Effects of agronomic factors on yield and quality of whole corn plants and the impact of feeding high concentrations of corn silage in diets containing distillers grains to finishing cattle[1]

D. B. Burken,* B. L. Nuttelman,* J. L. Gramkow,* 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; and †Department of Agronomy, University of Nebraska, Lincoln 68583

ABSTRACT: Corn plants were sampled over 2 consecutive years to assess the effects of corn hybrid maturity class, plant population, 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). The first 2 harvest dates were at the mid- and late-silage harvest times whereas the final harvest was at the grain harvest stage of plant maturity. 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, because grain percentage increased but 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) by replacing dry rolled and high moisture corn grain with corn silage 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. Calculated dietary NEm and NEg decreased linearly as corn silage inclusion increased indicating that net energy values were greater for corn grain than for corn silage. In addition, dressing percentage decreased linearly ($P < 0.01$) as silage inclusion increased suggesting more fill as silage inclusion increases in diets. Cattle fed greater than 15% corn silage in finishing diets based on corn grain will gain slower and be slightly less efficient and likely require increased days to market at similar carcass fatness and size. When 30% silage was fed with 65% MDGS, DMI, and ADG were decreased ($P < 0.01$) compared to feeding 30% silage with 40% MDGS suggesting some benefit to including a proportion of corn in the diet. Conversely, when 45% silage was fed with 40% MDGS, ADG, and G:F were greater ($P < 0.04$) than when 45% silage was fed with just grain implying a greater energy value for MDGS than for corn grain. Substituting corn silage for corn grain in finishing diets decreased ADG and G:F which would increase days to finish to an equal carcass weight; however, in this experiment, increasing corn silage levels with MDGS present reduced carcass fat thickness without significantly decreasing marbling score.

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

Transl. Anim. Sci. 2017.1:367–381
doi:10.2527/tas2017.0045

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 et al., 1998). However, the price of corn silage impacts its economics. Corn silage pricing is complex due to the variability in nutrient content and yield of corn silage, which can be affected by corn production management decisions (such as hybrid selection and plant population), growing conditions, and harvest timing. Pricing corn silage must also account for the opportunity costs/returns associated with dry commodity corn production as well as grain and silage harvest costs.

[1]A contribution of the University of Nebraska Agriculture Research Division, supported in part by funds provided through the Hatch Act.

[2]Corresponding author: gerickson4@unl.edu

Received January 21, 2017.
Accepted June 30, 2017.

Because ADG and G:F decrease as corn silage displaces dietary corn grain (Goodrich et al., 1974; Preston, 1975; Erickson, 2001), days on feed (DOF) need to be increased to compensate for lower ADG when high amounts of corn silage are fed if equal slaughter weights are desired, however effects on marbling score and fat thickness also may be altered by level of corn silage in the diet. With additional DOF, non-feed costs increase, so diet cost savings from feeding elevated concentrations of corn silage in finishing diets must compensate for these increased non-feed costs. However, most of the cattle performance data with increased concentrations of corn silage were completed prior to the expansion of the ethanol industry and inclusion of distillers grains in finishing diets. Distillers grains and corn silage generally are produced in the same geographic region, so the evaluation of feeding finishing diets with an increased proportion of corn silage with distillers grains appears warranted. The objectives of these experiments were 1) to assess the effects of hybrid relative maturity (RM), plant population, and harvest date on whole corn plant yield and quality measures, and 2) to evaluate animal performance and carcass characteristics of cattle fed higher concentrations of corn silage in finishing diets together with distillers grains.

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 4 target 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 × plant 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, and HPT 8041 Hx/LL/RR (Hoegemeyer Hybrids, Hooper, NE), and P1151 HR (DuPont Pioneer, Johnston, IA). 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 HP 1153 Hx/LL/RR; MLM hybrids in yr 2 were 8359 3000GT, HPT 8345 Hx/LL/RR, and HPT 8803 Hx/LL/RR. In yr 2, all hybrids evaluated were Hoegemeyer Hybrids. Plots were arranged throughout a cornfield as 4 rows (76 cm row width) that were 6 m in length. There were a total of 120 separate plots [10 hybrids × 4 plant populations × 3 repetitions (repetitions defined as 3 separate plots of each hybrid × population combination)] that were sampled at each harvest for a total of 360 samples (120 plots × 3 harvest dates) in yr 1; for yr 2, there were a total of 72 separate plots (6 hybrids × 4 plant populations × 3 repetitions) sampled at each harvest for a total of 216 samples (72 plots × 3 harvest dates).The outside 2 rows were sampled for this experiment, with the inside 2 rows utilized in commercial grain yield research trials. Actual plant population stand counts were completed when plant height was approximately 7 cm; plants were counted within a 6.096 m plot row and then converted to plant population per hectare. There was no irrigation water applied between harvests, however there was no apparent plant drought stress according to the collaborating commercial corn seed company representatives and soil moisture probes.

Five competitive corn plants (defined as healthy and plot-representative plants that were visually equidistantly spaced between other plants) were cut 15.2 cm above ground level and collected on 3 harvest dates to simulate corn silage harvest at approximately half starch milkline (EH) based on the mean visual appearance of the MEM and MLM hybrids, late corn silage harvest (LH), and grain and stover harvest (GH). In yr 1, harvest dates were September 1 (EH) which corresponded to 2,557 growing degree days (GDD), September 15 (LH) or 2,747 GDD, and September 29 (GH) or 2,907 GDD. In yr 2, harvest dates were August 23 (EH) or 2,532 GDD, September 6 (LH) or 2,846 GDD, and September 24 (GH) or 3,111 GDD. Both MEM and MLM hybrids were harvested on the same calendar date. Hand harvest, subsequent handling, and sample analyses methods were performed similarly across years except for harvest 3 in yr 1. For yr 1 (harvest 1 and 2) and for all harvests of yr 2, ear and husk fractions were separated and weighed at the 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 as 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 for 48 h in a 60º C forced-air oven and weighed for DM determination (AOAC, 1999 method 4.1.03) and used for yield/ha calculations (sample DM weight × actual population per ha). Another subsample of the stem, leaf, plus 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 3 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 maturities. For this harvest, 5 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 then were bundled together. Stalk bundles and individual plant parts were allowed to air dry (exposed to air inside a concrete floored building) for approximately 1 month. Stalks then were 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 of the air-dried components was determined for each individual plant part 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 Technology) 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 2 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% dry-rolled corn (DRC), and 0.4% trace minerals/vitamins. Two non-incubated bags (0 h) were also prepared for each sample to establish initial NDF. 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 (NDFD) was calculated by subtracting remaining residue of each sample (after 28 h incubation period) from the initial value (0 h), therefore, 28 hour NDFD assumed any washout was digested. Plant part data were summed utilizing plant part proportions of the whole plant to calculate the individual 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, no whole plant DM concentration data for harvest 3 of yr 1 are available; however, DM weights of these samples were used for corn silage yield calculations.

