Planting Date and Hybrid Influence on Corn Forage Yield and Quality

Heather M. Darby* and Joseph G. Lauer

ABSTRACT

Producers believe that corn (*Zea mays* L.) forage can be planted at later dates than corn grain because forage harvest does not have to wait until the grain matures fully. The objectives of this study were to determine relationships between planting date and corn forage yield and quality and to determine optimum planting dates of corn forage for the state of Wisconsin. Full- and shorter-season hybrids were planted on six dates at six locations in Wisconsin during 1998 and 1999. Few significant hybrid × planting date interactions or hybrid differences were observed. The optimum planting dates for dry matter yield and quality for southern, central, and northern Wisconsin were 10 May, 27 April, and 8 May, respectively. Corn forage yields remained at 95% of maximum yields when corn was planted in late May for all zones. In all zones, early June plantings exhibited an accelerated rate of yield decline of 0.2 Mg ha^{-1} d^{-1} delay in planting. Corn forage quality decreased progressively as planting dates progressed into June. The optimum planting date for milk yield ha^{-1} was 2 May in southern and central zones and late April in the northern zone. As planting was delayed past mid-May, rates of quality decline were more severe in central and northern zones compared with the southern zone. Therefore, planting of corn forage should occur between late April and mid-May for all production zones in Wisconsin, but planting could occur into late May in the southern production zone because milk yield ha^{-1} declined by only 8%.

Management practices used to produce corn forage are the same as those used for grain production in most areas. It has not been well established that the same management practices used for corn grain will produce optimum corn forage. Few management studies have been conducted on planting dates for corn forage.

Several studies have reported the influence of planting date and hybrid on corn grain yield. A recent Wisconsin study observed optimum planting dates between 1 to 7 May in southern locations and 8 to 14 May in northern locations (Lauer et al., 1999). A summary of planting date recommendations compiled by Benson (1990) reported optimum planting dates for the Corn Belt to be between 20 April and 10 May. Along with recommended optimums, several researchers have described a quadratic corn yield response to planting date (Lauer et al., 1999; Nafziger, 1994; Johnson and Mulvaney, 1980).

The relationship between corn forage yield and planting date has not been established. It has been hypothesized that planting corn for forage could theoretically be later than corn for grain because forage does not have to be harvested at maturity (Allen et al., 1995). In England, corn planted earlier or later than the end of April resulted in grain yield decline, but because the maximum dry matter yield of corn stover was obtained from a mid-May planting date, later planting of forage corn was recommended (Bunting, 1978). In Canada, White (1977) and Fairey (1983) documented maturity and yield advantages for corn planted in mid-May followed by a significant decline in dry matter content of corn forage if planting was delayed past early June. Fairey (1983) reported a 1% reduction in dry matter digestibility for every day planting was delayed beyond mid-May. Graybill et al. (1991) reported differences in fiber content between corn planted at varying dates and suggested that corn forage be planted between late April and early May in New York.

Corn hybrids respond differently to planting dates (Lauer et al., 1999; Graybill et al., 1991; Fairey, 1980). Hicks et al. (1970) reported an interaction between a hybrid's growing season length and optimum planting date, with a full-season hybrid benefiting most from an early planting date and also suffering the most from a delayed planting date. Bunting (1978) reported no planting date × hybrid interactions, and Nafziger (1994) reported varying results dependent on the particular year.

Few recent studies have been conducted to evaluate effects of planting date and hybrid on forage corn yield and quality. Optimum planting dates for forage corn will be affected by both yield and quality. The objectives of this study were to (i) describe relationships between planting date and hybrid on corn forage yield and quality and (ii) determine optimum planting dates for forage corn in Wisconsin.

MATERIALS AND METHODS

Experiments were conducted during 1998 and 1999 at the University of Wisconsin Research Stations located at Arlington and Lancaster (southern zone), Marshfield and Hancock (central zone), and Spooner and Ashland (northern zone). The experimental design at all locations was a randomized complete block in a split plot arrangement with four replications. Main plots were six planting dates spaced at about 14-d intervals from 20 April to 26 June. Split plots were two hybrids with similar quality traits that ranged from full-season to shorter-season maturity and were adapted to each production zone.

Other than planting date treatments, all plots were managed by practices similar to those used by producers in the surrounding area of that location (Table 1). Plot size was 3.1 by 7.6 m with four rows per plots. Plots were seeded at a rate of 83 500 kernels ha^{-1} and then hand-thinned to 78 600 plants ha^{-1} at the stage when five leaf collars were visible (V5) (Ritchie et al., 1996) to achieve as near a uniform stand as possible.

The kernel milkline was used as a visible indicator of when

H.M. Darby, Dep. of Hortic., Oregon State Univ., 4017 ALS, Corvallis, OR 97331; and J.G. Lauer, Dep. of Agron., Univ. of Wisconsin, 1575 Linden Drive, Moore Hall, Madison, WI 53706. Contribution of the University of Wisconsin Experiment Station and supported by Hatch. Received 6 Mar. 2001. *Corresponding author (darbyh@bcc.orst.edu).

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Abbreviations: ADF, acid detergent fiber; CP crude protein; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy.

Table 1. General plot management characteristics and descriptors of six Wisconsin locations where the forage corn hybrid by planting date study was conducted during 1998–1999.

