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Utilization of Bt corn residues by grazing beef steers and Bt corn silage and grain by growing beef cattle and lactating dairy cows[1]

J. D. Folmer*, R. J. Grant*[2], C. T. Milton*[3], and J. Beck†

*Department of Animal Science, University of Nebraska, Lincoln 68583-0908 and
†Syngenta Seeds, Inc., Golden Valley, MN 55427[1]

ABSTRACT: Three experiments were conducted to evaluate the impact of the *Bacillus thuringiensis* (Bt)-11 transformation event in two parental corn hybrids differing in date of maturity on beef and dairy cattle performance. Sixteen lactating Holstein dairy cows in replicated 4 × 4 Latin squares were assigned to four diets in a 2 × 2 factorial arrangement: Bt vs non-Bt trait and early- vs late-maturing corn hybrids. The diets contained 40% of the test corn silage plus 28% corn grain from the same corn hybrid (DM basis). There was no effect of the Bt trait on efficiency of milk production, ruminal pH, acetate:propionate ratio, or in situ digestion kinetics of NDF. The early-maturing corn hybrids resulted in greater total VFA concentrations in the rumen and efficiency of 4% fat-corrected milk production than the later-maturing hybrids ($P < 0.05$). Sixty-seven steer calves were used in a 70-d corn residue grazing trial for the late-maturing corn hybrids only. Daily BW gain of steers was similar for those grazing Bt and non-Bt corn residues, and the steers exhibited no grazing preference between Bt and non-Bt corn residue. One hundred twenty-eight steer calves were assigned to four silage-based growing diets in a 2 × 2 factorial arrangement: Bt vs non-Bt trait and early- vs late-maturing corn hybrids. The diets contained 90% corn silage and 10% supplement (DM basis). The DMI was higher for steers fed Bt compared with non-Bt hybrids ($P < 0.02$). An interaction ($P < 0.03$) was observed for feed efficiency between hybrid genotype and incorporation of the Bt trait. Feed efficiency was greater ($P < 0.05$) for steers fed the later-maturing non-Bt hybrid compared with the later-maturing Bt hybrid; however, feed efficiency was similar between steers fed early-maturing Bt and non-Bt corn silages. Steers fed the early-maturing hybrid gained 11% faster and were 7% more efficient compared with those fed the late-maturing hybrid. These latter results agree with the dairy experiment in which the early-maturing hybrid resulted in 5% greater efficiency of milk production than the later-maturing corn hybrid. In all experiments, incorporation of the Bt trait into corn had no consistent effect on cattle performance. In addition, background genetics of the corn hybrids appeared to have a more consistent impact on performance than did presence of the Bt trait.

Key Words: Beef Cattle, Dairy Cattle, Maize, Maize Byproducts, Maize Silage, *Bacillus thuringiensis*

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Introduction

Bacillus thuringiensis (**Bt**) is a naturally occurring soil bacterium that produces a protein that is toxic to some caterpillar (lepidopteran) insects, including European corn borer (Hyde et al., 1999). In this experiment, corn hybrids were used that contain a gene encoding for a Bt protein called ("Cry 1Ab" protein), which is one of several Bt-event hybrids that are commercially available. Transgenic corn plants used in this experiment that produce the Cry1Ab Bt protein provide protection against corn borer infestation throughout the life of the plant.

Bt corn hybrids are used for enhanced yields under conditions of borer pressure, which commonly occurs in the midwestern United States, and are becoming a widely accepted in the major corn-producing states. In many cases, the corn residue is used for growing or wintering beef cows and weaned calves. Corn silage is an important component of dairy feeding programs throughout the United States. Additionally, many beef calves are grown on silage-based diets in the fall and winter prior to finishing on high-grain diets in late winter and early spring. However, information on the feeding value of corn silage and corn residue from Bt hybrids compared with traditional hybrids is limited. Our hy-

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[2]Correspondence: C220j Animal Science Complex (phone: 402-472-6442; fax: 402-472-6362; E-mail: rgrant1@unl.edu).

Present address: Midwest PMS, 10249 W. Loup River Rd., Dannebrog, NE 68831.

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Table 1. Yield of grain, silage, and residual corn for experimental corn hybrids

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
Grain yield, kg/ha[b]	8,323	7,658	9,509	8,957
Grain yield, kg/ha[c]			11,549	11,424
Silage yield, kg/ha	31,608	27,125	36,315	39,453
Residual corn, kg/ha[d]			62.7	94.2

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Grain yield from nonirrigated field used for silage and grain production for beef growing and dairy lactation experiments.
[c]Grain yield from irrigated fields used for grain production and residue for cornstalk grazing experiment.
[d]Residual corn is amount of corn grain remaining in the field following grain harvest.

pothesis was that there would be similar performance between animals fed Bt and non-Bt corn.

Therefore, the objectives of this research were to 1) evaluate the effect of corn silage from two Bt corn hybrids (early- and late-maturing genotypes) and their respective near-isogenic counterparts on performance of growing beef steers, 2) evaluate the effect of corn residue from Bt and near-isogenic non-Bt corn hybrids on performance and grazing preference of growing beef steers, and 3) evaluate the effect of corn silage from the same two Bt corn hybrids and near-isogenic non-Bt hybrids on ruminal fermentation and short-term lactational performance of dairy cows.