A value for NDFD of the plant residue was calculated using the percentage of whole plant DM in each plant part (husk, cob, stem, leaf, shank), its NDF concentration, and its in-situ NDFD for husk, cob, stem, leaf, and shank sample. Total cell soluble concentration of the plant residues was determined by summing (1-NDF × respective plant part DM percentage of the whole plant) for husk, cob, and the stem, leaf, and shank sample. Addition of plant residue NDFD and total plant residue cell soluble concentration resulted in an estimate of true digestibility of the plant residues. From estimated true digestibility, TDN of residue was then calculated as this sum minus 12%, an estimate of metabolic fecal energy loss (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 an estimate for the amount of digestible plant residue. Digestible grain content was calculated as corn grain percentage of the whole plant multiplied by 0.93 (high moisture corn TDN, NRC, 1996). A final TDN for each hybrid × population × harvest × repetition corn plant sample was calculated as digestible plant residue + digestible grain content. Yield of TDN/ha was then calculated as TDN concentration × whole plant yield/ha.

Yield and nutritive value data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The experimental unit consisted of a composite of 5 corn plants per each hybrid × harvest time × plant population × repetition combination. There were 3 replications (from separate plots within the field) per hybrid × harvest date × plant population. Hybrid maturity class (MEM or MLM), plant population, and harvest date were fixed effects. Orthogonal contrasts were used to test the effects of harvest date and plant population. The IML procedure of SAS was used in yr 2 to calculate harvest date orthogonal contrast statement coefficients due to unequal spacing between harvest dates. Statistical interactions between fixed effects also were tested and will be presented when statistically significant at $P \leq 0.05$.

Cattle Finishing Experiment

For the cattle finishing experiment, crossbred steer calves (n = 324; BW = 324 ± 17 kg) were separated into 2 BW blocks and assigned randomly to 1 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 at 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, Zoetis Inc., New York, NY), a *Histophilus somnus* bacterin (Somubac, Zoetis Inc.), and an injectable anthelmintic (Dectomax, Zoetis Inc.). All steers were revaccinated approximately 14 to 28 d after initial processing with Bovi-Shield Gold 5 (Zoetis Inc.), 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 initiation of the experiment. Steers were limit fed

(Watson et al., 2013) 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 to equalize gastro-intestinal fill prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). Treatments (Table 1) consisted of 15, 30, 45, and 55% corn silage with 40% modified distillers grains with solubles (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). Corn silage and MDGS replaced a 1:1 blend of DRC: high moisture corn (HMC) on a DM basis. Corn silage was harvested from a commercial irrigated cornfield grown for corn grain production with a targeted DM content of 35%. Corn silage was kernel processed (rollers set at 2 mm) through an onboard kernel processor mounted on the custom chopper. Silage was harvested in early September, and the experiment was conducted from November to May. No inoculants were used on silage and silage was stored in silo bags (Ag-Bag Systems, St. Nazianz, WI). All steers were fed a supplement formulated to contain 33mg/kg monensin (Elanco Animal Health, Greenfield, IN) and a target 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 MP requirements (NRC, 1996). Fresh feed was provided once daily at approximately 0930 h. Steers were implanted with Revalor-IS (Merck Animal Health) 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 having only trace amounts of feed remaining at the time that fresh feed was delivered. All diets were fed once daily, and feed refusals were removed from feedbunks when needed, weighed, and subsampled. All feed refusals were subsampled

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

	Treatment[1]					
Item	15:40	30:40	45:40	55:40	30:65	45:0
Dry-rolled corn	20.0	12.5	5.0	0.0	0.0	25.0
High-moisture corn	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[2]	40.0	40.0	40.0	40.0	65.0	0.0
Supplement[3]	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[4]	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
Vitamin Premix[5]	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150
Thiamine Premix[6]	0.0167	0.0167	0.0167	0.0167	0.0167	0.0167
Tylan 40[7]	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
Rumensin 90[8]	0.0167	0.0167	0.0167	0.0167	0.0167	0.0167
Nutrient Composition[9]						
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]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 thiamine.

[7]Premix contained 198 g/kg monensin.

[8]Premix contained 88 g/kg tylosin.

[9]Based on analyzed nutrients for each ingredient.

and dried for 48 h in a 60ºC forced-air oven for determination of DM and calculation of refusal DM weight; composition of refused feed was considered to be equal to that of the feed offered assuming no sorting had occurred. Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly based on DM content of ingredients. Dietary ingredient weekly samples composited over the entire experiment were analyzed for CP (AOAC, 1999 method 990.03; TrueSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest et al., 1991), and ether extract (Bremer et al, 2010; Table 1). Composited weekly dietary ingredient samples were analyzed by a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) for Ca, P, K, and S concentration. Dietary mineral concentrations were calculated utilizing ingredient mineral concentration and ingredient inclusion level. All steers were on feed for 173 d and were harvested at a commercial abattoir (Greater Omaha, 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 to estimate final live BW and calculate dressing percentage. At slaughter the following morning, HCW and liver scores were obtained. 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 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 an assumed 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 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2); USDA, 2016].

