Harvest Date and Hybrid Influence on Corn Forage Yield, Quality, and Preservation

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ABSTRACT

The selection of corn (*Zea mays* L.) hybrids and the timing of harvest are important management considerations for dairy and livestock operations. Objectives of this study were to determine the effect of harvest date on yield and quality of corn hybrids and to describe the relationship between harvest date and the yield and quality of corn forage, silage, and stover. During 1998 and 1999, four hybrids were harvested at eight different harvest times between 521 and 1224 growing degree units (GDUs) after planting. Few hybrid or hybrid × harvest date effects were observed. As GDUs accumulated, dry matter yield increased from 8 to 25 Mg ha^{-1}. Lowest concentrations of neutral detergent fiber (NDF) and acid detergent fiber (ADF) and highest concentrations of in vitro true digestibility (IVTD) occurred when forage was harvested between 700 and 650 g kg^{-1} moisture (1025 and 1186 GDUs after planting). Potential milk yield indices of milk Mg^{-1} corn forage (794 kg) and milk ha^{-1} corn forage (19 049 Mg) were reached when corn was harvested between 670 and 630 g kg^{-1} moisture. In general, silage had 15% lower concentrations of NDF, 8% lower IVTD, 48% lower cell wall digestibility, 7% lower crude protein, and 15% higher concentrations of ADF than unfermented fresh forage. Harvesting can be accomplished until 580 g kg^{-1} moisture while maintaining 95% of the maximum yield and milk ha^{-1}.

Adverse spring conditions often push planting dates for corn past the optimum for grain and sometimes silage production. Likewise, less-than-optimum conditions for grain production may force farmers to harvest corn for silage. The ability to utilize immature corn silage enables a farmer to salvage corn that was planted late or replanted due to poor growing conditions or management.

The decline in energy in slightly immature corn silage may be less than expected because the cell wall fraction [acid detergent fiber (ADF) and neutral detergent fiber (NDF)] in the stover is more available due to reduced complexity of the bonding within the cell wall carbohydrate complex (Morrison et al., 1998). Johnson and McClure (1968) conducted a feeding trial of corn silage harvested from blister to physiological maturity and concluded that maturity had little effect on intake of corn silage. Poor starch fill (and grain yield) can cause photosynthetic energy to remain as sugar in the stover and leaves, thus diluting fiber content but not yielding the expected net energy (Coors et al., 1997; Fairey, 1983; Deinum and Knoppers, 1979). Johnson and McClure (1968) reported increased soluble carbohydrate in stalks from tasseling to the milk stage and a decline thereafter with advancing maturity. Most researchers have related maximum dry matter yield and quality with high grain content (Coors et al., 1997; Phipps et al., 1979).

Quality measurements of corn forage are often reported for fresh-cut corn only. Several reports have indicated an increase in concentrations of fiber and crude protein (CP) and a decrease in digestibility when corn forage is ensiled (Hunt et al., 1992; McAllan and Phipps, 1977). Ensiling does not provide perfect preservation of crop quality. Harvesting forages when they are too wet or too dry makes the silage susceptible to effluent losses and respiration losses, respectively (Barnett, 1954). There are additional losses due to plant and microbial respiration, which are significant and the cause of the majority of the dry matter losses that are typically measured in farm silos. This respiratory activity is especially damaging because it results in the oxidation of the most digestible portion of the crop.

Various experiments have documented the best time to harvest corn for silage to optimize yield and quality (Bal et al., 1997; Philippeau and Michalet-Doreau, 1997; Weaver et al., 1978). Wiersma et al. (1993) reported that corn silage quality is inversely related to stage of maturity at harvest. Reported values of one-fourth to two-thirds milkline (650–680 g kg^{-1} moisture) are considered the optimum stage of harvest to maximize intake, digestion, and milk production (Bal et al., 1997). Corn harvested outside this optimum range has a higher risk of reduced forage quality and poor silage preservation.

