix[6]	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamin Premix[7]	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
Thiamine Premix[8]	0.0167	0.0167	0.0167	0.0167	0.0167	0.0167
Tylan 40[9]	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
Rumensin 90[10]	0.0167	0.0167	0.0167	0.0167	0.0167	0.0167
Nutrient Composition[11]						
Crude Protein, %	17.0	16.9	16.8	16.7	21.9	12.7
NDF, %	28.2	34.1	39.9	43.8	40.5	29.3
Ether Extract, %	7.2	7.0	6.7	6.6	8.9	3.5
Ca, %	0.75	0.78	0.81	0.83	0.77	0.61
P, %	0.56	0.55	0.54	0.54	0.69	0.31
K, %	0.73	0.85	0.96	1.04	1.02	0.68
S, %	0.36	0.36	0.36	0.36	0.51	0.12

[1] 15:40 = 15% Corn Silage, 40% MDGS; 30:40 = 30% Corn Silage, 40% MDGS; 45:40= 45% Corn Silage, 40% MDGS; 55:40= 55% Corn Silage, 40% MDGS; 30:65= 30% Corn Silage, 65% MDGS; 45:0= 45% Corn Silage, 0% MDGS.

[2] DRC = Dry rolled corn.

[3] HMC = High moisture corn.

[4] MDGS = Modified distillers grains with solubles.

[5] Supplement formulated to be fed at 5.0% of diet DM.
[6] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.
[7] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.
[8] Premix contained 88 g/kg thiamine.
[9] Premix contained 198 g/kg monensin.
[10] Premix contained 88 g/kg tylosin.
[11] Based on analyzed nutrients for each ingredient.

Table III-2. Effect of season and harvest timing on whole corn plant characteristics (yr 1).

	Season x Harvest[1]							*P*-value[2]			
Item	MEM:1	MEM:2	MEM:3	MLM:1	MLM:2	MLM:3	SEM	F-test	Int.	Season	Harvest
Actual Population[3]	62134	62134	62134	63454	63454	63454	588	0.98	1.00	<0.01	NS
Grain Yield	11.87	11.87	11.87	12.50	12.50	12.50	0.17	0.04	1.00	<0.01	NS
Corn Stover Yield[45]	10.01	10.91	9.97	11.06	11.83	11.07	0.20	<0.01	0.85	<0.01	Q
Whole Plant Yield[45]	21.29	23.17	21.97	21.92	24.62	24.08	0.36	<0.01	0.10	<0.01	Q
Grain, %[5]	52.96^{b}	52.84^{bc}	54.57^{a}	49.71^{d}	51.96^{c}	53.96^{a}	0.33	<0.01	<0.01	<0.01	Q^{MEM}, L^{MLM}
Residue NDF, %	65.13	61.79	65.44	66.43	63.76	67.13	0.47	<0.01	0.76	<0.01	Q
Residue NDFD, %[6]	34.83^{c}	35.25^{bc}	24.73^{d}	38.87^{a}	36.83^{b}	25.59^{d}	0.61	<0.01	0.02	<0.01	$Q^{MEM,MLM}$
Residue TDN, %	48.98	50.95	42.05	49.47	50.49	41.04	0.41	<0.01	0.16	0.37	Q
Whole Plant TDN, %	70.76	71.64	68.21	69.71	71.04	67.47	0.20	<0.01	0.48	<0.01	Q
TDN yield/ha[7]	15.03	16.62	15.03	15.16	17.47	16.26	0.31	<0.01	0.10	<0.01	Q

^{abc} Means with different superscripts differ ($P < 0.05$)

[1] MEM = moderately early maturity, MLM = moderately late maturity; harvest dates: 1= September 1, 2011; 2=September 15, 2011; 3=September 29, 2011.

[2] F-test = overall F-test, Int = Interaction between season and harvest, Season = *P*-value for the season effect, Harvest = orthogonal contrast *P*-value for the harvest effect; NS = not significant ($P > 0.05$), L = linear response ($P < 0.05$), Q = quadratic response ($P < 0.05$).

[3] Actual population in plants/ha.

[4] Yield in t/ha.