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] × 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) and are based on NRC (1996) equations.

Performance and carcass data 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. Orthogonal contrasts were used to test the effects of corn silage concentration within diets containing 40% MDGS. The IML procedure of SAS 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 65% MDGS assuming equal variance across treatments given the study design. Prevalence of liver abscesses was analyzed using the GLIMMIX procedure of SAS using a binomial distribution. Significance of effects was determined at $P \leq 0.05$.

RESULTS AND DISCUSSION

Corn Plant Sampling

Hybrid Maturity Class × Harvest Date Interactions. There was a tendency ($P = 0.09$) for a hybrid maturity class × plant population × harvest time interaction for residue NDFD in yr 2, however there were no hybrid maturity class × plant population × harvest time interactions for all other variables ($P \geq 0.28$). For clarity of presentation, all three-way interactions were ignored and will not be discussed. Whole corn plant DM averaged 35.8% (harvest 1) and 42.4% (harvest 2) for yr 1 (harvest 3 DM data are not available). For yr 2, whole corn plant DM was 37.4, 47.8, and 59.2% for harvest 1, 2, and 3, respectively. Although harvest 2 and 3 were dryer than ideal corn silage moisture reported in the literature (Darby and Lauer, 2002; Hunt et al., 1989; Afuakwa and Crookston, 1984), one of the goals of the experiment was to document changes in the corn plant across maturities for use in the decision of whether to harvest a corn field for corn silage or for corn grain and corn stalks.

For actual plant population (plant stand counts conducted when plants were approximately 7 cm in height), an effect of hybrid maturity class for yr 1 ($P < 0.01$; Table 2) was detected with MEM hybrids (107 to 111 d RM; 62,134 plants/ha) having a lower population compared to MLM hybrids (112 to 117 d RM; 63,454 plants/ha). This agrees with a tendency for a decrease in plant population at harvest for MEM hybrids compared to MLM hybrids in yr 2 (66,975 compared with 67,961 plants/ha; $P = 0.09$; Table 3). These differences in plant population could be a result of differing plant germination or survival rates, or potentially to imprecision of seeding rate estimates.

In both years, there was an interaction between hybrid maturity class and harvest date for grain yield ($P \geq 0.02$). In yr 1, grain yield responded quadratically across harvest dates for MEM hybrids (11.28, 12.26, and 12.00 t/ha for harvest 1, 2, and 3 respectively; $P < 0.01$). Grain yield also responded quadratically across harvest dates

Table 2. Effect of hybrid maturity class and harvest date on whole corn plant characteristics (yr 1)

	Hybrid maturity class × Harvest[1]							*P*-value[2]			
Item	MEM:1	MEM:2	MEM:3	MLM:1	MLM:2	MLM:3	SEM	F-test	Int.	Maturity	Harvest
Plant DM, %[3]	37.56	44.50	–	34.05	40.30	–	–	–	–	–	–
Actual Population[4]	62134	62134	62134	63454	63454	63454	588	0.98	1.00	< 0.01	NS
Grain Yield	11.28^{d}	12.26^{bc}	12.00^{c}	10.86^{d}	12.79^{ab}	13.01^{a}	0.28	< 0.01	< 0.01	0.01	$Q^{MEM,MLM}$
Corn Stover Yield[5,6]	10.01	10.91	9.97	11.06	11.83	11.07	0.20	< 0.01	0.85	< 0.01	Q
Whole Plant Yield[5,6]	21.29	23.17	21.97	21.92	24.62	24.08	0.36	< 0.01	0.10	< 0.01	Q
Grain, %[6]	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, %[7]	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	0.35	Q
Whole Plant TDN, %	72.35	73.23	69.84	71.21	72.60	69.09	0.20	< 0.01	0.40	< 0.01	Q
TDN yield/ha[8]	15.37	16.98	15.39	15.48	17.86	16.59	0.31	< 0.01	0.11	< 0.01	Q

[a–d]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 hybrid maturity class and harvest, Maturity = *P*-value for the hybrid maturity class 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]Average plant DM as a reference for each hybrid maturity class × harvest combination (no data available for harvest 3).

[4]Actual population in plants/ha.

[5]Yield in t/ha.

[6]Harvest Index, DM basis.

[7]Residue in-situ NDF digestibility.

[8]TDN yield/ha (t of TDN/ha) = whole plant TDN × whole plant yield.

Table 3. Effect of hybrid maturity class and harvest date on whole corn plant characteristics (yr 2)

	Hybrid maturity class × Harvest[1]							*P*-value[2]			
Item	MEM:1	MEM:2	MEM:3	MLM:1	MLM:2	MLM:3	SEM	F-test	Int.	Maturity	Harvest
Plant DM, %[3]	39.28	48.54	60.81	35.50	47.15	57.54	–	–	–	–	–
Actual Population[4]	66975	66975	66975	67961	67961	67961	3076	1.00	1.00	0.09	NS
Grain Yield	11.84^{cd}	12.55^{bc}	12.92^{ab}	11.45^{d}	13.34^{ab}	13.75^{a}	0.25	< 0.01	0.02	0.04	Q^{MEM}, L^{MLM}
Corn Stover Yield[5,6]	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[5,6]	21.53	22.44	22.69	22.17	23.41	23.37	0.51	0.07	0.92	0.03	L
Grain, %[6]	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, %[7]	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, %	73.30^{a}	72.73^{ab}	72.84^{ab}	71.26^{c}	72.57^{b}	72.51^{b}	0.26	< 0.01	< 0.01	< 0.01	$Q^{MEM,MLM}$
TDN yield/ha[8]	15.78	16.48	16.53	15.87	17.01	16.95	0.40	0.12	0.72	0.23	L

[a–d]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 hybrid maturity class and harvest, Maturity = *P*-value for the hybrid maturity class 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]Average plant DM as a reference for each hybrid maturity class × Harvest combination (no data available for harvest 3).