	Southern Wisconsin		Central Wisconsin		Northern Wisconsin	
Descriptor	Lancaster	Arlington	Hancock	Marshfield	Spooner	Ashland
Latitude	42°50′ N	43°18′ N	44°7′ N	44°39′ N	45°49′ N	46°34′ N
Soil series	Rozetta silt loam Fayette silt loam	Plano silt loam	Plainfield sand	Withee silt loam	Antigo silt loam Huagen silt loam	Superior sandy loam
Soil family	Fine-silty, mixed mesic	Fine-silty, mixed mesic	Mixed, mesic	Fine loamy, mixed	Fine-silty over sandy mixed	Course-loamy over clayey, mixed, frigid
Previous crop†						
1998	Corn	Alfalfa	Pea	Alfalfa	Alfalfa	Corn
1999	Corn	Soybean	Pea	Corn	Alfalfa	Corn
Soil fertility						
pH	7.0	6.2	6.2	6.8	6.9	6.8
P, g kg^{-1}	25–85	50	105–130	55–73	35–55	170
K, g kg^{-1}	115–238	190	83–123	153–198	118–123	103
Fertilizer						
N, kg ha^{-1}	180	179	180	67.2	180	180
Hybrid‡						
Full season	GH2497	GH2497	DLH1203	DLH1203	GHH2279	GH2279
Shorter season	RK617	RK617	NKN3030	NKN3030	P3936	P3936
Fall frost date§						
1998	9 Oct.	10 Oct.	13 Oct.	22 Oct.	5 Oct.	5 Oct.
1999	2 Oct.	4 Oct.	2 Oct.	3 Oct.	4 Oct.	3 Oct.

† Corn, *Zea mays* L.; alfalfa, *Medicago sativa* L.; pea, *Psium sativum* L.; soybean, *Glycine Max* L.
‡ GH, Golden Harvest; DL, Dairyland; RK, Renk; NK, NK Brand; P, Pioneer.
§ Fall frost date = ≤0°C.

to harvest (Wiersma et al., 1993). Kernel milkline was determined by random sampling of five ears per subplot. Ears were broken in the middle, and kernel milkline was visually assessed by observing the endosperm side of exposed kernels. The percentage from the tip of the kernel to the kernel milkline was recorded. Harvesting would have ideally begun at one-half to three-fourths kernel milkline or following the occurrence of a killing frost.

At harvest, two samples of five consecutive plants each were collected from an area of 0.76 by 2.58 m from the middle two rows. In one sample, whole plant (stalk, leaf, and ear) was weighed, chopped with a Troy-Built Tomahawk Pro-Chipper (Troy-Built, Troy, NY), mixed, and an approximate 1-kg subsample collected for moisture determination (weighing fresh, drying at 60°C for 7 d, and reweighing) and quality analysis. The second five-plant sample was weighed, and ears (kernels and cob) were removed and the stover portion weighed. Stover was chopped, mixed, and an approximate 1-kg subsample collected for moisture and quality analysis. The remaining plants were harvested by hand, weighed, and discarded. Final stand, whole plant and stover moisture, and dry matter yield were determined.

Samples of whole plant and stover collected at harvest were ground with a 20.3-cm hammer mill (Christy Hunt Corp., Scunthorpe, UK) through a 1.0-mm screen. Ground samples were scanned on a NIRSystems 6500 near-infrared reflectance spectrophotometer (NIRSystems, Silver Spring, MD) to determine neutral detergent fiber (NDF), acid detergent fiber (ADF), in vitro true digestibility (IVTD), and crude protein (CP) concentrations (Marten et al., 1985).

Separate calibration sets were derived from the 1998 and 1999 data. The near-infrared reflectance spectroscopy (NIRS) calibration was based on analysis of representative samples that included stover and whole-plant samples. Sample selection was performed using the computer program SELECT (Shenk and Westerhaus, 1994).

Samples from each calibration set were analyzed for NDF, ADF, IVTD, and CP. A 0.50-g sample was used for sequential detergent analysis to determine NDF and ADF using the ANKOM^{200} fiber analyzer (Ankom Technol. Corp., Fairport, NY). The NDF and ADF procedures used for the ANKOM (Komarek et al., 1996) were modified to include a 120-min reflux and 4-min rinse with 48 mL of a 5% (v/v) alpha amylase solution (Termamyl 120 L, Novo Nordisk Biochem North America, Franklinton, NC) followed by four additional 4-min rinses. Duplicate 0.50-g samples were used to determine IVTD by a modification of the method of Goering and Van Soest (1970). The 48-h fermentation was performed in a Daisy II Incubator (ANKOM Technology Corp., Fairport, NY). Twenty-five samples were placed into each of four Daisy II reaction jars, 1200 mL of buffer solution was added, and the jars were placed in a 39°C incubator. Rumen contents were strained through two and then eight layers of cheesecloth. The strained fluid was kept under CO_2. Particle matter was washed with buffer solution as described by Craig et al. (1984). This was strained through eight layers of cheesecloth and added to the strained rumen fluid, and then 800 mL of this mixture was added to each jar. Jars were purged with CO_2, capped, and placed in the 39°C incubator for 48 h. Jars were constantly rotated for the entire 48-h period. Following the incubation period, undigested residue was refluxed in neutral detergent solution with alpha amylase, as described above. Neutral detergent dissolves bacterial debris and only undigested plant residue remains.

Concentrations of N were determined by rapid combustion (850°C), conversion of all N-combustible products to N_2, and subsequent measurement by a thermoconductivity cell (LECO Model FP-428, LECO Corp., St. Joseph, MI). Crude protein percentage was calculated by multiplying percent N by 6.25.

From the data obtained in the laboratory, prediction equations were developed that related near-infrared wavelengths to each of the quality responses following the guidelines of Shenk and Westerhaus (1994). The criteria used to select prediction equations were high coefficients of determination (R^2) and low standard errors of calibration and cross validation. Modified partial least square (PLS) analyses were used to determine what wavelengths to include in calibrations (Martens and Naes, 1989). Statistics relating to NIRS prediction are provided in Table 2.