[5] Harvest Index, DM basis.

[6] Residue in-situ NDF digestibility.

[7] TDN yield/ha (t of TDN/ha) = whole plant TDN x whole plant yield.

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Table III-3. Effect of season and harvest timing on whole corn plant characteristics (yr 2).

	Season x Harvest[1]							P-value[2]			
Item	MEM:1	MEM:2	MEM:3	MLM:1	MLM:2	MLM:3	SEM	F-test	Int.	Season	Harvest
Actual Population[3]	66975	66975	66975	67961	67961	67961	3076	1.00	1.00	0.09	NS
Grain Yield	13.95	13.95	13.95	15.28	15.28	15.28	0.25	<0.01	1.00	<0.01	NS
Corn Stover Yield[4,5]	9.69^{b}	9.89^{b}	9.77^{b}	10.72^{a}	10.08^{ab}	9.62^{b}	0.24	0.02	0.04	0.06	NS^{MEM}, L^{MLM}
Whole Plant Yield[4,5]	21.53	22.44	22.69	22.17	23.41	23.37	0.51	0.07	0.92	0.03	L
Grain, %[5]	54.79^{c}	55.86^{bc}	57.03^{b}	51.49^{d}	56.96^{b}	58.91^{a}	0.50	<0.01	<0.01	0.76	L^{MEM}, Q^{MLM}
Residue NDF, %	61.27	64.32	63.11	65.40	68.10	67.96	0.60	<0.01	0.55	<0.01	Q
Residue NDFD, %[6]	33.21^{b}	32.12^{b}	28.71^{c}	37.88^{a}	32.30^{b}	27.76^{c}	0.67	<0.01	<0.01	0.01	L$^{MEM, MLM}$
Residue TDN, %	49.36	46.95	46.15	48.29	45.47	43.04	0.51	<0.01	0.08	<0.01	L
Whole Plant TDN, %	71.66^{a}	71.05^{ab}	71.14^{ab}	69.72^{c}	70.86^{b}	70.74^{b}	0.25	<0.01	<0.01	<0.01	NS^{MEM},Q^{MLM}
TDN yield/ha[7]	15.42	16.09	16.14	15.52	16.61	16.53	0.39	0.14	0.74	0.23	L

^{abc} Means with different superscripts differ ($P < 0.05$)

[1] MEM = moderately early maturity, MLM = moderately late maturity; harvest dates: 1= August 23, 2012; 2=September 6, 2012; 3=September 24, 2012.

[2] F-test = overall F-test, Int = Interaction between season and harvest, Season = P-value for the season effect, Harvest = orthogonal contrast P-value for the harvest effect; NS = not significant ($P > 0.05$), L = linear response ($P < 0.05$), Q = quadratic response ($P < 0.05$).

[3] Actual population in plants/ha.

[4] Yield in t/ha.

[5] Harvest Index, DM basis.

[6] Residue in-situ NDF digestibility.

[7] TDN yield/ha (t of TDN/ha) = whole plant TDN x whole plant yield.

Table III-4. Effect of season and population density on whole corn plant characteristics (yr 1).

Item	Season x Density[1]								SEM	P-value[2]			
	MEM: 49,421	MEM: 64,247	MEM: 79,073	MEM: 93,900	MLM: 49,421	MLM: 64,247	MLM: 79,073	MLM: 93,900		F-test	Int.	Season	Density
Actual Population[3]	43017	56183	69501	79835	42481	57484	71032	82820	680	<0.01	0.08	<0.01	Q
Grain Yield	10.15^{d}	11.39^{b}	12.71^{a}	13.26^{a}	10.74^{c}	13.17^{a}	12.87^{a}	13.24^{a}	0.20	<0.01	<0.01	<0.01	L^{MEM}, Q^{MLM}
Corn Stover Yield[45]	9.49	10.33	10.79	10.58	10.32	11.06	11.66	12.24	0.23	<0.01	0.16	<0.01	Q
Whole Plant Yield[45]	19.51	22.24	23.57	23.27	20.77	23.12	24.72	25.55	0.42	<0.01	0.33	<0.01	Q
Grain, %[5]	51.41	53.63	54.34	54.52	50.39	52.22	52.83	52.03	0.38	<0.01	0.27	<0.01	Q
Residue NDF, %	62.27	63.65	64.70	65.96	63.52	64.61	67.23	67.71	0.54	<0.01	0.34	<0.01	L
Residue NDFD, %[6]	33.12	31.67	31.01	30.55	35.33	32.89	32.69	34.30	1.10	0.03	0.17	<0.01	Q
Residue TDN, %	48.40	47.75	47.07	45.95	48.65	47.26	45.89	46.35	0.78	0.06	0.22	0.37	L
Whole Plant TDN, %	69.84	70.48	70.44	70.05	69.64	69.62	69.24	69.19	0.32	0.02	0.13	<0.01	NS
TDN yield/ha[7]	13.62	15.67	16.59	16.46	14.39	16.08	17.11	17.62	0.33	<0.01	0.56	<0.01	Q