Materials and Methods

Corn Cultivation, Harvest, and Chemical Composition

Four commercial corn hybrids (N4242Bt, N4242 non-Bt, N7333Bt, and N7333 non-Bt; Syngenta Seeds, Golden Valley, MN) were planted at the University of Nebraska Agricultural Research and Development Center located at Mead, NE in 1998. The Bt hybrids were derived from transformation event Bt11, and the non-Bt hybrids represented the corresponding near-isolines developed by conventional breeding methods. The N4242 hybrids were earlier-maturing (harvested for silage at 103 d), whereas the N7333 hybrids were later-maturing (harvested for silage at 112 d). All four hybrids were grown for harvest of silage in adjacent fields under comparable agronomic conditions without irrigation. At another site at the Research Center, under pivot irrigation, hybrids N7333 Bt and non-Bt were grown in adjacent fields for harvest of grain and used to conduct the corn residue grazing study. The seed drop rate per hectare for each hybrid at planting was as follows: N4242 Bt, 55,524; N4242 non-Bt, 56,950; N7333 Bt, 54,741; and N7333 non-Bt, 54,496. The yields of corn grain, corn silage, and residual corn in the crop residue for each hybrid are summarized in Table 1.

Agronomic characteristics, including plant height, number of ears, stalk and root lodging, and stalk diameter, were measured for all hybrids at 112 d after planting (three replicates of 10 plants each per field). These results are summarized in Table 2. Agronomic data were collected for all four hybrids grown without irrigation, in addition to the later-maturing Bt and non-Bt hybrids grown under irrigation for use in the stalk grazing experiment.

Each cornfield was evaluated for European corn borer infestation over a 5-d period on d 112, 113, and 116. For each field, 30 corn stalks (three replicates of 10 each) were evaluated for corn borer infestation. Samples were taken at least 10 rows from the field edge. The stalks were cut at the base and promptly dissected in the field. Leaf sheaths were removed and examined for feeding and for presence of larvae. The stalks were cut longitudinally to measure tunneling and to expose larvae. The ear and shank were examined also for larvae and measurement of tunnel length. Damage to individual plants was evaluated using the Guthrie visual rating scale (Guthrie et al., 1978). The corn borer pressure data are summarized in Table 3. These results apply to both irrigated (corn residue grazing experiment) and nonirrigated (corn silage feeding trials) fields.

The corn for silage was harvested at 3/4 milk line stage of maturity using a field chopper with knives adjusted to a 1-cm theoretical length of cut. For each hybrid, the chopped corn was ensiled in a separate Ag-Bag plastic silage bag (AgBag Int., Warrenton, OH) prior to the start of the beef and dairy experiments. Silage bags were opened and the feeding trials began a minimum of 100 d after ensiling. Grain was harvested at 85.3% DM for the earlier-maturing Bt and non-Bt hybrids (129 d after planting) and at 84.9% DM for the later-maturing hybrids (172 d after planting).

Corn Silage Chemical Composition. A weekly composite sample of each of the corn silage hybrids was created during the course of the animal experiments and was subsequently dried (60°C), ground (1-mm screen, Wiley mill, Arthur H. Thomas, Philadelphia, PA), and analyzed for CP (AOAC, 1990), ADF, NDF (Van Soest et al., 1991), acid detergent lignin (Goering and Van Soest, 1970), and permanganate lignin (Goering and Van Soest, 1970). Starch content of the silages was determined enzymatically (SDK Laboratories, Hutchinson, KS). Nitrogen fractions were measured according to the procedures of Licitra et al. (1996) to estimate the A, B_1, B_2, B_3, and C fractions for use in the Cornell Net Carbohydrate and Protein Model (1994).

The 30-h in vitro NDF digestibility was measured using ruminal fluid obtained from a grass-fed steer. Buffer solution was prepared as described by Goering and Van Soest (1970). From each composite sample created during the animal experiments, 300 mg of representative sample was taken and placed into 50-mL polypropylene tubes. There were two tubes per time point, and the entire in vitro experiment was replicated three times. The pH of ruminal fluid was 6.5 ± 0.3 for all replicates, and the temperature of the ruminal fluid

Table 2. Agronomic characteristics of silage fields measured 112 d after planting

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
Nonirrigated field				
Harvest population, plants/ha	54,363	51,892	54,363	51,892
Plant height, cm	244	236	274	277
Ears per 100 plants	92	92	96	96
Root lodged, %	0	0	0	0
Stalk lodged, %	0	3	0	0
Stalk diameter, cm	2.30	2.22	2.22	2.22
Irrigated field				
Harvest population, plants/ha			69,189	69,189
Plant height, cm			282	282
Ears per 100 plants			99	98
Root lodged, %			0	0
Stalk lodged, %			1	0
Stalk diameter, cm			2.38	2.54

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.

and buffer mixture was adjusted to 39°C. While each tube was being purged with CO_2, a 20% solution of ruminal fluid with buffer was dispensed in 30-mL aliquots using a Unispense II automatic dispensing machine (Wheaton Instruments, Millville, NJ). Tubes were sealed immediately with gas-release rubber stoppers. Samples were fermented for 30 h with gentle swirling occurring at 6-h intervals. Ash-free NDF was measured according to Van Soest et al. (1991). The IVDMD was measured using a modification of the original Tilley and Terry (1963) procedure. Briefly, a 48-h in vitro ruminal fermentation was carried out as described above. Then, the residue was incubated with pepsin and HCl for 24 h at 30°C. The inoculum was composed of a 1:1 mixture of ruminal fluid plus buffer.