Neutral detergent fiber and IVTD were used to calculate cell wall digestibility (CWD) (Van Soest, 1994) by the following equation:

$$\mathrm{CWD} = \frac{\mathrm{NDF} - (1000 - \mathrm{IVTD})}{\mathrm{NDF}} \times 1000 \qquad [1]$$

The animal performance indices of milk Mg^{-1} (kg milk Mg^{-1}

Table 2. Statistics relating to near-infrared reflectance spectroscopy (NIRS) prediction, which were derived using partial least squares and used to select prediction equations.

Trait†	n‡	Mean	SEC§	R^2	SEV(C)¶
			1998		
CP, g kg^{-1}	96	6.9	0.36	0.95	0.45
ADF, g kg^{-1}	97	63.1	1.83	0.98	2.78
NDF, g kg^{-1}	95	35.8	2.85	0.92	3.82
IVTD, g kg^{-1}	96	72.9	0.77	0.98	1.35
			1999		
CP, g kg^{-1}	107	7.1	0.32	0.94	0.43
ADF, g kg^{-1}	110	60.8	1.52	0.98	1.73
NDF, g kg^{-1}	109	31.6	0.72	0.99	0.88
IVTD, g kg^{-1}	108	65.1	2.04	0.95	2.49

† CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; IVTD, in vitro true digestibility.
‡ n, final number of data points used to develop NIRS calibration.
§ SEC, standard error of calibration.
¶ SEV(C), standard error of cross validation.

corn forage) and milk ha^{-1} (kg milk ha^{-1} corn forage) were used to evaluate the economic value of the forage produced from the treatments (Undersander et al., 1993). Milk Mg^{-1} was predicted using IVTD, CP, and NDF values from equations for feed intake and animal requirements for a standard dairy cow (*Bos taurus*) with 613 kg of body weight producing 36 kg milk d^{-1} at 3.8% fat. Milk ha^{-1} is the product of Milk Mg^{-1} and dry matter yield of corn forage.

Because different hybrids were used in each production zone, data were analyzed across environments within a production zone. All data were analyzed using a mixed-model analysis where environment was considered a random effect within each production zone. Mixed-model analysis for each zone was calculated using the PROC MIXED procedure of SAS (SAS Inst., 1999). Linear or quadratic equations were developed when orthogonal contrasts were significant. The LSD procedure was used to separate hybrid means when the F-test was significant ($P \leq 0.05$). Regression analysis was used to examine the relationship between planting date and whole-plant and stover dry matter yield, quality traits, and performance indices. Regression coefficients were described when significant ($P \leq 0.05$).

For each production zone, the optimum yields were obtained by calculating the first derivatives of the response equation to zero, solving for x (optimum planting date), substituting x into the response equation, and solving for y. The date at which yields were at 95% of optimum y was calculated by substituting 95% of the optimum yield into the model and solving for x. Yield changes were calculated by measuring rate of change over 2-wk periods.

Data were combined across environments into three production zones. Few interactions were observed among the hybrids tested and, if observed, were minimal in relation to the main effects; therefore, data were averaged across hybrids.

RESULTS AND DISCUSSION

During 1998, a cool June was observed for all locations. Above-normal fall temperatures, however, extended the 1998 growing season, with the first frost not occurring until mid- to late October (Table 1). During 1999, temperatures were warmer during July but were cooler in August and September than in 1998. Frost occurred in early October in 1999. Accumulated growing degree units were about the same for both years. The northern and central zones had below-average precipitation during 1998, causing drought stress of corn at the Ashland and Marshfield locations. The Spooner and Hancock sites also had below-average precipitation, but effects were partially alleviated with irrigation. Above-average temperatures for both 1998 and 1999 brought drier-than-normal fall conditions and earlier-than-normal harvests in the fall. Dry down of plants was highly unpredictable, especially in areas where drought stress had occurred. This huge environmental effect resulted in little relationship between kernel milkline and harvest moisture compared with other years. The dates of planting, dates of harvest, and percent of moisture and growth stage at the time of harvest for each individual environment are reported in Table 3.

Relationships between planting day of the year and forage and stover yield and quality are reported in Tables 4 and 5 and Fig. 1 through 3. Planting date has been reported to significantly affect yield and quality of silage (Graybill et al., 1991; Fairey, 1980; White, 1978). A significant planting date effect on whole-plant dry matter yield was seen for all zones, and this relationship was best described with a quadratic model (Table 4 and Fig. 1a). Among the hybrids studied, the optimum forage yield was 10 May for the southern zone, 27 April for the central zone, and 7 May for the northern zone (Table 4). In all zones, 95% of optimum yield was still realized until late May, and after late May, yield decline became more rapid, decreasing up to 0.20 Mg ha^{-1} d^{-1}. In all zones, if corn were planted earlier than the optimum, yield loss would occur.

A progression of optimum planting dates was not observed across different latitudes in Wisconsin. Optimum planting dates for forage corn were slightly later for the southern zone and similar for the northern zone of Wisconsin compared with those reported for grain in a study by Lauer et al. (1999). These researchers reported optimum grain-planting dates for southern Wisconsin between 1 and 7 May and between 8 and 14 May for northern Wisconsin. However, 95% of the optimum forage yield can be realized much later into the growing season than grain yield reported by Lauer et al. (1999). Graybill et al. (1991) also observed a progression of planting dates from late April to late May across hybrid maturity for forage corn grown in New York. The optimum planting dates observed in this study were heavily weighed by the hybrids utilized as only a limited set of hybrids were used. Possibly using later maturing hybrids in all zones would have given more consistent results with other studies.