[abc] Means with different superscripts differ ($P < 0.05$)

[1] MEM = moderately early maturity, MLM = moderately late maturity; density: 1= September 1, 2011; 2=September 15, 2011; 3=September 29, 2011.

[2] F-test = overall F-test, Int = Interaction between season and harvest, Season = P-value for the season effect, Harvest = orthogonal contrast P-value for the harvest effect; NS = not significant ($P > 0.05$), L = linear response ($P < 0.05$), Q = quadratic response ($P < 0.05$).

[3] Actual population in plants/ha.

[4] Yield in t/ha.

[5] Harvest Index, DM basis.

[6] Residue in-situ NDF digestibility.

[7] TDN yield/ha (t of TDN/ha) = whole plant TDN x whole plant yield.

Table III-5. Effect of season and population density on whole corn plant characteristics (yr 2).

Item	Season x Density[1]								SEM	P-value[2]			
	MEM: 49,421	MEM: 69,189	MEM: 88,958	MEM: 108,726	MLM: 49,421	MLM: 69,189	MLM: 88,958	MLM: 108,726		F-test	Int.	Season	Density
Actual Population[3]	43892^{e}	58125^{d}	72715^{c}	93167^{a}	45208^{e}	59798^{d}	75586^{b}	91253^{a}	801	<0.01	0.02	0.09	Q^{MEM}, L^{MLM}
Grain Yield	13.37	13.52	14.28	14.51	15.03	15.19	15.43	15.47	0.30	<0.01	0.49	<0.01	L
Corn Stover Yield[45]	8.92	10.11	9.84	10.27	9.75	9.93	10.22	10.65^{a}	0.27	<0.01	0.32	0.06	L
Whole Plant Yield[45]	19.05	22.49	23.27	24.08	21.15	22.81	23.79	24.19^{a}	0.51	<0.01	0.18	0.03	Q
Grain, %[5]	53.18^{e}	55.12^{cd}	57.86^{a}	57.41^{ab}	53.84^{de}	56.45^{abc}	56.99^{abc}	55.88^{bc}	0.67	<0.01	0.02	0.76	$Q^{MEM, MLM}$
Residue NDF, %	60.29^{d}	61.28^{d}	63.70^{c}	66.34^{b}	64.17^{c}	67.39^{ab}	68.08^{a}	68.97^{a}	0.61	<0.01	0.02	<0.01	L^{MEM}, Q^{MLM}
Residue NDFD, %[6]	32.57	31.66	29.98	31.24	33.52	32.09	31.58	33.03	1.00	0.25	0.83	0.01	Q
Residue TDN, %	48.74	48.41	46.98	45.99	47.14	45.45	44.94	44.72	0.66	<0.01	0.48	<0.01	L
Whole Plant TDN, %	70.68	71.34	71.92	71.20	70.27	70.78	70.67	70.10	0.29	<0.01	0.37	<0.01	Q
TDN yield/ha[7]	13.46^{c}	16.12^{a}	16.72^{a}	17.18^{a}	14.95^{b}	16.12^{a}	16.83^{a}	16.98^{a}	0.39	<0.01	0.12	0.23	Q

[abc] Means with different superscripts differ ($P < 0.05$)

[1] MEM = moderately early maturity, MLM = moderately late maturity; harvest dates: 1= August 23, 2012; 2=September 6, 2012; 3=September 24, 2012.