Dairy Lactation Experiment

Twelve intact (four primiparous, eight multiparous) and four ruminally fistulated, multiparous Holstein dairy cows were assigned to one of four treatments in a replicated 4 × 4 Latin square design with 3-wk periods. Cows averaged 162 ± 10 d in milk when they were assigned to treatments. Cows were not injected with bovine somatotropin during this experiment. Dietary treatments were arranged as a 2 × 2 factorial of corn hybrid (early- vs later-maturing) and Bt trait. The diets contained (DM basis) 10% alfalfa silage, 40% of the test corn silage, 28% rolled corn grain, and 22% of a concentrate mixture composed of soybean meal, blood meal, tallow, minerals, and vitamins. The diets were designed so that the corn grain and corn silage were from the same hybrid for each diet to maximize any possible effect of the Bt trait on animal response. The ingredient composition of the experimental diets is shown in Table 4. All diets were formulated to contain approximately 17.5% CP and to meet the metabolizable protein requirement as predicted by the Cornell Net Carbohydrate and Protein Model (1994). The four diets were fed as total mixed rations twice daily in amounts to ensure a minimum of 10% refusals.

Table 3. Summary of Guthrie scale ratings and other indicators of larval infestation (irrigated and nonirrigated fields)

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
Number of observations	30	30	60	60
% Infestation[b]	0	33	0	56
Larvae/plant	0	1.8	0	0.6
Average tunnel lengths, cm				
Stalk	0	5.1	0.025	1.5
Ear shank	0	0.57	0	0.12
Ear	0	0.33	0.025	0.25
Guthrie rating[c]	1.0	2.3	1.0	1.4

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Infested with live larvae (% of stalks).
[c]As calculated by Guthrie et al. (1978). Guthrie Scale = 1 no or minimal leaf damage to 9 severe leaf damage.

Experimental periods were 21 d, with the last 7 d used for sample and data collection. Cows were housed in a tie-stall barn equipped with individual feeding boxes. Cows were removed from the barn for milking, exercise, and estrus detection twice daily for a total of approximately 4 h.

Daily milk yields were recorded electronically. Composite a.m. and p.m. milk samples were collected for 2 d at the end of each period and analyzed for fat, protein, and lactose (Milko-Scan Fossomatic; Foss Food Technology Corp., Eden Prairie, MN). Calculation of milk composition was weighted according to a.m. and p.m. milk yields. Body weight was measured weekly immediately following the a.m. milking.

For fistulated cows only, samples of ruminal fluid were collected during the last week of each period by collecting fluid immediately beneath the ruminal mat at 0, 6, 12, 18, and 24 h after feeding. Ruminal pH was

Table 4. Ingredient and chemical composition of experimental diets used in dairy experiment (% of DM)

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
Ingredient				
Alfalfa silage[b]	10.0	10.0	10.0	10.0
Corn silage	40.0	40.0	40.0	40.0
Rolled corn grain	28.0	28.0	28.0	28.0
Soybean meal (46.5% CP)	17.9	17.9	18.3	18.3
Blood meal	0.67	0.67	0.69	0.69
Tallow	0.57	0.57	0.57	0.57
Mineral and vitamin mix[c]	2.86	2.86	2.44	2.44
Composition				
DM, %	52.3	52.3	52.8	52.8
CP	17.5	17.5	17.3	17.3
RUP[d]	6.31	6.32	6.27	6.29
ADF	16.6	15.3	17.4	16.0
NDF	26.3	25.5	27.0	27.8
NE_L, Mcal/kg[d]	1.68	1.68	1.68	1.68

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Chemical composition of first-cutting alfalfa silage harvested at bud stage was (DM basis): DM, 45.1%; CP, 21.9%; ADF, 35.0%; and NDF, 44.8%.
[c]Supplement contained (DM basis) 15.2% Ca, 7.2% P, 4.1% Mg, 4% Na, 3,000 mg/kg of Zn, 1,750 mg/kg of Mn, 400 mg/kg of Cu, 200,000 IU/kg of vitamin A, 36,000 IU/kg of vitamin D_3, and 600 IU/kg of vitamin E.
[d]Calculated using nutrient composition and digestibility data from Tables 6 and 7 plus data in NRC (1989).

measured using a portable pH meter, and samples were prepared to determine VFA concentration using GLC (Erwin et al., 1961). The VFA samples were analyzed using a chromatograph (model 5890; Hewlett Packard, Wilmington, DE) with a 2-mm i.d. column that was 2.4 m in length and packed with SP 1200 (Supelco, Bellefonte, PA). The rate of N_2 flow was 20 mL/min, injection temperature was 170°C, column temperature was 120°C, and the flame ionization detector temperature was 200°C.