Seasonal changes of whole-plant and stover quality of fresh or ensiled material are not well documented. It is important to know the impact of harvesting at immature growth stages on the quality of forage and silage. In many years, corn that has not reached the proper stage of harvest due to early frost or late planting will need to be utilized in some manner, and the only option may be silage. The objectives of the study were to (i) determine the effect of harvest date on yield and quality of corn hybrids and (ii) describe the relationship between harvest date and the yield and quality of fresh forage, silage, and stover.

MATERIALS AND METHODS

Field and Laboratory Procedures

Plots were established at the University of Wisconsin Agricultural Research Station in Arlington on a Plano silt loam (fine silty, mixed, mesic Typic Argiudoll) during 1998 and 1999. Previous crops at this site were alfalfa (*Medicago sativa* L.) for the site used in 1998 and soybean [(*Glycine max* (L.) Merr.] for the site used in 1999. Soil P and K were maintained

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; CWD, cell wall digestibility; GDUs, growing degree units; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy; RM, relative maturity rating.

at optimum levels based on University of Wisconsin recommendations (Kelling et al., 1991). Plot size was 12.2 by 7.6 m. Plots received an annual application of 168 kg N ha^{-1} before planting. In addition, 28, 56, and 56 kg ha^{-1} N, P_2O_5, and K_2O, respectively, were row-applied as starter fertilizer before planting. Pre-emergence applications of alachlor [2-chloro-*N*-(2,6-iethylphenyl)-*N*-methoxymethyl] at 2.3 kg a.i. ha^{-1} and cyanazine [2-chloro-4-(1-cyano-1-methylethylamino)-6-ethylanimo-1,3,5-trizine] at 2.25 kg a.i. ha^{-1} were applied in 1998 and 1999 for annual weed control. Plots were cultivated each year to aid in annual weed control. Planting dates were 12 May 1998 and 27 Apr. 1999. Corn was seeded at a rate of 83 500 kernels ha^{-1} and then hand-thinned to 78 600 plants ha^{-1} at the V5 growth stage (Ritchie et al., 1996).

The experimental design was a randomized complete block in a split-plot arrangement with four replicates. Main plots were four hybrids varying in relative maturity rating (RM) and forage NDF concentration. In 1998, the hybrids grown in the study were Golden Harvest H2497 [high NDF, 110-d Minnesota RM], Dekalb DK591 (low NDF, 100-d RM), Golden Harvest H2387 (high NDF, 100-d RM), and Dairyland Stealth1400 (low NDF, 100-d RM). In 1999, the Dairyland Stealth1400 hybrid was not available, so it was replaced with Pioneer 36H36 (low NDF, 100-d RM).

Daily growing degree units (GDUs) were calculated using Eq. [1]:

$$\text{GDUs} = [(T_{\max} - T_{\min})/2] - T_b \qquad [1]$$

where $T_{\max}$ is the maximum daily temperature (upper limit of 30°C), $T_{\min}$ is the minimum daily temperature (with a lower limit of 10°C), and T_b is equal to 10°C (McMaster and Wilhelm, 1997). To calculate accumulated GDUs, the daily GDUs were summed for the number of days of growth beginning at plantings.

Split plots were eight harvest dates, starting at the V17 stage (Ritchie et al., 1996), that were spaced approximately 10 d apart throughout the remainder of the growing season. Harvest date was randomly assigned to a row section measuring 0.76 by 2.6 m and bordered by unharvested rows. Harvesting started on 15 July 1998; additional harvests occurred on 24 July, 3 Aug., 12 Aug., 22 Aug., 1 Sept., 11 Sept., and 21 Sept. These dates corresponded to 612, 733, 821, 843, 947, 1058, 1127, and 1224 GDUs after planting, respectively. Harvesting in 1999 started on 12 July and continued with subsequent harvests on 19 July, 28 July, 6 Aug., 15 Aug., 25 Aug., 3 Sept., and 13 Sept. These dates corresponded to 521, 607, 738, 850, 921, 1011, 1097, and 1147 GDUs after planting, respectively.