Planting date differences in whole-plant quality have been documented (Graybill et al., 1991; Fairey, 1983). Linear responses best described the relationship between quality responses and planting date in southern and northern zones (Table 4). Only NDF exhibited a linear relationship in the central zone. The concentration of NDF exhibited a positive linear relationship with planting date across all zones (Table 4 and Fig. 1d). There was a notable difference in fiber increase between zones. Concentration of NDF increased at a rate of 0.7, 1.1, and 1.4 g kg^{-1} d^{-1} delay in planting in the southern, central, and northern zones, respectively.

Crude protein had a positive linear response in the southern and northern zones and a quadratic response in the central zone (Table 4 and Fig. 1b). Crude protein

Table 3. Planting date, harvest date, average growth stage, and average plant moisture of corn hybrids used in this study at six Wisconsin locations (1998–1999). Data are averaged across full- and shorter-season hybrids.

1998				1999			
Planting date	Harvest date	Growth stage at harvest†	Harvest moisture	Planting date	Harvest date	Growth stage at harvest	Harvest moisture
			$g\ kg^{-1}$				$g\ kg^{-1}$
Arlington							
23 Apr.	8 Sep.	5.7	600	20 Apr.	10 Sep.	5.5	621
1 May	8 Sep.	5.6	600	1 May	10 Sep.	5.5	612
14 May	17 Sep.	5.8	570	15 May	17 Sep.	5.5	602
1 June	2 Oct.	5.6	590	28 May	8 Oct.	5.8	570
14 June	2 Oct.	5.3	640	12 June	8 Oct.	5.1	689
25 June	2 Oct.	5.1	700	25 June	8 Oct.	5.0	723
Lancaster							
24 Apr.	10 Sep.	5.8	530	20 Apr.	5 Sep.	5.5	610
1 May	10 Sep.	5.6	600	30 Apr.	5 Sep.	5.6	590
14 May	17 Sep.	5.4	620	14 May	13 Sep.	5.7	530
28 May	8 Oct.	5.4	620	28 May	13 Oct.	5.8	510
16 June	8 Oct.	5.5	600	14 June	13 Oct.	5.1	670
25 June	8 Oct.	5.2	690	25 June	13 Oct.	5.0	700
Hancock							
24 Apr.	3 Sep.	5.7	580	26 Apr.	10 Sep.	5.9	520
1 May	3 Sep.	5.6	610	3 May	10 Sep.	5.8	550
15 May	3 Sep.	5.7	580	14 May	10 Sep.	5.8	540
29 May	20 Sep.	5.9	530	1 June	22 Sep.	5.7	580
15 June	29 Sep.	5.4	580	14 June	24 Sep.	5.0	670
26 June	29 Sep.	5.0	680	28 June	24 Sep.	2.2	780
Marshfield							
20 Apr.	15 Sep.	5.4	580	27 Apr.	22 Sep.	5.6	550
1 May	15 Sep.	5.8	540	3 May	22 Sep.	5.5	610
14 May	15 Sep.	5.5	590	15 May	27 Sep.	5.5	610
2 June	1 Oct.	5.7	560	1 June	27 Sep.	5.0	680
17 June	1 Oct.	5.3	650	11 June	27 Sep.	4.2	710
1 July	1 Oct.	4.3	740	25 June	27 Sep.	3.0	780
Ashland							
23 Apr.	7 Sep.	5.7	500	20 Apr.	19 Sep.	5.7	570
4 May	7 Sep.	5.7	540	30 Apr.	19 Sep.	5.6	590
18 May	7 Sep.	5.7	510	14 May	25 Sep.	5.5	580
1 June	20 Sep.	5.5	590	28 May	25 Sep.	5.5	570
14 June	20 Sep.	5.0	680	9 June	25 Sep.	5.0	670
25 June	20 Sep.	3.3	740	25 June	25 Sep.	3.0	780
Spooner							
28 Apr.	7 Sep.	5.7	600	20 Apr.	11 Sep.	5.7	590
4 May	7 Sep.	5.6	610	30 Apr.	11 Sep.	5.6	610
15 May	7 Sep.	5.9	490	14 May	11 Sep.	5.3	650
29 May	19 Sep.	5.8	570	28 May	26 Sep.	5.4	620
12 June	19 Sep.	5.2	650	9 June	26 Sep.	5.0	710
24 June	19 Sep.	3.0	740	25 June	26 Sep.	3.0	760

† Reproductive, R1 = silking, R2 = blister, R3 = milk, R4 = dough, R5 = dent, R5.5 = 50% milkline, and R6 = physiological maturity (Ritchie et al., 1996; Wiersma et al., 1993).

was always highest when corn was planted in late June. This agrees with Wiersma et al. (1993), who reported higher CP concentrations when corn was harvested before the one-half milkline (Table 3).

A negative linear relationship between IVTD and planting date was seen only for the southern zone (Table 4 and Fig. 1e). In vitro true digestibility declined only 2% from the first to the last planting date. Fairey (1983) observed a decline in dry matter digestibility as planting dates progressed through the growing season. Cell wall digestibility was highest at later planting dates and decreased at accelerating rates as planting dates became earlier in the southern and northern zones (Table 4 and Fig. 1f). Farmers looking to increase digestibility values of their feed rations may consider planting some of their corn at later dates. There has been interest by growers to double-crop corn following the first cutting of hay to maximize feed production on fields. The ability to obtain high stover digestibilities at later planting dates may allow a grower to double-crop some fields.

Milk Mg^{-1} and Milk ha^{-1} responses to planting date are reported in Table 4 and Fig. 2. Milk Mg^{-1} decreased linearly from late April until late June at a rate of 2.4 and 2.3 kg milk $Mg^{-1}\ d^{-1}$ in the southern and central zones, respectively, and 4.5 kg milk $Mg^{-1}\ d^{-1}$ in the northern zone. Milk Mg^{-1} decreased 16 and 20% in the southern and central zones, respectively, and 30% in northern zones when corn planting was delayed from late April to late June. The relationship between planting date and milk ha^{-1} was best explained using a quadratic model in the southern and central zones and a linear model in the northern zone (Table 4). Maximum milk ha^{-1} was produced when corn was planted on 2 May in southern and central zones. More than 50% of the maximum milk ha^{-1} was lost if planting was delayed until late June in central and northern zones, and 30% was lost in the southern zone.