Fractional rate of NDF digestion of each corn silage hybrid was determined using the in situ bag technique. Dacron bags (Ankom, Fairport, NY) containing 5 g of substrate were incubated in duplicate within the rumen of each fistulated cow for 0, 6, 12, 18, 24, 36, 48,72, and 96 h. Bags were 10 × 20 cm with a mean pore size of 53 μm. Prior to ruminal incubation, dried corn silage samples were ground through a 2-mm screen using a Wiley mill. After removal from the rumen and rinsing (Wilkerson et al., 1995), all bags were dried at 60°C and weighed. Contents were analyzed for ash-free NDF (Van Soest et al., 1991), and values within time were pooled. The kinetics of ruminal NDF digestion were calculated as described by Grant (1994).

Performance data for cows were analyzed as a replicated 4 × 4 Latin square design with model effects for square, cow within square, period, treatment, square × treatment, and residual error using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Orthogonal comparisons were performed for early- vs later-maturing hybrids, Bt vs non-Bt trait, and the interaction of background genotype and Bt trait. Unless otherwise stated, significance was declared at $P < 0.05$.

Corn Residue Grazing Experiment

Sixty-seven large-framed steer calves (284 ± 3.7 kg) were used in a two-part, 70-d grazing trial. The total area available for grazing contained 11.3 ha of crop residue from the later-maturing non-Bt and 12.1 ha of residue from the later-maturing Bt corn hybrids. The two fields of corn residue were divided into six pastures (three Bt and three non-Bt) and then stocked with 51 steers. To achieve equal stocking rates (0.28 animal units/ha), the three non-Bt pastures were each assigned eight steers and the three Bt pastures were each assigned nine steers. These six pastures accounted for 8.5 and 9.3 ha of the non-Bt and Bt corn residue, respectively. The remaining 2.8 hectares of Bt and non-Bt residue were used for a grazing preference experiment. Steer BW was measured for two consecutive days, at the start and finish of the trial, and after a 3-d period of limit-feeding (2% of BW) to minimize fill effects. Steers received a protein supplement at approximately 0.68 $kg·steer^{-1}·d^{-1}$ to ensure that protein intake did not limit performance while grazing the corn residue.

Prior to grazing, residual corn (kg/ha) was estimated by counting full and partial ears from one row (76 cm width) for 30.5 m at six locations in each of the six pastures. Corn kernels were then removed from the cob and weighed to determine the amount of corn remaining in the field for each hybrid. Residue samples were collected three times during the grazing period to reflect the entire grazing period. Samples were collected on d 5, 36, and 72, by gathering all residue (corn, leafs, husks, and stalk) from one row (76 cm width) for 3.5 m at two locations in each of the pastures and analyzed for IVDMD. Although grazing cattle do not typically consume actual corn stalks, corn stalk samples were used to determine stalk-breaking strength in an attempt to discover any physical differences that would deter grazing. The corn stalk samples were collected at the same time as the residue samples by cutting the stalk between the root crown and the first node, in two locations in each of the pastures. Corn stalks were then dried in a 60°C oven 24 h prior to measuring breaking strength. An INSTRON 5500R Universal Testing Machine (Instron, Canton, MA) equipped with a 2,500-kg load cell and a crosshead speed of 50 mm/min was used to measure the total energy required to break the stalk (Bourne, 1978). A blunt wedge was used to break the corn stalk after it was placed on a bone breaking bridge with a width of 9 cm and a depth of 4 cm.

The steer BW and gain data were analyzed as a randomized complete block design. Pasture was the experimental unit, resulting in three replications for Bt and non-Bt treatments. Least squares means (SAS Inst. Inc., Cary, NC) were used to compare ADG of steers grazing Bt and non-Bt corn residue. Residual error was used to calculate the *F*-test for determining the significance of treatment effects.

The second component of the stalk grazing experiment evaluated grazing preference for Bt and non-Bt corn residue. Sixteen steers grazed one pasture containing equal areas (2.8 ha) of Bt and non-Bt corn residue for 70 d. These steers also received 0.68 kg of protein supplement daily on a per-steer basis. Animals were observed once daily to collect grazing preference data, and numbers of animals grazing Bt and non-Bt stalks were recorded. All measurements were collected prior to supplementation between 0600 and 1000 daily. There were a total of 50 observations made during the 70-d grazing period. On the remaining 20 d, all steers were observed in the supplementation areas or near water tanks rather than grazing. Additionally, snow cover prevented grazing for a portion of these 20 d. The entire 20 d were removed from the analysis, and only the days that the steers were observed grazing were included. The percentage of steers grazing Bt and non-Bt hybrids was analyzed using the PROC GLM procedure of SAS (SAS Inst. Inc.). Residual error was used to calculate an *F*-test for least square mean separation.

Table 5. Experimental diets for beef steer growing experiment using corn silage (% of DM)

Item	Early maturing		Late maturing	
	Bt[a]	Non-Bt	Bt	Non-Bt
Ingredients				
Corn silage	90.0	90.0	90.0	90.0
Supplement	10.0	10.0	10.0	10.0
Supplement ingredients				
Soybean meal (46.5% CP)	65.0	65.0	75.0	75.0
Dry-rolled sorghum	11.6	11.6	0	0
Urea	8.50	8.50	10.0	10.0
Limestone	8.23	8.23	8.47	8.47
Salt	3.0	3.0	3.0	3.0
Tallow	2.2	2.2	2.2	2.2
Dicalcium phosphate	1.02	1.02	0.86	0.86
Vitamin and mineral mix[b]	0.47	0.47	0.47	0.47
Chemical composition				
DM, %	37.3	37.3	37.3	37.3
CP	12.4	12.4	12.3	12.3
NDF	35.0	33.1	37.0	38.2
ADF	22.2	19.9	23.7	21.4
Ca	0.60	0.60	0.61	0.61
P	0.25	0.25	0.25	0.25

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Mix was formulated to meet or exceed nutrient requirements of NRC (1996).