[4]Actual population in plants/ha.

[5]Yield in t/ha.

[6]Harvest Index, DM basis.

[7]Residue in-situ NDF digestibility.

[8]TDN yield/ha (t of TDN/ha) = whole plant TDN × whole plant yield.

for MLM hybrids in yr 1 (10.86, 12.79, and 13.01 t/ha for harvest 1, 2, and 3 respectively; $P < 0.01$). In yr 2, there was a quadratic effect on grain yield for MEM hybrids across the 3 harvest dates ($P < 0.01$), however the response was linear for MLM hybrids ($P < 0.01$).

Norwood (2001) compared 75, 92, 98, 106, and 110 d RM and reported greater grain yield from longer hybrid maturity class hybrids compared to shorter hybrid maturity class hybrids under dryland corn production in western Kansas when soil moisture was not limiting.

Farnham (2001) reported greater grain yields in Iowa by planting longer hybrid maturity class (110 to 114 d RM) hybrids compared to shorter hybrid maturity class (94 to 102 d RM) hybrids. Farnham (2001) also acknowledged the commonly held assumption that longer hybrid maturity class 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. Staggenborg 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 silage harvest maturity by frost. These responses are due to higher 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 hybrid maturity class and harvest time for corn stover yield or whole plant yield ($P \geq 0.10$) in yr 1. For the main effect of hybrid maturity class, 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 2 harvest times (10.00 t/ha to 10.99 t/ha) and then decreasing at the third harvest (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 2 harvests, there was an increase of 2.29 t/ha (21.61 t/ha for harvest 1 compared to 23.17 t/ha for harvest 2). From harvest 2 to harvest 3 in yr 1, corn plant yield slightly decreased to 23.03 t/ha. In yr 2, there was a hybrid maturity class × 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 et al. (2007) collected 3 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. (2012) also reported maximal stover yield at the initiation of their experiment (August 21) and a decrease in stover yield as the experiment progressed until the end (November 23). 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 milk line, 2/3 milk line, and black layer. 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 milk line, 2/3 milk line, and black layer (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 et al., 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., 2012). 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 2 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. This might vary among hybrids especially with newer hybrids and "stay green" technology which likely continues to accumulate sugars despite physiological maturity of grain and black layer preventing translocation to the kernels.

For yr 2, there was no hybrid maturity class × harvest time interaction for whole plant yield ($P = 0.92$). For the main effect of hybrid maturity class, 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 4 of 5 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 RM 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 up to 48%. Grain yields (85% DM) for separate harvest times were 6.2, 7.0, and 7.7 t/ha (100% DM), while whole plant yields were 11.3, 11.5, and 12.6 t/ha on a 100% DM basis (Moss et al., 2001). Whole corn plant yield was maximized at 39% DM in Ontario (Daynard and Hunter, 1975). 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). Wiersma et al. (1993) reported that corn silage yield was maximized at 0.5 to 0.75 milk line based on 3 years of data in Wisconsin; however, in 1 of the years, frost damage reduced yield at 0.75 milk line and black layer sampling times which would have affected the across yr average yields for those harvest times.

There was an interaction between hybrid maturity class and harvest time for grain percent or harvest index (calculated as: grain DM yield/plant DM yield × 100) 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% ($P < 0.01$). Across years, grain percentage generally 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 et al. (2003) stated that later-maturing hybrids tend to have lower grain/stover ratios and consequently an increased total fiber concentration.

There was no interaction between hybrid maturity class 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), they concluded that hybrid quality varied similarly across harvest times. In the present experiment with harvest on a similar calendar date, the later hybrid maturity class had a greater ($P < 0.01$) residue NDF concentration, being 65.8% for MLM compared to 64.1% for MEM in yr 1. In yr 2, MLM hybrids (67.15%) also had a 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 when harvested on the same date. 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 silage harvest time increased from harvest 1 to harvest 2, NDF concentration decreased from 65.78 to 62.78%, but as plants increased to full grain maturity (harvest 3), NDF concentration increased to 66.28%. For yr 2, there was an increase between the first 2 harvests (63.34 to 66.21%) but no difference in NDF concentration between the second and third harvests (66.21 compared to 65.54%). 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 beyond silage harvest is a classical response. The decrease in residue NDF concentration in yr 1 between the first 2 harvests is not consistent with other studies (Hunt et al., 1989; Darby and Lauer, 2002).

An interaction between hybrid maturity class and harvest time was observed for in situ 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 the stover portion, Darby and Lauer (2002) reported a linear decrease in stover quality as growing degree days accumulated. In most studies, in vitro NDF digestibility remains constant across silage or decreases slightly as maturity within the silage harvest window.

There were no interactions between hybrid maturity class 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 hybrid maturity classes ($P = 0.35$) in yr 1. As well, there was only a very slight decrease in whole plant TDN concentration for MLM (70.97%) compared to MEM (71.81%; $P < 0.01$). When calculating yield of TDN/ha, there was an increase in TDN yield/ha for MLM (16.64 t/ha) compared to MEM hybrids (15.91 t/ha; $P < 0.01$) due to the increased whole plant yield for MLM compared to MEM hybrids as would be expected for later maturing hybrids harvested on the same date. 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 2 harvests representing the silage harvest window and then a decrease to the third harvest as plants reached grain maturity. Residue TDN concentrations for the 3 harvests were 49.22, 50.71, and 41.55% (harvest 1, 2, and 3, respectively). Whole plant TDN concentration was 71.78, 72.92, and 69.47% 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 15.43 t/ha to 17.42 t/ha within the silage harvest window followed by a decrease to 15.99 t/ha ($P < 0.01$) as plants reached grain maturity.

For yr 2, there was a tendency ($P = 0.08$) for an interaction between hybrid maturity class 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 hybrid maturity class and harvest time for whole plant TDN concentration in yr 2 ($P < 0.01$). In both MEM and MLM hybrid maturity classes, the response to harvest date was quadratic for whole plant TDN ($P < 0.01$). There were no interactions between hybrid maturity class and harvest timing for yield of TDN/ha ($P = 0.72$). 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 (16.61 t/ha) compared to MEM hybrids (16.26 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 (15.83 t/ha, 16.75 t/ha, and 16.74 t/ha for harvest 1, 2, and 3, respectively; $P<0.01$).