At harvest time, two samples of five consecutive plants were hand-harvested by cutting 15 cm above the soil surface from each harvest area. The first sample was harvested as whole plant, weighed, and chopped with a Troy-Built Tomahawk chipper (Troy Corp., Troy, NY). After mixing, chopped whole-plant samples were subdivided into fresh or ensiled subsamples. Approximately 1-kg of fresh sample was subsampled and used to determine moisture and quality. Ensiled samples were hand-packed with a wooden dowel into airtight laboratory silos of 0.47-L capacity. Equal amounts of dry matter were packed into the silos at each harvest date. The second five-plant sample was weighed, and the ears were removed and stover plant parts reweighed. Stover plant parts were chopped, mixed, and subsampled as fresh forage only. The remaining plants in the harvest area were hand-harvested, weighed, and discarded.

During the ensiling period, laboratory silos were stored in an unheated building and subjected to environmental temperatures ranging from 5 to 22°C. During this time, CO_2 and effluent was released daily from the silos but not measured. After 30 d of storage, ensiled samples were removed from the silos and frozen (−5°C). After samples from the last harvest date had been frozen for at least 2 wk, all samples were transferred into a freeze drier (Model 24DX24/48, Virtis Corp., Gardiner, NY). Freeze drying reduces the loss of readily available organic constituents of fermented forages, such as volatile acids, compared with oven drying (Danley and Vetter, 1971).

Fresh whole-plant and stover samples were weighed, dried at 60°C for 7 d, and reweighed. All samples were ground with a hammer mill (Christy Hunt Corp., Scunthorpe, UK) to pass through a 1.0-mm screen. Ground samples were scanned on a NIRSystems 6500 near-infrared reflectance spectrophotometer (NIRS) (NIRSystems, Silver Spring, MD) to determine concentrations of NDF, ADF, in vitro true digestibility (IVTD), and CP (Marten et al., 1985).

Separate calibration sets were derived from the ensiled and fresh plant material for 1998 and 1999. The NIRS calibration for fresh forage 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 0.5-g sample was used for sequential detergent analysis to determine NDF and ADF (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% heat-stable α-amylase solution (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 in buffered rumen fluid was performed in a Daisy II Incubator (ANKOM Technol. 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 rumen 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 α-amylase, as described previously. Neutral detergent dissolves bacterial debris, and only undigested plant residue remains (Van Soest, 1994).

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). The percentage of CP was calculated by multiplying percent N by 6.25.

From the data obtained in the laboratory, prediction equations were developed that related NIR 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 multiple determination (R^2) and low standard errors of calibration and cross validation. Modified partial least square analyses were used to determine what wavelengths to include in calibrations (Martens and Naes, 1989). Statistics relating to NIRS prediction are provided in Table 1.

Concentrations of NDF and IVTD were used to calculate cell wall digestibility (CWD) (Van Soest, 1994) by the following equation:

$$CWD = [NDF - (1000 - IVTD)]/NDF \times 1000 \quad [2]$$

Potential milk yield indices were used to evaluate the economic value of fresh and ensiled forage produced from the treatments (Undersander et al., 1993). Milk per megagram (kg milk Mg^{-1} corn forage) 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 d^{-1} milk at 3.8% fat. Milk per hectare (kg milk ha^{-1} corn forage) is the product of Milk per megagram and dry matter yield of corn forage.

Mixed-model analysis across year was calculated using PROC MIXED of SAS (SAS Inst., 1999). Hybrid, harvest date, and corn preservation (forage or silage) factors in this experiment were considered fixed, but replicates and years were considered random. Because significant year × treatment interactions were not observed for most measurements, a combined analysis was performed across both years. Mean separation among treatments and interactions involving hybrids, harvest dates, and corn preservation was obtained using a LSD test when significant *F*-tests ($P < 0.05$) were observed. Regression analysis examined the relationship between dependent variables and harvest date expressed as accumulated GDUs. The model with the highest R^2 value was the basis used for selecting regression model. Coefficients were reported when the regression was significant ($P < 0.05$).

Effects were considered significant in all statistical calculations for *P*-values < 0.05.

Table 1. Statistics relating to near-infrared reflectance spectroscopy (NIRS) prediction derived by using partial least squares analysis and used to select equations for prediction of nutritive value attributes.