Minimal decline in quality traits and performance indices of forage between planting dates in the southern zone suggest that corn planted at this range of dates

Table 4. Regression equations for corn forage yield and quality in Wisconsin (1998–1999). Data are pooled across environment within a production zone, hybrid, and replication (n = 192) and regressed against planting day of year.

Trait†	Regression equation‡	R^2
	Southern Wisconsin	
DM yield, Mg ha^{-1}	$-22.3 + 0.678 - 0.003d^2$	0.93
CP, g kg^{-1}	$58.8 + 0.122d$	0.90
ADF, g kg^{-1}	no significant coefficients	–
NDF, g kg^{-1}	$383 + 0.677d$	0.92
IVTD, g kg^{-1}	$807 - 0.268d$	0.81
CW digestibility, g kg^{-1}	$944 - 6.10d + 0.022d^2$	0.80
Milk, kg Mg^{-1}	$1\,257 - 2.43d$	0.95
Milk, kg ha^{-1}	$-16\,007 + 606d - 2.47d^2$	0.95
	Central Wisconsin¶	
DM yield, Mg ha^{-1}	$-13.7 + 0.592d - 0.0025d^2$	0.99
CP, g kg^{-1}	$234 - 2.46d + 0.009d^2$	0.92
ADF, g kg^{-1}	$508 - 4.05d + 0.015d^2$	0.97
NDF, g kg^{-1}	$341 + 1.09d$	0.95
IVTD, g kg^{-1}	no significant coefficients	–
CW digestibility, g kg^{-1}	$1\,068 - 8.90d + 0.034d^2$	0.97
Milk, kg Mg^{-1}	$1\,194 - 2.27d$	0.73
Milk, kg ha^{-1}	$-29\,288 + 752d - 3.08d^2$	0.96
	Northern Wisconsin#	
DM yield, Mg ha^{-1}	$-27.9 + 0.715d - 0.0028d^2$	0.97
CP, g kg^{-1}	$56.5 + 0.159d$	0.83
ADF, g kg^{-1}	no significant coefficients	–
NDF, g kg^{-1}	$305 + 1.39d$	0.81
IVTD, g kg^{-1}	no significant coefficients	–
CW digestibility, g kg^{-1}	no significant coefficients	–
Milk, kg Mg^{-1}	$1\,455 - 4.25d$	0.75
Milk, kg ha^{-1}	$33\,812 - 141d$	0.80

† DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTD, in vitro true digestibility; CW digestibility, cell wall digestibility.
‡ d = planting day of the year (1 May = 121).
§ Arlington and Lancaster.
¶ Hancock and Marshfield.
# Ashland and Spooner.

Table 5. Regression equations for corn forage stover yield and quality in Wisconsin (1998–1999). Data are pooled across environment within a production zone, hybrid, and replication (n = 192) and regressed against planting day of year.

Trait†	Regression equation‡	R^2
	Southern Wisconsin§	
DM yield, Mg ha^{-1}	$6.59 - 0.021d$	0.67
CP, g kg^{-1}	$168 - 1.60d + 0.006d^2$	0.99
ADF, g kg^{-1}	$504 - 0.949d$	0.82
NDF, g kg^{-1}	$825 - 1.12d$	0.73
IVTD, g kg^{-1}	no significant coefficients	–
Ear/stover ratio, g kg^{-1}	$-358 + 15.5d - 0.060d^2$	0.98
	Central Wisconsin¶	
DM yield, Mg ha^{-1}	$12.0d - 0.026d$	0.95
CP, g kg^{-1}	$236 - 2.79 + 0.011d^2$	0.98
ADF, g kg^{-1}	no significant coefficients	–
NDF, g kg^{-1}	$-525 + 18.1d - 0.065d^2$	0.92
IVTD, g kg^{-1}	$1399 - 11.9d + 0.045d^2$	0.97
Ear/stover ratio, g kg^{-1}	$-1620 + 33.3d - 0.120d^2$	0.95
	Northern Wisconsin#	
DM yield, Mg ha^{-1}	no significant coefficients	–
CP, g kg^{-1}	$22.3 + 0.294d$	0.80
ADF, g kg^{-1}	$-256 + 10.2d - 0.038d^2$	0.99
NDF, g kg^{-1}	$-486 + 17.8d - 0.064d^2$	0.87
IVTD, g kg^{-1}	$1235 - 9.23d + 0.034d^2$	0.92
Ear/stover ratio, g kg^{-1}	$-1800 + 37.1d - 0.140d^2$	0.96

† DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTD, in vitro true digestibility.
‡ d = planting day of the year (1 May = 121).
§ Arlington and Lancaster.
¶ Hancock and Marshfield.
# Ashland and Spooner.

reached similar harvest maturities (Table 3). Central and northern zones, which experienced earlier frosts and cooler average temperatures than the southern zone, had larger changes in forage quality across planting dates. Corn planted at later dates in the central and northern zones was more immature at harvest (Table 3). Corn forage harvested at immature stages was observed by Wiersma et al. (1993) to be lower in quality than that harvested between one-half and three-fourths milkline. This agrees with a study conducted by Coors et al. (1997), who reported decreased CP, NDF, and ADF and increased IVTD as ear fill increased from 0 to 100%. Several researchers have suggested the importance of the grain portion of a corn plant to maximize corn forage dry matter yield and quality (Denium and Knoppers, 1979; Phipps and Weller, 1979).