Differences in both years for whole plant TDN were quite minimal and would suggest whole plant quality does not change across the 3 harvest times tested in these experiments. However, the source of whole plant TDN is changing, with greater amounts of grain in later harvests but less digestible NDF. Amounts of digestible corn silage components were nearly 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).

Hybrid Maturity Class × Plant Population Interactions. In this study, plant population was varied by increasing the number of plants within rows spaced 76 cm apart. There were differences in plant population treatments applied to the corn field across years. In yr 1, there was a tendency for a hybrid maturity class by plant population interaction for actual population ($P = 0.08$; Table 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 hybrid maturity class and plant population for actual population ($P = 0.02$; Table 5).The increase in actual population was a quadratic response due to plant population treatments for MEM hybrids ($P < 0.01$). For MLM hybrids in yr 2, there was a linear increase for actual population due to plant population treatments ($P < 0.01$).

In the analysis of harvested grain yield, there was not a hybrid maturity class by plant population interaction in yr 1($P = 0.70$). Grain yield increased quadratically across plant population treatments for yr 1 (10.76, 12.63, 13.50, and 13.68 t/ha for the 4 plant population treatments; $P < 0.01$). However, the grain yield response was quadratic across the plant population treatments for MLM (10.24, 11.99, 12.92, and 13.00 t/ha across the 4 plant population treatments; $P < 0.01$). In yr 2, there was an interaction between plant population and hybrid maturity class for grain yield ($P = 0.04$).As plant population increased in both MEM and MLM hybrids in yr 2, grain yield quadratically ($P < 0.01$) increased. Shapiro and Wortmann (2006) stated that corn grain yield typically exhibits a quadratic response to plant population, 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 grain 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 hybrid maturity class by plant population 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 (hybrid maturity class) and plant population exists; however, controlled research experiments (Alessi and Power, 1974; Thomison and Jordan, 1995) have reported little to no relative maturity by plant population interactions. For the main effect of plant population in yr 1, corn stover yield was quadratically increased ($P = 0.05$) across plant population treatments. Corn stover yield was 9.91, 10.70, 11.23, and 11.41 t/ha for the 4 plant population 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

Table 4. Effect of hybrid maturity class and population on whole corn plant characteristics (yr 1)

	Hybrid maturity class × Population[1]									*P*-value[2]			
Item	MEM: 49,421	MEM: 64,247	MEM: 79,073	MEM: 93,900	MLM: 49,421	MLM: 64,247	MLM: 79,073	MLM: 93,900	SEM	F-test	Int.	Maturity	Population
Actual Population[3]	43017	56183	69501	79835	42481	57484	71032	82820	680	< 0.01	0.08	< 0.01	Q
Grain Yield	10.02	11.91	12.78	12.69	10.45	12.06	13.06	13.31	0.25	< 0.01	0.70	0.01	Q
Corn Stover Yield[4,5]	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[4,5]	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	0.35	L
Whole Plant TDN, %	71.38	72.09	72.07	71.69	71.15	71.18	70.82	70.75	0.32	0.01	0.14	< 0.01	Q
TDN yield/ha[7]	13.92	16.02	16.97	16.85	14.70	16.44	17.45	18.02	0.34	< 0.01	0.67	< 0.01	Q

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

[2]F-test = overall F-test, Int = Interaction between hybrid maturity class and harvest, Maturity = *P*-value for the hybrid maturity class 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 × whole plant yield.

Table 5. Effect of hybrid maturity class and population on whole corn plant characteristics (yr 2)

	Hybrid maturity class × Population[1]									*P*-value[2]			
Item	MEM: 49,421	MEM: 69,189	MEM: 88,958	MEM: 108,726	MLM: 49,421	MLM: 69,189	MLM: 88,958	MLM: 108,726	SEM	F-test	Int.	Maturity	Population
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	10.12^{e}	12.38^{c}	13.43^{ab}	13.81^{a}	11.40^{d}	12.88^{bc}	13.56^{ab}	13.54^{ab}	0.31	< 0.01	0.04	0.04	$Q^{MEM, MLM}$
Corn Stover Yield[4,5]	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[4,5]	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, %	72.27	73.00	73.65	72.91	71.88	72.48	72.38	71.78	0.30	< 0.01	0.33	< 0.01	Q
TDN yield/ha[7]	13.77	16.50	17.13	17.60	15.30	16.51	17.24	17.39	0.41	< 0.01	0.12	0.23	Q

[a–d]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 hybrid maturity class and harvest, Maturity = *P*-value for the hybrid maturity class 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 × whole plant yield.

to 10.46 t/ha for the plant population treatments of 49,421 to 108,726 plants/ha. For whole plant yield in yr 1, there was a quadratic increase as plant population increased ($P < 0.01$). Whole plant yield increased at a decreasing rate as plant population was increased, with whole plant yield increasing by 12.6% between the lowest 2 plant densities, 6.5% between the middle 2 plant densities, and by only 1.1% between the 2 greatest plant densities for yr 1. In yr 2, there was also a quadratic response for whole plant yield due to plant population treatments ($P < 0.01$). In yr 2, whole plant yield increased by 12.7% between the lowest 2 plant densities, 3.9% between the middle 2 plant densities, and by 2.6% between the highest 2 plant densities. Whole plant yield has been shown to be maximized between 80,000 and 100,000 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 hybrid maturity class by plant population 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 population in yr 1, there was a quadratic response ($P < 0.01$) for grain percent due to imposed plant population treatments. Actual grain percentage of the whole corn plant were 50.90, 52.93, 53.59, and 53.28% for the plant population 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 population 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 population treatments of 49,421; 69,189; 88,958; and 108,726 plants/ha; respectively. Plant population 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 population increased from 49,000 to 124,000 plants/ha in Alberta. Sanderson et al. (1995) also reported decreases in grain content as plant population increased.