Corn Silage Beef Growing Experiment

One hundred twenty-eight medium-framed steer calves (282 ± 16 kg) were used in a completely randomized design with a 2 × 2 factorial arrangement of treatments. Steers were stratified by initial BW and assigned randomly to pens to ensure that the initial starting weight and coefficient of variation for each pen were similar. A total of 16 pens were used with eight steers per pen, yielding four replications per treatment. Steers were implanted on d 1 with Ralgro Magnum (Mallinckrodt Veterinary, Mundelein, IL; 72 mg of Zeranol) and fed diets for 101 d. During this time steers were allowed ad libitum access to treatment diets and water. Initial and final BW were measured on two consecutive days following a 3-d period of limited feed intake (approximately 2% of BW) to minimize fill effects. Additionally, interim BW were measured at 35-d intervals to monitor animal performance. Steers used in this experiment had been vaccinated against bacterial and viral diseases and treated for internal and external parasites approximately 2 mo prior to initiation of the experiment.

The diets (Table 5) contained 90% corn silage and 10% supplement (DM basis). A blend of soybean meal and urea (75:25% N basis) was used as the protein supplement. Because the silage hybrids varied slightly in CP concentration, supplements were formulated to be equal across treatments to meet NRC requirements for MP (Table 5). Finely ground grain sorghum was included at 11.6% (DM basis) of the supplement for the diets containing earlier-maturing corn to equalize dietary MP requirements. This amount of inclusion in the supplement resulted in 1.2% of the diet as grain sorghum. All diets contained 20 g/t Rumensin (monensin sodium).

Data were analyzed as a completely randomized design with a 2 × 2 factorial arrangement of treatments. Pen was the experimental unit. Orthogonal contrasts were used to compare early- vs later-maturing hybrids, Bt vs non-Bt trait, and the interaction of corn hybrid genotype and Bt trait. Residual error was used for testing orthogonal contrasts and treatment effects. When interactions were present, the PDIFF procedure of SAS (SAS Inst. Inc.) was used to separate differences among the four treatments. Unless otherwise stated, significance was declared at $P < 0.05$.

All animals in this series of experiments were managed using protocols approved by the Institutional Animal Care and Use Committee at the University of Nebraska.

Results and Discussion

Corn Borer Pressure

The Bt11 event results in endotoxin production in all plant tissues providing 98% control of first and second, generation corn borers (Rice and Pilcher, 1998). Results of the larval infestation evaluations (Table 3) indicated that the plants without Bt protection did incur some degree of corn borer infestation relative to the Bt hybrids (0 vs 33 and 56% infestation). The amount of infestation was unexpectedly high given the generally low population levels for European corn borer observed throughout much of Nebraska in 1998. Results from strip trials conducted at six sites in Nebraska during

Table 6. Nitrogen and protein fractions of experimental silages used in beef and dairy experiments

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
DM%	40.2	39.0	37.6	37.8
	% of DM			
CP	6.82	6.68	6.44	6.51
Nonprotein nitrogen	3.42	3.17	3.13	3.49
True protein	3.41	3.51	3.31	3.02
True soluble protein	0.33	0.34	0.48	0.17
Insoluble protein	3.08	3.18	2.83	2.85
NDIP[b]	1.34	1.39	1.07	1.10
ADIP[c]	1.11	0.90	0.84	0.91
Protein fraction[d]				
A	3.42	3.17	3.13	3.49
B_1	0.33	0.34	0.48	0.17
B_2	1.74	1.89	1.76	1.76
B_3	0.23	0.39	0.23	0.19
C	1.11	0.90	0.84	0.91

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Neutral detergent insoluble protein.
[c]Acid detergent insoluble protein.
[d]Protein fractions measured according to the procedures of Licitra et al. (1996).

Table 7. Carbohydrate and lignin composition of experimental silages and grain used in beef and dairy experiments

	Early maturing		Late maturing	
Item	Bt[a]	Non-Bt	Bt	Non-Bt
Corn silage				
DM, %	40.2	39.0	37.6	37.8
	% DM			
Ash	4.1	4.5	6.1	4.7
ADF	25.0	21.9	26.9	23.9
NDF	38.9	36.7	41.1	42.4
ANDF[b]	38.0	36.2	38.6	41.2
ADL[c]	3.25	2.69	3.62	3.36
PL[d]	4.90	4.14	5.26	5.04
Starch	37.6	38.6	37.3	37.1
30-h NDF digestion, %[e]	32.4	30.8	34.4	31.6
IVDMD, %[f]	74.3	65.6	69.1	65.6
Corn grain				
DM, %	85.8	85.9	85.2	85.4
CP	7.1	7.0	6.0	6.1
Starch	76.7	74.5	76.5	76.6

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]NDF corrected for ash content according to Van Soest et al. (1991).
[c]Acid detergent lignin measured according to Goering and Van Soest (1971).
[d]Permanganate lignin measured according to Goering and Van Soest (1971).
[e]Measured in vitro.
[f]In vitro dry matter digestibility measured using modified procedures of Tilley and Terry (1963) as described in text.