[2] F-test = overall F-test, Int = Interaction between season and harvest, Season = *P*-value for the season effect, Harvest = orthogonal contrast *P*-value for the harvest effect; NS = not significant ($P > 0.05$), L = linear response ($P < 0.05$), Q = quadratic response ($P < 0.05$).

[3] Actual population in plants/ha.

[4] Yield in t/ha.

[5] Harvest Index, DM basis.

[6] Residue in-situ NDF digestibility.

[7] TDN yield/ha (t of TDN/ha) = whole plant TDN x whole plant yield.

Table III-6. Effect of corn silage and MDGS inclusion on cattle performance and carcass characteristics.

	Treatment[1]							*P*-value[2]			
Item	15:40	30:40	45:40	55:40	30:65	45:0	SEM	Lin.	Quad.	30	45
Performance											
Initial BW, kg	325	324	323	324	324	325	1	0.09	0.29	0.69	0.06
Final BW[3], kg	642	631	618	600	608	602	5	<0.01	0.21	<0.01	0.02
DMI, kg	10.5	10.3	10.3	9.9	9.8	10.1	0.1	0.01	0.45	0.01	0.30
ADG, kg[3]	1.83	1.78	1.71	1.60	1.64	1.61	0.03	<0.01	0.19	<0.01	0.02
Gain:Feed[3]	0.175	0.173	0.166	0.161	0.168	0.160	0.002	<0.01	0.33	0.12	0.04
NEm[4]	2.00	1.99	1.94	1.92	1.97	1.90	0.02	<0.01	0.55	0.58	0.13
NEg[4]	1.34	1.33	1.29	1.28	1.32	1.26	0.02	<0.01	0.55	0.58	0.13
Carcass Characteristics											
HCW, kg	404	398	390	378	383	380	3	<0.01	0.21	<0.01	0.02
Dressing %	63.3	62.6	61.9	61.1	62.1	61.2	0.3	<0.01	0.54	0.19	0.07
LM area, cm^2	93.6	93.7	92.2	90.5	91.6	90.7	1.5	0.13	0.46	0.34	0.49
12th-rib fat, cm	1.40	1.35	1.33	1.10	1.27	1.25	0.06	<0.01	0.09	0.29	0.29
Calculated YG[5]	3.13	3.02	3.02	2.77	2.92	2.91	0.11	0.05	0.47	0.50	0.45
Marbling Score[6]	455	456	442	431	446	439	12	0.13	0.52	0.55	0.85

[1] 15:40 = 15% Corn Silage, 40% MDGS; 30:40= 30% Corn Silage, 40% MDGS; 45:40= 45% Corn Silage, 40% MDGS; 55:40= 55% Corn Silage, 40% MDGS; 30:65= 30% Corn Silage, 65% MDGS; 45:0= 45% Corn Silage, 0% MDGS.

[2] Lin. = *P*-value for the linear response to corn silage inclusion, Quad.= *P*-value for the quadratic response to corn silage inclusion, 30 = t-test comparison of treatments 30:40 and 30:65, 45 = t-test comparison of treatments 45:40 and 45:0.

[3] Calculated from hot carcass weight, adjusted to a common 63% dressing percentage.

[4] NEm and NEg calculated using methodology by Galyean (2009).

[5] Calculated YG (yield grade) = [2.5 + (6.35 x fat thickness, cm) + (0.2 x 2.5% KPH) + (0.0017 x HCW, kg) – (2.06 x LM area, cm2)]; (Boggs and Merkel, 1993).

[6] Marbling Score: 400 = Small00, 500 = Modest00.

Figure III-1. Effect of corn silage harvest DM content on grain yield relative to maximum grain yield (adapted from yr 2 of corn plot experiments; calculated as grain percent x whole plant DM yield / (harvest 3 grain percent x whole plant DM yield).