Positive and negative linear responses described the relationship between stover dry matter yield and planting date in the production zones (Table 5 and Fig. 3a). In the central zone, dry matter yield of corn stover declined linearly at a rate of 0.026 Mg ha^{-1} d^{-1} from the late-April to late-June planting date, which agrees with the results of Fairey (1980). A positive linear response best described dry matter yield of corn stover at the southern zone. Several researchers have reported increased plant height and leaf number with later plantings (Bonaparte and Brawn, 1976; Genter and Jones, 1970), which may have caused increased stover yield at later plantings. There was no observed relationship between stover dry matter yield and planting date for the northern zone.

Relationships between stover quality responses and planting date were most often described with quadratic models in the central and northern zones (Table 5). Only CP exhibited a linear relationship in the northern zone. Linear models typically best described the relationship between quality responses and planting date in the southern zone, with the exception of CP, which was best described with a quadratic model (Table 5).

Stover CP increased as planting date was delayed (Fig. 3b). The southern and central zones had a decline in CP content until mid-May and then had increased CP as planting date was delayed. Stover CP exhibited a positive linear response to planting date in the northern zone (Table 5). When averaged across environments, stover CP increased as much as 22 g kg^{-1} from the late-April to the late-June planting date.

Corn stover fiber concentrations were lowest at the late-June planting date in all zones. A positive linear relationship between planting date and stover fiber concentrations was observed in the southern zone (Table 5; Fig. 3c and 3d). Stover NDF concentrations decreased by 10% and stover ADF concentrations by 30% as planting was delayed from late April to late June. The central and northern zones had an increase in stover NDF content until 23 May and then had a decrease at increasing rates as planting was delayed (Table 5 and Fig. 3d). A similar relationship between stover ADF and planting date was observed for the northern zone but not the central zone (Table 5 and Fig. 3c).

A quadratic relationship between stover IVTD and planting date was observed in the central and northern zones (Table 5 and Fig. 3e). Stover IVTD decreased until mid-May and than began to increase at accelerating

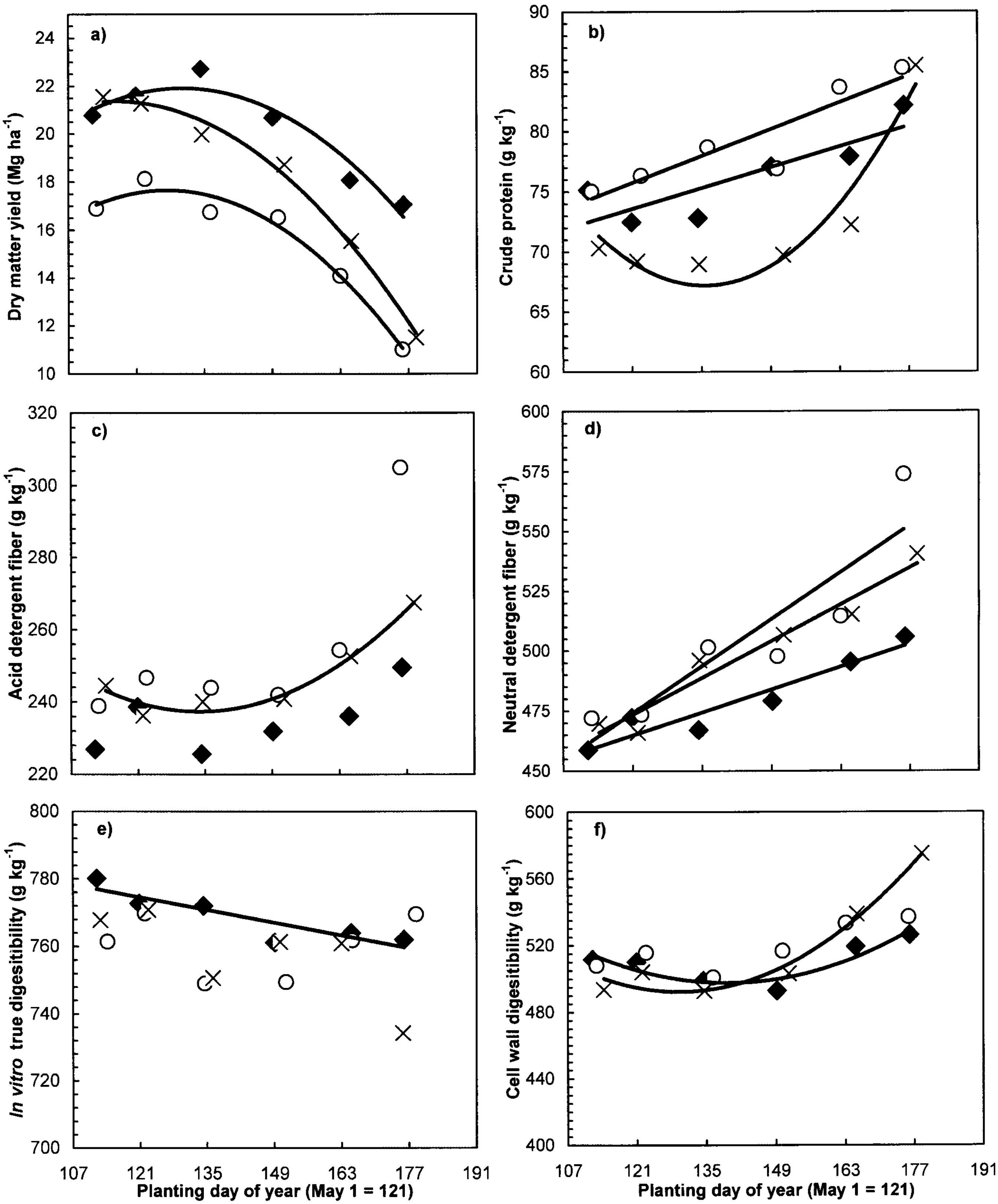

Fig. 1. Relationship in the southern (◆), central (×), and northern (○) zones between planting day of year and whole-plant (a) dry matter yield, (b) crude protein (CP) concentration, (c) acid detergent fiber (ADF) concentration, (d) neutral detergent fiber (NDF) concentration, (e) in vitro true digestibility (IVTD) concentration, and (f) cell wall digestibility concentration. Data are averaged across environment, hybrid, and replication (each point is the mean of 192 points). Equations and coefficients of determination (R^2) for Fig. 1. are reported in Table 4.