Storage†	Variable‡	N§	Mean	SEC¶	SEV(C)#	R^2
			1999			
Ensiled	CP	24	8.80	0.46	0.61	0.96
Fresh	CP	44	8.20	0.45	0.88	0.95
Ensiled	NDF	24	55.9	0.73	1.13	0.99
Fresh	NDF	42	61.4	1.06	2.30	0.99
Ensiled	ADF	24	33.4	0.29	1.28	1.00
Fresh	ADF	41	33.4	0.59	1.82	0.99
Ensiled	IVTD	24	61.2	0.49	2.11	0.98
Fresh	IVTD	44	61.1	2.45	3.28	0.92
			1999			
Ensiled	CP	24	9.90	0.26	0.90	0.99
Fresh	CP	50	8.50	0.28	0.62	0.98
Ensiled	NDF	24	56.3	0.93	2.44	0.99
Fresh	NDF	48	58.0	1.37	1.53	0.98
Ensiled	ADF	26	32.7	0.25	1.60	1.00
Fresh	ADF	50	29.8	0.75	1.38	0.99
Ensiled	IVTD	24	65.9	0.80	3.17	0.96
Fresh	IVTD	48	65.4	1.71	2.29	0.96

† Ensiled: stored as whole-plant silage; fresh: stored as fresh whole-plant and stover forage.
‡ CP, crude protein; NDF, neutral detergent fiber; ADF, acid 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.

RESULTS AND DISCUSSION

Seasonal temperature was above normal for both years (data not shown). In 1998, mean monthly temperature (20°C) was 2°C higher than the 20-yr average in July, and the August and September mean monthly temperatures (21 and 17°C, respectively) were 2°C higher than average. In 1999, an opposite trend was seen as mean monthly temperature (23°C) was 4°C higher than the 20-yr average in July, and the August and September mean monthly temperatures (19 and 14°C, respectively) were 3°C lower than the average for those months. Rainfall for both years was adequate but was slightly below average during July 1998, and very dry conditions occurred during the fall in both years. Cumulative GDUs were slightly higher in 1998 (2541 GDUs) than 1999 (2512 GDUs), probably due to the warmer fall and slightly warmer spring conditions.

Hybrid × Harvest Date Interactions

Few hybrid × harvest date interactions were observed (data not shown). A hybrid × harvest date interaction for forage and silage dry matter yield was observed where hybrids performed similarly across harvest times until the sixth harvest date (1035 GDUs) when the full-season hybrids began to accumulate more dry matter than shorter-season hybrids (data not shown). Irlbeck et al. (1993) and Fairey (1980) also observed hybrid × harvest date interactions for dry matter yield. A hybrid × harvest date interaction was also observed for the concentrations of NDF, IVTD, and CWD in silage (data not shown). Shorter-season hybrids had the lowest ADF and NDF concentrations and the highest concentration of IVTD on the first six harvest dates. On the seventh harvest date (1112 GDUs), concentrations of ADF and NDF in shorter-season hybrids exceeded those of the full-season hybrids, and IVTD of the shorter-season hybrids declined below that of the full-season hybrids. These interactions were not observed for unfermented forage, thereby suggesting that the ensiling process accentuated the differences in hybrid quality across the range of harvest dates.

Because few interactions were found and were minimal in relation to main effects, these data suggest that hybrid quality varied similarly across harvest times. This agrees with the work of Irlbeck et al. (1993), who reported no hybrid × harvest date interactions for NDF or ADF.

Hybrid Effects

Most studies have reported differences among hybrids for whole-plant corn yield and quality when forage was harvested between 600 to 650 g kg^{-1} moisture (Fairey, 1980; Denium, 1988; Cox et al., 1994). The whole-plant moisture content on the seventh harvest date was between 600 to 650 g kg^{-1}; this was used to describe the hybrid effects (Table 2). Because there was a general lack of hybrid differences and interactions throughout the experiment, the hybrids Dairyland Stealth 1400 and Pioneer 36H36 were averaged and treated as one common treatment. In this experiment, there were no hybrid differences observed for forage, silage, and stover yield; quality; or performance indices. In general, concentrations of ADF and NDF were in the range of those reported by Allen et al. (1990) and

Table 2. Response of yield, quality, and performance indices to corn hybrid and fresh, ensiled, and stover forage when harvested on Harvest Date 7 [1112 growing degree units (GDUs)] in Arlington, WI (1998–1999).