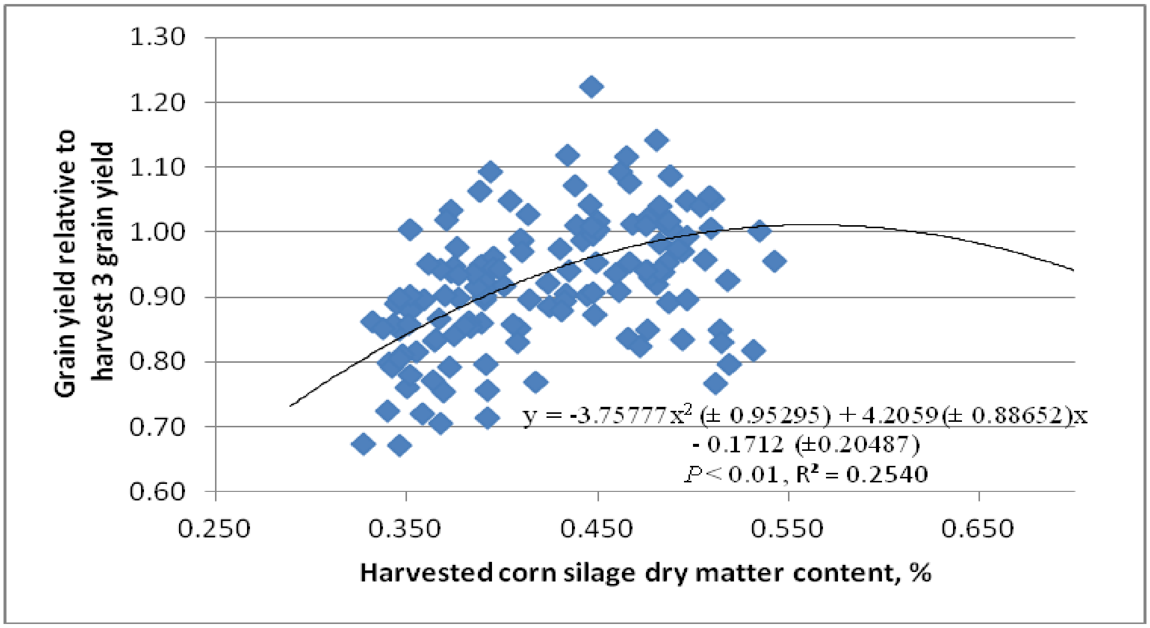

Figure III-2. Effect of corn price ($/t) on per steer returns from feeding elevated concentrations of corn silage (harvested at 35% DM with 10% shrink) in finishing diets containing 40% modified distillers grains with solubles.