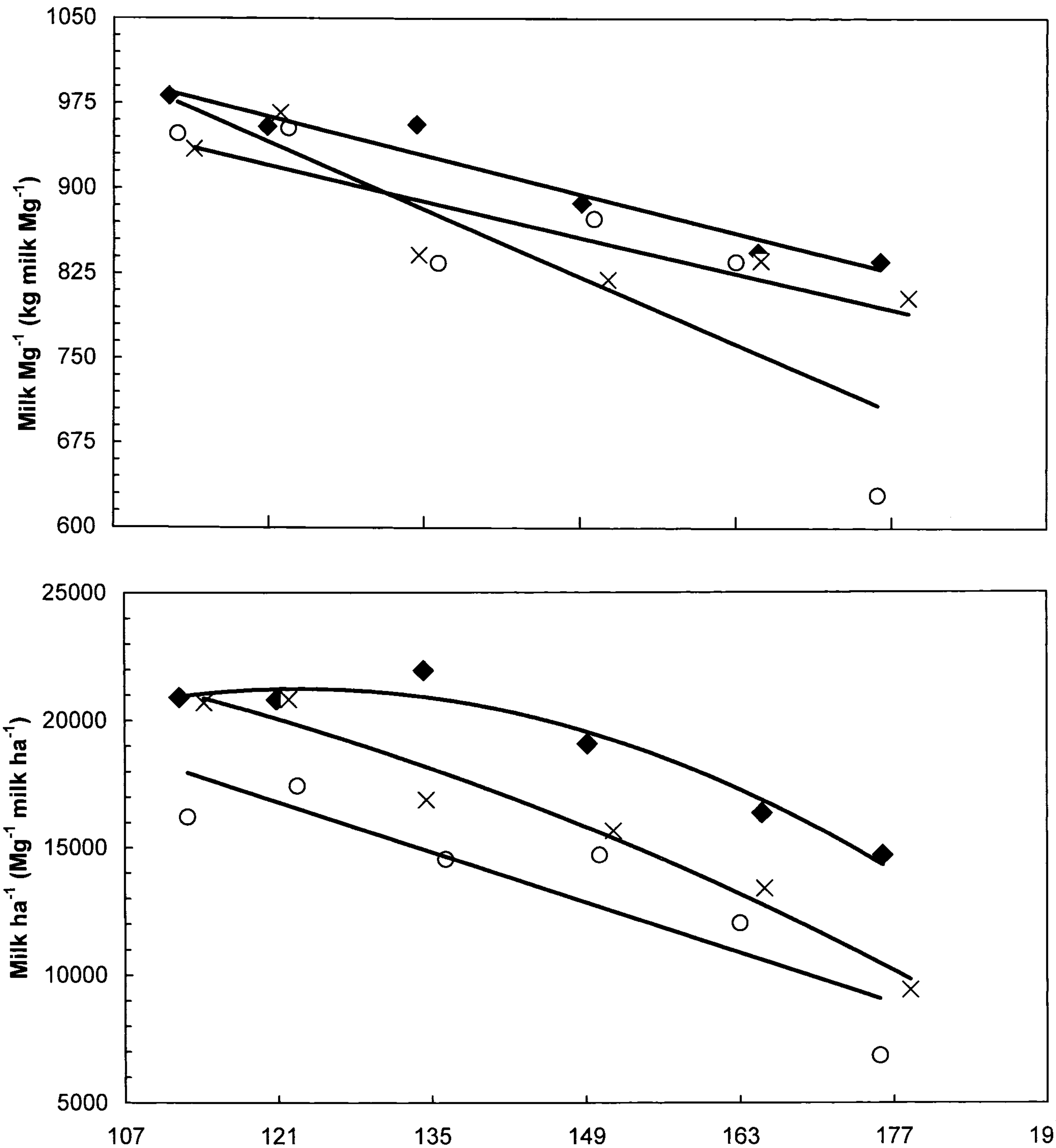

Fig. 2. Relationship in the southern (◆), central (×), and northern (○) zones between planting day of year and milk Mg^{-1} and milk ha^{-1}. Data are averaged across environment, hybrid, and replication (each point is the mean of 192 points). Equations and coefficients of determination (R^2) for Fig. 2 are reported in Table 4.

rates until the end of June. No relationship was observed between IVTD and planting date in the southern zone.

The relationship of planting date and ear/stover ratio was explained using a quadratic model in all production zones (Table 5 and Fig. 3f). Maximum ear/stover ratio was observed in mid-May planting dates at all productions zones. Late-June planting dates reduced ear/stover ratio by 250, 300, and 400 g kg^{-1} in southern, central and northern zones, respectively.