There was not a hybrid maturity class × plant population interaction ($P = 0.34$) for residue NDF concentration in yr 1. For the main effect of plant population, there was a linear ($P < 0.01$) increase in NDF concentration as plant population 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 hybrid maturity class × plant population 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 population increased. In MLM hybrids, there was a quadratic increase in NDF concentration as plant population increased (64.17, 67.39, 68.08, and 68.97%; $P = 0.05$). Previous research has shown an increase in NDF as plant population increases (Cox et al., 1998; Cusicanqui and Lauer, 1999; Stanton et al., 2007). There was no interactions between hybrid maturity class and plant population 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 population 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 population increased, respectively). Increases in plant population (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 hybrid maturity class and plant population for TDN concentration of the residue ($P \geq 0.22$), whole plant TDN concentration ($P \geq 0.14$), or yield of TDN/ha ($P \geq 0.12$). As plant population within a row was increased, there was a linear ($P < 0.01$) decrease in TDN concentration of the residue from 48.52% at the lowest plant population to 46.15% at the highest plant population 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 population increased ($P < 0.01$). However, when assessing the TDN concentration of the whole plant in yr 1, there was a quadratic response ($P = 0.05$) as plant population increased, but numerically across plant densities there is a range of only 0.42 percentage units (71.22 to 71.64%). There was also a quadratic response for whole plant TDN concentration ($P < 0.01$) across plant densities in yr 2. These results would suggest that whole plant quality is minimally affected by planting population. These results are in contrast to findings by other researchers; generally *in vitro* true DM digestibility decreases as plant population 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 1,000 plants/ha increase in plant population. Stanton et al. (2007) reported a more gradual decrease in *in vitro* true DM digestibilities of 72.6 to 71.5% as plant population increased from 49,421 to 123,553 plants/ha.However, there are differences in grain percent between the present experiment (generally increased as plant population increased) and the experiments conducted by Stanton et al. (2007; decrease in cob:stover as plant population increased), Cox et al. (1998; no differences across plant population), and Sanderson et al. (1995; decreased grain content as plant population increased). In yr 1, yield of TDN/ha was quadratically increased as plant population increased (from 14.31 to 17.44 t TDN/ha; $P < 0.01$). As well in yr 2, the response to increases in plant population was a quadratic increase in yield of TDN/ha from 14.54 to 17.50 t of TDN/ha ($P < 0.01$).

Generally, the current experiment results agree with previous research with differing plant populations within a row. 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 relatively consistent as harvest is progressed (at least across the harvest window tested in these experiments). The selection of longer compared to shorter hybrid maturity class or 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. Whether varying plant population by altering row spacing has similar effects on yield and quality as varying plant population within a row remains uncertain.

Cattle Finishing Experiment

As corn silage displaced corn grain in the diet, final BW, ADG, and DMI linearly decreased ($P \leq 0.01$; Table 6). Gain:feed also decreased linearly ($P < 0.01$) with corn silage displacing corn grain 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. Due partially to decreased DM and energy intake, this resulted in feeding values of 91, 83, and 81% that of corn for the added 15, 30, and 40% replacement of corn compared to the diets with only 15% silage. Feeding value of 81% for 55% silage was calculated as the difference in G:F between 15% silage and 55% silage (0.175 to 0.161) divided by 0.175 or the control G:F. The relative change was assumed to be due to just the additional 40% silage replacing grain and suggested the corn silage was only 81% of corn grain. Performance-calculated dietary NEm and NEg concentrations linearly decreased as corn silage replaced corn grain 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, 2001) for cattle fed diets with higher ratios of corn silage:corn grain. Erickson (2001) conducted 3 experiments evaluating 15, 30, and 45% corn silage displacing dry-rolled corn in finishing diets without distillers grains. These researchers reported a linear decrease in ADG and G:F as corn silage replaced dietary grain in 2 of their three experiments (1 with calf-fed steers and 1 with yearling steers). When feeding calf-fed steers, the class of cattle as fed in the current experiment, DMI in their experiment was increased for cattle fed 30 and 45% corn silage compared to 15% silage. However, rate of gain decreased linearly from 1.59 to 1.42 kg/d as corn silage replaced corn grain in the diet (Erickson, 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 in their experiment. For the yearling steer experiment conducted by Erickson (2001), DMI was not different across treatments, but G:F was decreased by 5.6% by displacing 15% of the grain with corn silage (30 versus 15% corn silage) and by 7.4% when silage displaced 30% of the grain (45 versus 15% corn silage). In the third experiment by Erickson (2001), ADG and G:F decreased 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

Table 6. Effect of corn silage and modified distillers grains plus solubles 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 × fat thickness, cm) + (0.2 × 2.5% KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm2)]; (USDA, 2016).

[6]Marbling Score: 400 = Small 00, 500 = Modest 00.

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 displacing rolled corn grain. Comparing the present experiment to the previous research with substitution of corn silage for corn grain in diets without distillers grains, there is general agreement that ADG and G:F decreases as corn silage displaces corn grain 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. This compared with the approximately 15% reduction reported by Goodrich et al. (1974) and Erickson (2001) from increasing corn silage from 15 to 45% of the diet. These differences might be explained partially to differences in corn silage quality across experiments; however, this is unknown due to lack of consistent chemical analyses across experiments. Distillers grains are a source of highly digestible fiber with minimal starch concentration (Klopfenstein et al., 2008). Perhaps finishing diets containing distillers grains with increased concentrations of corn silage may improve fiber digestion of both corn silage and MDGS when compared with feeding these ingredients individually in typical high grain diets due to the reduced 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 with either 10% corn grain plus 40% MDG or 50% corn grain, there was no difference in DMI (P = 0.30). Steers fed 45% corn silage with 10% corn grain and 40% MDGS instead of with 50% grain and 0% MDGS had greater ADG (P = 0.02) and a mean of 16 kg greater 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 also were numerical increases in NEm (1.90 to 1.94 Mcal/kg) and NEg (1.26 to 1.29 Mcal/kg) with the diet containing MDGS (P = 0.13) with these 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% from substitution of MDGS for the DRC and HMC grain blend. This feeding value would be within 6 percentage units of the 116% predicted feeding value for G:F from a meta-analysis for finishing 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 also was 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 either 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 to 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 decreased DMI with DGS inclusion levels above 30 to 40% may be explained partially by S concentration, lipid concentration, or both in DGS.