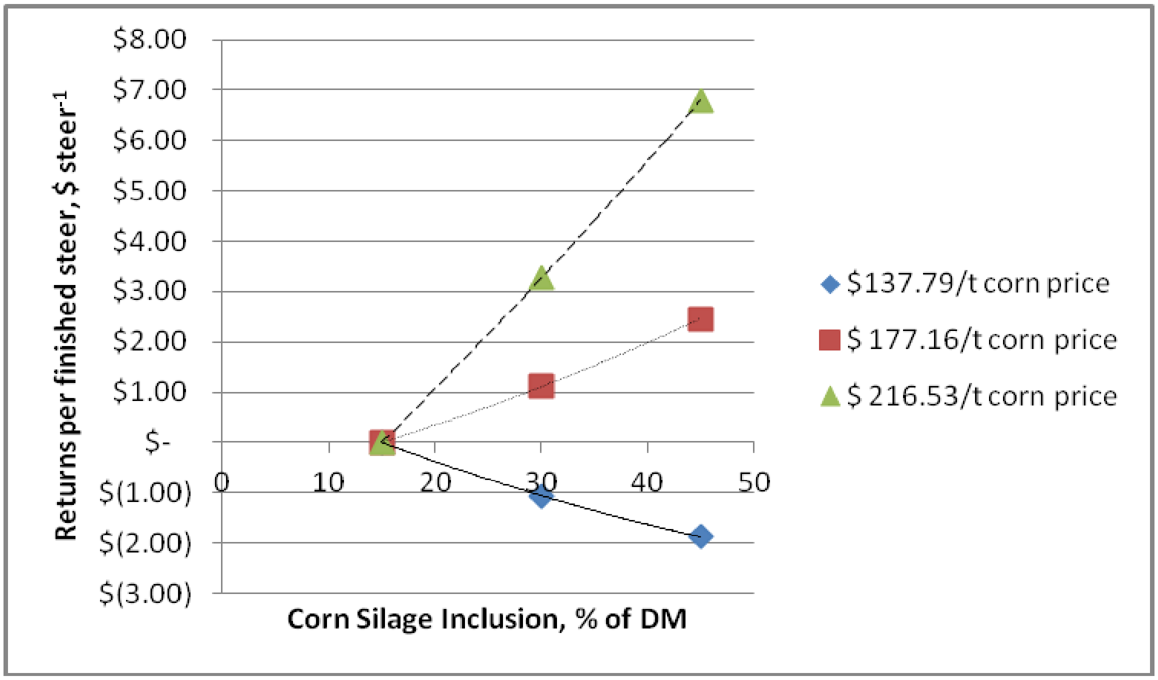

Figure III-3. Effect of corn silage shrink on per steer returns from feeding elevated concentrations of corn silage in finishing diets containing 40% modified distillers grains with solubles when corn is priced at $177.16/t.

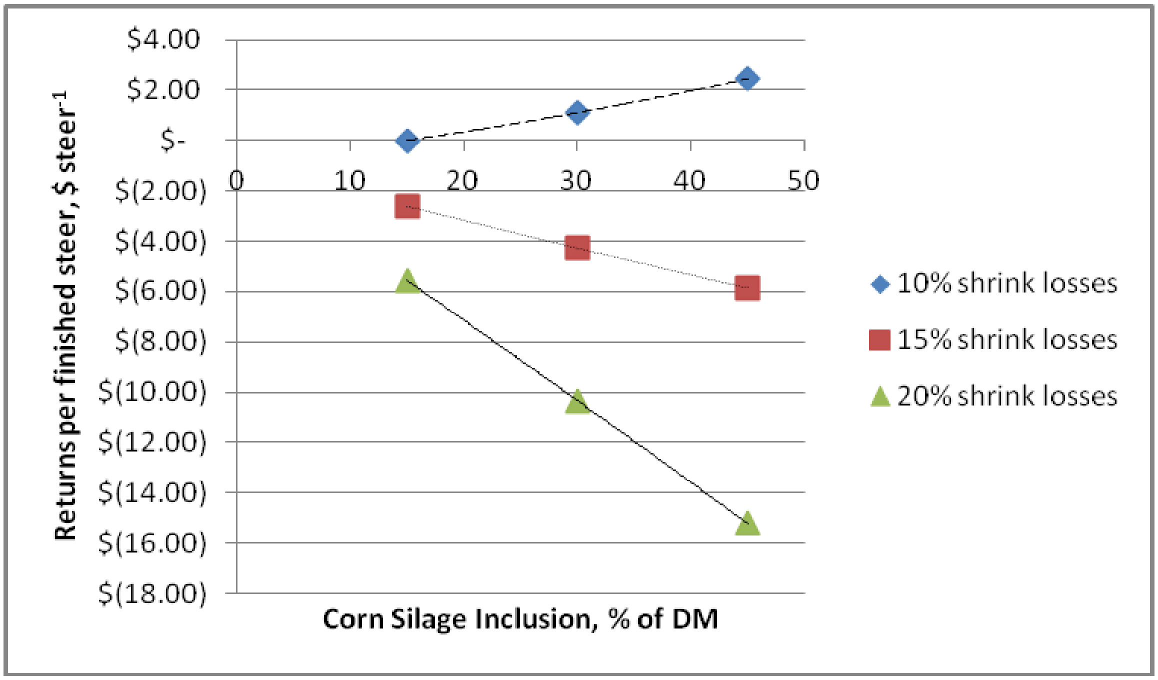

Figure III-4. Effect of corn silage DM content at harvest on per steer returns from feeding elevated concentrations of corn silage (10% shrink) in finishing diets containing 40% modified distillers grains with solubles when corn is priced at $177.16/t.