These results suggest that stover quality traits declined with increased plant maturity, as induced by later harvesting (Table 3). In general, stover quality improved as planting dates were delayed, usually with highest quality as dates approached June. However, in late June,

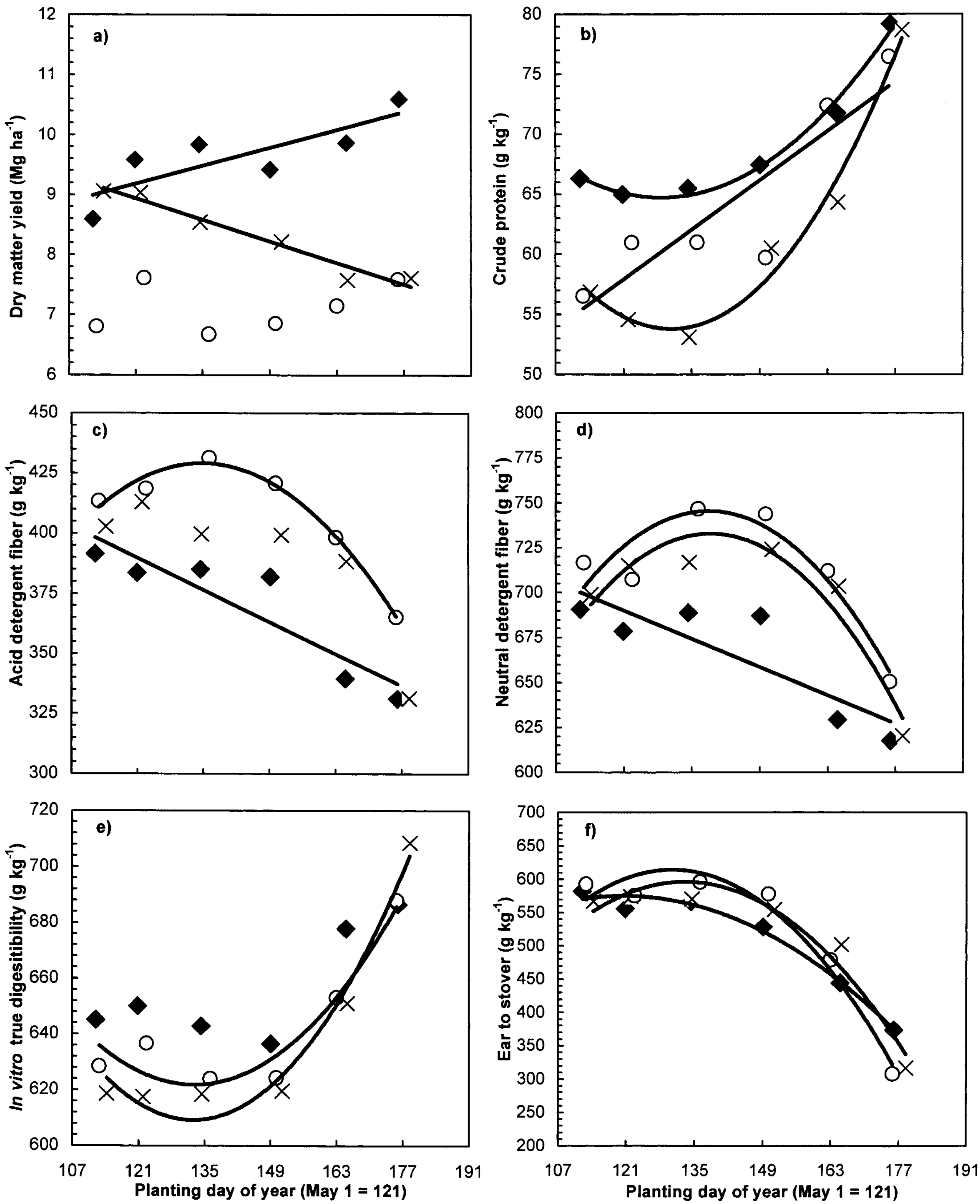

Fig. 3. Relationship in the southern (◆), central (×), and northern (○) zones between planting day of year and stover (a) dry matter yield, (b) crude protein (CP) concentration, (c) acid detergent fiber (ADF) concentration, (d) neutral detergent fiber (NDF) concentration, (e) in vitro true digestibility (IVTD) concentration, and (f) ear/stover ratio. Data are averaged across environment, hybrid, and replication (each point is the mean of 192 points). Equations and coefficients of determination (R^2) for Fig. 3 are reported in Table 5.

the grain portion of the plant had decreased a substantial amount, especially for the central and northern zones. Several researchers have reported increased stover fiber concentrations and decreased digestibility with decreased maturity or grain fill (Coors et al., 1997; Wiersma et al., 1993; Fairey, 1983; Weaver et al., 1978).

CONCLUSIONS

The response of whole-plant dry matter yield to planting date was quadratic, with maximum dry matter production between 21.9 and 17.7 Mg ha^{-1} and optimum planting dates between 27 April and 10 May. Whole-plant forage quality decreased as planting dates progressed through the growing season with the exception of CP, which increased with later planting dates. Whole-plant NDF and ADF concentrations were lowest and IVTD concentration highest at late-April to mid-May planting dates. Maximum milk Mg^{-1} and milk ha^{-1} were obtained between late April and early May for all zones. Stover yield, however, responded variably among zones, but stover quality increased substantially in all zones with later planting dates. Mobilization and translocation of nonstructural carbohydrates from stover to the developing ear probably contributed to this inverse relationship (Coors et al., 1997; Genter et al., 1970). Corn forage yields remained at 95% of maximum yields when corn was planted in late May for all zones. As planting was delayed past mid-May, rates of quality decline were more severe in central and northern zones compared with the southern zone. We recommend that corn producers in southern Wisconsin plant corn for grain first (1 to 7 May optimum planting date for grain) because milk yield ha^{-1} declined only 2% by 14 May and 8% by 28 May in the southern zone. In contrast, corn producers in northern Wisconsin should plant corn for forage first and plant corn for grain second (8 to 14 May optimum planting date for grain) because milk yield ha^{-1} had already declined by more than 10% by 14 May in the northern zone.

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