Hot carcass weight decreased linearly as corn silage increased in the diet ($P < 0.01$). As corn silage replaced corn grain in the diet, dressing percentage linearly decreased ($P < 0.01$). This linear reduction in dressing percentage was expected as it agrees with previous reports feeding diets with more corn silage and less corn grain (Peterson et al., 1973; Danner et al., 1980). Cattle that have less carcass fat generally 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 at 173 DOF, and the yield grade difference would suggest that cattle fed the higher concentrations of corn silage would have had higher carcass weights had they been fed for more days. Nevertheless, there were no differences in marbling score ($P \geq 0.13$) associated with corn silage substitution for corn grain. There also 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. An increased HCW (10 kg; $P = 0.02$) was noted 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 should be expected as corn silage is increased when diets contain 40% MDGS. With this and the reported linear reductions 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 was fed in finishing diets, the substituting corn grain from dry rolled and high moisture corn for MDGS improved cattle ADG and G:F.

LITERATURE CITED

Afuakwa, J. J., and R. K. Crookston. 1984. Using the kernel milk line to visually monitor grain maturity in maize. Crop Sci. 24:687–691. doi:10.2135/cropsci1984.0011183X002400040015x

Allen, M. S., J. G. Coors, and G. W. Roth. 2003. Corn silage. In: D. R. Buxton, R. E. Muck, and J. H. Harrison, editors, Silage Science and Technology. Agronomy Monograph. Vol. 42. ASA, CSSA, SSSA, Madison, WI. p. 251–304.

Alessi, J., and J. F. Power. 1974. Effects of plant population, row spacing, and relative maturity on dryland corn in the northern plains. I. Corn forage and grain yield. Agron. J. 66:316–319. doi:10.2134/agronj1974.00021962006600020037x

AOAC. 1999. Official methods of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bolinger, D., L. Nuzback, and F. N. Owens. 2014. Impact of hybrid and growing location on yield and composition of corn plants harvested for silage. J. Anim. Sci. 92(E-Suppl. 2):535. (Abstr.)

Bremer, V. R., C. D. Buckner, A. W. Brown, T. P. Carr, R. M. Diedrichsen, G. E. Erickson, and T. J. Klopfenstein. 2010. Lipid and NDF analysis of ethanol byproduct feedstuffs. Univ. of Nebraska, Lincoln, NE. MP-93:83–86.

Bremer, V. R., A. K. Watson, A. J. Liska, G. E. Erickson, K. G. Cassman, K. J. Hanford, and T. J. Klopfenstein. 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. Prof. Anim. Sci. 27:449–455.

Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. J. Anim. Sci. 68:1201. doi:10.2527/1990.6851201x

Cox, W. J., D. R. Cherney, and J. J. Hanchar. 1998. Row spacing, hybrid, and plant density effects on corn silage yield and quality. J. Prod. Agric. 11:128–134. doi:10.2134/jpa1998.0128

Cusicanqui, J. A., and J. G. Lauer. 1999. Plant density and hybrid influence on corn forage yield and quality. Agron. J. 91:911–915. doi:10.2134/agronj1999.916911x

Danner, M. L., D. G. Fox, and J. R. Black. 1980. Effect of feeding system on performance and carcass characteristics of yearling steers, steer calves and heifer calves. J. Anim. Sci. 50:394–404. doi:10.2527/jas1980.503394x

Darby, H. M., and J. G. Lauer. 2002. Harvest date and hybrid influence on corn forage yield, quality and preservation. Agron. J. 94:559–566. doi:10.2134/agronj2002.5590

Daynard, T. B., and R. B. Hunter. 1975. Relationships among whole-plant moisture, grain moisture, dry matter yield, and quality of whole-plant corn silage. Can. J. Plant Sci. 55:77–84. doi:10.4141/cjps75-010

DiCostanzo, A., C. M. Zehnder, H. Chester-Jones, D. Ziegler, and R. Greenwald. 1997. Effect of dietary com silage proportion on yearling steer performance and economic returns. Univ. of MN, St. Paul, MN. B-442:14–20.

DiCostanzo, A., C.M. Zehnder, J.M. Cassady, H. Chester-Jones, D. Ziegler, and R. Greenwald. 1998. Effects of com silage hybrid or dietary proportion on yearlingsteer performance. Univ. of MN, St. Paul, MN. B-451:1–5.

Erickson, G. E. 2001. Designing beef feedlot nutrition programs to solve environmental challenges related to nitrogen and phosphorus. Ph.D. Diss. Univ. of Nebraska, Lincoln.

Fairey, N. A. 1982. Influence of population density and hybrid maturity on productivity and quality of forage maize (Zea mays). Can. J. Plant Sci. 62:427–434. doi:10.4141/cjps82-061

Farnham, D. E. 2001. Row spacing, plant density, and hybrid effects on corn grain yield and moisture. Agron. J. 93:1049–1053. doi:10.2134/agronj2001.9351049x

Galyean, M. 2009. The Home Page of Michael Galyean. NEm and NEg Calculations. http://www.depts.ttu.edu/afs/home/mgalyean/. (Accessed 14 October 2014.)

Goodrich, R. D., D. W. Crawford, M. L. Thonney, and J. C. Meiske. 1974. Influence of corn silage level on the performance and economic returns of steer calves. Univ. of MN, St. Paul, MN. B-195:14–19.