1998 indicated an infestation rate of only 11% (B. Siegfried, University of Nebraska Entomology Department, personal communication).

Determination of Cry 1Ab Protein Concentrations

The Cry 1Ab protein content was measured using an enzyme-linked immunosorbent assay (Syngenta Seeds, Research Triangle Park, NC) for the freshly chopped, pre-ensiled corn plant, the silages, and stalk residue (only hybrid 7333, which was used in the grazing study). The Cry1Ab protein was detected in the fresh, pre-ensiled Bt plant material at concentrations of 4,923.5 and 8,508.8 ng Cry1Ab/g dry weight for N4242Bt and N7333Bt, respectively. For hybrid 4242Bt, Cry 1Ab content declined to trace, unquantifiable amounts by 9 d after ensiling, whereas for hybrid 7333Bt, Cry1Ab content declined to trace amounts by 4 d after ensiling. Stalk samples for hybrid 7333 used in the grazing study had a Cry1Ab content of 935.9 ng/g dry weight after harvest, compared with 590.2 ng/g 3 mo later during the grazing study. There was no detectable Cry1Ab protein in 7333 non-Bt stalks.

Chemical Composition and Digestibility of Corn Hybrids

The chemical composition and digestibility of the experimental silages obtained from the weekly composite samples are detailed in Tables 6 and 7. The later-maturing corn hybrids contained less CP than the earlier-maturing hybrids, although the protein fractions were similar among hybrids. Additionally, the earlier-maturing hybrids contained less NDF and ADF than the later hybrids, which likely reflected a greater starch and CP content. Lignin, measured as either permanganate lignin or as acid detergent lignin, was slightly greater for the Bt vs non-Bt hybrids and was substantially lower for the earlier- vs later-maturing hybrids. Starch content and IVDMD were greater for the earlier- vs later-maturing hybrids. There was very little difference among the hybrids in 30-h in vitro NDF digestibility, although the Bt hybrids were consistently higher than non-Bt hybrids. The relative lack of chemical composition differences between the Bt and non-Bt hybrids from transformation event Bt11 agrees with the data of Faust and Spangler (2000), who evaluated the nutritive value of several MON810 Bt and near-isogenic corn hybrids and observed no differences among the hybrids. These observations indicate that Bt corn silage should have a feeding value similar to that of non-Bt corn silage.

Dairy Lactation Experiment

Feed Intake, Milk Production, and Milk Composition. There was no effect of either maturation date or Bt vs non-Bt trait on DMI in kilograms per day or as a percentage of BW (Table 8). Daily DMI averaged 22.8 kg/d or 3.77% of BW. Average BW (618 kg) and change in BW per 21-d period (20.8 kg) did not differ among treatments. Due to the short duration of experimental periods (21 d), body condition score was not measured.

Table 8. Effect of Bt[a] vs non-Bt corn hybrid on short-term performance of lactating dairy cows

	Early maturing		Late maturing		
Item	Bt	Non-Bt	Bt	Non-Bt	SEM
DMI					
kg/d	22.8	22.4	23.2	22.7	0.1
% of BW	3.75	3.72	3.84	3.75	0.02
BW					
kg	619	615	615	621	3.0
Change per 21-d period	21.4	22.7	21.1	18.0	1.9
Milk, kg/d	29.2	28.6	28.7	28.5	0.3
Milk fat					
%	3.80	3.82	3.70	3.73	0.06
kg/d	1.11	1.09	1.06	1.06	0.02
Milk protein					
%	3.54	3.55	3.51	3.52	0.02
kg/d	1.03	1.01	1.01	1.00	0.01
Milk lactose					
%	4.90	4.85	4.87	4.80	0.40
kg/d	1.43	1.38	1.40	1.37	0.04
4% Fat-corrected milk (FCM), kg/d	28.3	27.7	27.4	27.3	0.5
FCM/DMI, kg/kg[b]	1.26	1.24	1.19	1.20	0.03

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Significant effect of early versus late-maturing corn hybrid ($P < 0.05$).

As with DMI, there was no influence of corn hybrid or Bt trait on milk production. There was a range of only 0.6 kg/d in milk production per cow across all four treatments. Average milk production was 28.8 kg/d.

Milk protein percentage, and most importantly, milk protein production were unaffected by treatment (Table 8). Milk protein percentage averaged 3.53%, and milk protein production averaged 1.01 kg/d. Likewise, milk lactose percentage (4.86%) and lactose production (1.40 kg/d) were similar among diets. There was no effect ($P > 0.05$) of earlier- vs later-maturing corn hybrid on milk fat percentage. In summary, there was no effect of Bt vs non-Bt trait on any measure of milk composition.

Efficiency of 4% fat-corrected milk production (FCM/DMI, kg/kg) was greater for the earlier- vs later-maturing hybrids ($P < 0.05$). This response likely reflected the higher digestibility and lower fiber content of the earlier-maturing hybrid. There is a considerable body of literature that shows the relationship between variation in composition and digestibility of corn silage and variation in milk production and efficiency as summarized by Johnson et al. (1999). Again, there was no effect, or any interactions, of Bt vs non-Bt trait on production of FCM or efficiency of FCM production.

Ruminal pH, VFA, and NDF Digestion Kinetics. The effect of corn silage hybrid on ruminal pH and VFA

Table 9. Effect of corn silage hybrid on ruminal pH and VFA concentrations in lactating dairy cows[a]

	Early maturing		Late maturing		
Item	Bt[b]	Non-Bt	Bt	Non-Bt	SEM
Ruminal pH[c]	5.87	5.67	5.81	5.82	0.06
Total VFA, m*M*[d]	97.2	93.8	83.2	85.0	1.7
Acetate (A)	55.1	57.2	53.3	51.3	<0.1
Propionate (B)	21.3	20.3	16.9	19.6	<0.1
n-Butyrate	9.9	11.5	9.6	10.0	<0.1
Isobutyrate	1.05	1.19	0.96	1.02	<0.1
n-Valerate	1.33	1.61	1.06	1.35	<0.1
Isovalerate	1.69	1.97	1.38	1.66	<0.1
A:P	2.8	2.9	3.1	3.1	0.1

[a]Results obtained from fistulated cows.
[b]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[c]Mean of samples collected every 4 h for 24 h.
[d]Significant effect of early- vs later-maturing corn hybrid ($P < 0.05$).

Table 10. In situ NDF digestion kinetics of corn silage hybrids measured in lactating dairy cows

	Early maturing		Late maturing		
Item	Bt[a]	Non-Bt	Bt	Non-Bt	SEM
Lag, h[b]	5.96	8.89	6.19	6.26	0.74
K_d, h[c]	0.034	0.035	0.038	0.033	0.005
Extent, %[d]	57.6	57.4	64.6	57.2	0.44

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]Discrete lag time prior to NDF digestion.
[c]Fractional rate of NDF digestion.
[d]Potential extent of NDF digestion at 96 h of fermentation.

concentrations is summarized in Table 9. There were no significant interactions (P > 0.05) between time of ruminal fluid sampling and diet on ruminal pH or VFA; therefore, means over 24 h are presented. Ruminal pH was unaffected by treatment and averaged 5.79. Total VFA concentration was greater for the earlier-maturing Bt and non-Bt hybrids compared with the later-maturing Bt and non-Bt hybrids. There was no effect of the Bt trait itself on total VFA concentration or acetate:propionate ratio.

There was no effect of the Bt trait or hybrid background genotype on in situ digestion kinetics of NDF (Table 10). The fractional rate of NDF digestion averaged 0.035 h^{-1}, and the potential extent of NDF digestion averaged 59.2%. These data support the in vitro 30-h NDF digestion data, which indicate little difference in NDF digestion between Bt and non-Bt hybrids.

Corn Residue Grazing Experiment

Performance of steers grazing corn residue is presented in Table 11. There was no effect (P = 0.12) of the Bt trait on daily gain of steers. Similarly, Russell et al. (2000) observed no deleterious effects on gestating beef cows when grazing Bt corn residue. Previous Nebraska research has demonstrated a positive correlation (r = 0.79) between residual corn and daily BW gain (Jordon et al., 1997). Gains observed in our study were lower than those often observed with calves grazing corn residues, typically 0.40 to 0.54 kg/d (Clanton, 1989; Jordan et al., 1997). As a result of low European corn borer pressure and good harvest conditions, the amount of residual corn was lower than normally observed at this location, typically 2 to 4% of corn yield. The amount of residual corn was 62.7 and 94.2 kg/ha for the Bt and non-Bt hybrids, respectively. These amounts correspond to 0.5 and 0.8% of corn yield for the Bt and non-Bt hybrids, respectively (Table 1).

Table 11. Performance and grazing preference of growing steers grazing Bt and non-Bt corn residue (later-maturing hybrid only)

Item	Bt[a]	Non-Bt	SEM	P-value
Performance				
Initial BW, kg	284	284	0.35	0.89
Final BW, kg	301	306	2.0	0.20
ADG, kg/d	0.24	0.32	0.03	0.12
IVDMD, %[b]	33.0	36.0	0.7	0.04
Energy required to break stalk, mJ[c]	2,687	2,349	152	0.13
Grazing preference distribution[d]	47.5	52.5	5.2	0.5

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b]In vitro dry matter digestibility measured using modified procedures of Tilley and Terry (1963) as described in text.
[c]Total energy required to break corn stalks measured by an INSTRON Universal Testing Machine.
[d]Percentage of steers observed grazing Bt or non-Bt corn residue.