Hoover, W. H. 1986. Chemical Factors Involved in Ruminal Fiber Digestion. J. Dairy Sci. 69:2755–2766. doi:10.3168/jds.S0022-0302(86)80724-X

Huang, H., D. B. Faulkner, V. Singh, M. C. Danao, and S. R. Eckhoff. 2012. Effect of harvest date on yield, composition, and nutritive value of corn stover and DDGS. Trans. ASABE 55(5):1859–1864. doi:10.13031/2013.42338

Hunt, C. W., W. Kezar, and R. Vinande. 1989. Yield, chemical composition, and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. J. Prod. Agric. 2:357–361. doi:10.2134/jpa1989.0357

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223–1231.

Lewis, A. L., W. J. Cox, and J. H. Cherney. 2004. Hybrid, maturity, and cutting height interactions on corn forage yield and quality. Agron. J. 96:267–274.

McGee, A. L. 2013. Effect of residue removal on subsequent year quality and quantity of corn residue and cattle performance while grazing corn residue at different stocking rates. M.S. Thesis. Univ. of Nebraska.

Minson, D. J. 1990. Digestible energy of forage In: Forage in ruminant nutrition. Academic Press, Inc., San Diego, CA. doi:10.1016/B978-0-12-498310-6.50010-9

Moss, B. R., D. W. Reeves, J. C. Lin, H. A. Torbert, W. H. Mcelhenney, P. Mask, and W. Kezar. 2001. Yield and quality of three corn hybrids as affected by broiler litter fertilization and crop maturity. Anim. Feed Sci. Technol. 94:43–56. doi:10.1016/S0377-8401(01)00303-0

Norwood, C. A. 2001. Planting date, hybrid maturity, and plant population effects on soil water depletion, water use, and yield of dryland corn. Agron. J. 93:1034–1042. doi:10.2134/agronj2001.9351034x

NRC. 1996. Nutrient Requirements of Beef Cattle, 7th ed. Natl. Acad. Press, Washington, DC.

Owens, F. 2008. Corn silage – facts, fantasies, and the future. http://vffarms.com/Images/Resources/ProductionChoices/Pioneer_silage_data.pdf. (Accessed 12 May 2014.)

Peterson, L. A., E. E. Hatfield, and U. S. Garrigus. 1973. Influence of concentration of dietary energy on protein needs of growing-finishing cattle. J. Anim. Sci. 36:772–781. doi:10.2527/jas1973.364772x

Pordesimo, L. O., W. C. Edens, and S. Sokhansanj. 2004. Distribution of above-ground biomass in corn stover. Biomass Bioenergy 26:337–343. doi:10.1016/S0961-9534(03)00124-7

Preston, R. L. 1975. Net energy evaluation of cattle finishing rations containing varyingproportions of com grain and com silage. J. Anim. Sci. 41:622–624. doi:10.2527/jas1975.412622x

Raymond, F. D., M. M. Alley, D. J. Parrish, and W. E. Thomason. 2009. Plant density and hybrid impacts on corn grain and forage yield and nutrient uptake. J. Plant Nutr. 32:395–409. doi:10.1080/01904160802660727

Sanderson, M. A., R. M. Jones, J. C. Read, and H. Lippke. 1995. Digestibility and lignocellulose composition of forage corn morphological components. J. Prod. Agric. 8:169–174. doi:10.2134/jpa1995.0169

Schwab, E. C., R. D. Shaver, J. G. Lauer, and J. G. Coors. 2003. Estimating silage energy value and milk yield to rank corn hybrids. Anim. Feed Sci. Technol. 109:1–18. doi:10.1016/S0377-8401(03)00210-4

Shapiro, C. A., and C. S. Wortmann. 2006. Corn response to nitrogen rate, row spacing, and plant density. Agron. J. 98:529–535. doi:10.2134/agronj2005.0137

Shinners, K. J., B. N. Binversie, R. E. Muck, and P. J. Weimer. 2007. Comparison of wet and dry corn stover harvest and storage. Biomass Bioenergy 31:211–221. doi:10.1016/j.biombioe.2006.04.007

Stanton, D., A. W. Grombacher, R. Pinnisch, H. Mason, and D. Spaner. 2007. Hybrid and population density affect yield and quality of silage maize in central Alberta. Can. J. Plant Sci. 87:867–871. doi:10.4141/CJPS06024

Staggenborg, S. A., D. L. Fjell, D. L. Devlin, W. B. Gordon, L. D. Maddus, and B. H. Marsh. 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. J. Prod. Agric. 12:85–90. doi:10.2134/jpa1999.0085

Stock, R., T. Klopfenstein, D. Brink, S. Lowry, D. Rock, and S. Abrams. 1983. Impact of weighting procedures ad variation in protein degradation rate on measured performance of growing lambs and cattle. J. Anim. Sci. 57:1276–1285. doi:10.2527/jas1983.5751276x

Thomison, P. R., and D. M. Jordan. 1995. Plant density effects on corn hybrids differing in ear growth habit and prolificacy. J. Prod. Agric. 8:394–400. doi:10.2134/jpa1995.0394

Undersander, D., and J. Lauer. 2005. Selecting corn silage hybrid maturities. http://corn.agronomy.wisc.edu/WCM/W166.aspx. (Accessed 22 July 2014.)

USDA. 2016. United States Standards for Grades of Carcass Beef. https://www.ams.usda.gov/sites/default/files/media/Carcass%20Beef%20Standard.pdf. (Accessed 6 December 2016.)

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Watson, A. K., T. J. Klopfenstein, L. W. Lomas, G. E. Erickson, and B. L. Nuttelman. 2013. Limit feeding to decrease variation and increase accuracy of cattle weight. J. Anim. Sci. 91:5507–5517. doi:10.2527/jas.2013-6349

Wiersma, D. W., P. R. Carter, K. A. Albrecht, and J. G. Coors. 1993. Kernel milk-line stage and corn forage yield, quality, and dry matter content. J. Prod. Agric. 6:94–99. doi:10.2134/jpa1993.0094