The IVDMD of the Bt corn residue was 3 percentage units lower (P = 0.04) than the residue from non-Bt hybrids (Table 11). This small change in IVDMD, although statistically significant, appeared to have little impact on animal performance. As mentioned previously, performance of steers grazing corn residue is highly correlated to the amount of residual corn remaining in the field. Moreover, there were no significant effects of corn residue type (Bt vs non-Bt) on steer performance in this experiment. The IVDMD of the residue in this study is quite low in comparison to previous research (Fernandez-Rivera and Klopfenstein, 1989) due to our sampling technique of gathering total residue including unselected, poor-quality portions of the residue. The amount of energy required to break the corn stalk was similar (P = 0.13) for Bt and non-Bt corn stalks. Although animals grazing stalks rarely consume the stalks (Fernandez-Rivera and Klopfenstein, 1989), we wanted to preclude differences in stalk strength as a potential reason for preference of Bt or non-Bt residue.

The distribution of steers grazing Bt and non-Bt corn residue was similar (F-test; P = 0.51). On average, 47.5% of the steers were observed grazing Bt corn residue, and 52.5% of the steers were observed grazing non-Bt residue. Similarly, Hendrix et al. (2000) found no effect of the Bt trait on corn residue grazing preference for beef steers.

Corn Silage Beef Growing Experiment

Results for the silage growing study are summarized in Table 12. Feeding Bt corn hybrids resulted in higher (P = 0.02) DMI than feeding near-isogenic non-Bt hybrids. An interaction (P < 0.05) was observed for ADG and feed efficiency between background genotype of the hybrid (early vs later maturity) and the presence of the Bt trait. Daily gain was higher (P < 0.05) for steers fed the earlier-maturing Bt compared with the earlier-maturing non-Bt hybrids. However, ADG was similar between steers fed later-maturing Bt and non-Bt hybrids. In contrast, feed efficiency was better (P < 0.05) for steers fed later-maturing non-Bt compared with later-maturing Bt hybrids. Feed efficiency was similar between steers fed earlier-maturing Bt and non-Bt hybrids. Although an interaction was observed for ADG and feed efficiency, overall, steers fed the earlier-matur-

Table 12. Performance (101 d) of growing beef steers fed experimental corn hybrids as silage

	Early maturing		Late maturing			*P*-values		
Item	Bt[a]	Non-Bt	Bt	Non-Bt	SEM	Bt	Hybrid	Bt × hybrid
Initial BW, kg	281	282	281	282	<1	0.08	0.88	0.93
Final BW, kg	428[b]	419[bc]	407[d]	413[bc]	3	0.56	0.002	0.04
DMI, kg/d	8.71	8.42	8.51	8.22	0.11	0.02	0.09	0.96
ADG, kg	1.46[b]	1.36[c]	1.25[d]	1.30[bc]	0.03	0.39	<0.001	0.03
Gain/feed, kg/kg	0.167[b]	0.161[bc]	0.147[d]	0.158[b]	0.003	0.43	0.001	0.007

[a]Bt = *Bacillus thuringiensis* (Bt)-11 transformation event.
[b,c,d]Means within the same row not bearing a common superscript differ ($P < 0.05$).

ing hybrids gained 11% faster ($P < 0.01$) and were 7% more efficient ($P < 0.01$) than those fed corn silage produced from the later-maturing hybrids. The interaction of corn hybrid and incorporation of the Bt gene is difficult to explain, but was likely related to differences in silage chemical composition (NDF, ADF, lignin, starch; Table 7).

Overall Corn Hybrid Effects

For both the beef and dairy experiments, the earlier-maturing hybrids resulted in greater efficiency of production than the later-maturing hybrids. An explanation for this response may be found by comparing several of the compositional differences between the two hybrids. Although we could not measure a difference in NDF digestibility between the two hybrids, when comparing them, we observed that the earlier-maturing hybrid had 10.6% lower NDF content, 17.5% less acid detergent lignin, 2.5% higher starch content, 9.8% higher nonfiber carbohydrates, and 4.2% higher IVDMD. Our conclusion is that the increased animal performance in the silage growing experiment reflects the cumulative benefits of all of these compositional changes. Data generated at Kansas State University (Bolsen, 1992), which summarized several years of silage comparisons, concluded that these cumulative changes in chemical composition, even though some are relatively small, such as starch, could explain observed differences in animal performance.

Overall Bt Trait Effects

Incorporation of the Bt trait into two different background genotypes had no influence on performance or grazing distribution of steers grazing corn residue or lactating dairy cows consuming corn silage and corn grain. The interaction observed between hybrid genetics and incorporation of the Bt trait for growing steers consuming corn silage-based diets is difficult to explain, and is most likely related to slight changes in the chemical composition of the silages. Most importantly, the background genetics of the hybrids selected for incorporation of the Bt gene had a much larger influence on daily gain and feed efficiency of growing steers fed corn silage-based diets than did incorporation of the Bt gene into these hybrids.

Implications

Data from these experiments suggest that the Bt trait had no effect on the preference for or performance of steers grazing Bt or non-Bt corn residue. Incorporation of the Bt gene into these two background genotypes resulted in different effects on the feeding value of the silage for growing steers, but no difference for lactating dairy cows. The Bt corn had no measurable impact on short-term lactational performance of dairy cows and did not negatively affect ruminal fiber degradation. Across these beef and dairy experiments, incorporation of the Bt trait into corn had no consistent effect on animal performance. However, parental hybrid genotype affected efficiency of animal production similarly in both the beef and dairy experiments. Producers can take advantage of increased yields and reduced pesticide use with Bt corn hybrids without adversely affecting corn residue grazing or use of silage and grain for growth and lactation.

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