Hybrid‡	Dry matter yield	Harvest moisture	Ear/stover ratio	Quality traits†					Potential milk yield indices	
				CP	NDF	ADF	IVTD	CWD	Milk Mg^{-1} forage	Milk ha^{-1} forage
	Mg ha^{-1}	g kg^{-1}							kg Mg^{-1}	Mg ha^{-1}
				Fresh forage§						
Golden Harvest H2497	26.5	631	–	74.8	479	252	683	337	687	17 900
Dekalb DK591	24.5	634	–	76.0	466	232	708	370	793	19 300
Golden Harvest H2387	23.6	616	–	78.7	485	238	682	347	673	16 600
Dairyland Stealth 1400 and Pioneer 36H36	23.5	628	–	75.2	488	251	686	357	676	15 900
SE¶	1.39	1.58	–	3.63	13.5	6.47	5.39	19.3	36.5	1 110
				Ensiled forage						
Golden harvest H2497	26.5	643	–	77.7	392	207	676	173	860	22 700
Dekalb DK591	24.5	652	–	78.7	416	227	659	174	756	18 800
Golden Harvest H2387	23.6	639	–	81.5	396	205	680	192	860	20 500
Dairyland Stealth 1400 and Pioneer 36H36	23.5	638	–	78.6	425	242	661	199	744	17 400
SE	1.39	1.58	–	2.84	17.8	15.8	13.4	32.1	68.6	2 350
				Fresh stover						
Golden Harvest H2497	11.7	753	561	71.8	683	392	524	303	–	–
Dekalb DK591	11.3	749	538	67.9	671	392	546	325	–	–
Golden Harvest H2387	10.1	735	570	74.3	696	385	520	312	–	–
Dairyland Stealth 1400 and Pioneer 36H36	11.0	721	530	66.2	695	393	527	319	–	–
SE	0.779	0.902	2.03	3.54	10.6	10.5	18.9	19.3	–	–

† CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTD, in vitro true digestibility; CWD, cell wall digestibility.
‡ Hybrids grown during 1998 and 1999, with the exception of Dairyland Stealth 1400 grown in 1998 and replaced with Pioneer 36H36 in 1999.
§ Preservation method: (i) fresh forage that included unfermented stalk, leaves, and grain; (ii) ensiled forage that included fermented stalk, leaves, and grain; and (iii) fresh stover that included stalk and leaves.
¶ SE, standard error of mean. There were no significant ($P < 0.05$) differences among hybrids for any response variables.

Hunt et al. (1992), who observed that concentrations of ADF and NDF among hybrids varied from 174 to 283 g kg^{-1} and 364 to 490 g kg^{-1}, respectively. Concentrations of IVTD were slightly lower than reported by Vattikonda and Hunter (1983) and Cox et al. (1994), who observed that digestibility among hybrids varied between 751 to 818 g kg^{-1}. Similar to the findings of Hunt et al. (1993), no interactions involving preservation method and hybrid for whole-plant characteristics were observed (data not shown). Lack of evidence of an interaction suggests that hybrids superior in quality maintain these characteristics when ensiled.

Hybrids with inherently different concentrations of NDF may not always perform the same in different environments. Cox et al. (1994) and Denium (1988) reported that the relative performance of individual hybrids could change with environmental conditions, whereas other experiments report that hybrids act consistently across years (Vattikonda and Hunter 1983; Allen et al., 1990).

Harvest Date Effects

Forage and Silage Yield

Maximum whole-plant corn yield is generally reported to occur when the whole-plant moisture content is between 700 and 650 g kg^{-1} (Wiersma et al., 1993). Forage and silage whole-plant dry matter yield increased as GDUs accumulated through the growing season in a linear fashion (Table 3 and Fig. 1a). Maximum yield was realized at the last harvest date, which occurred at 580 g kg^{-1} moisture. Wiersma et al. (1993) observed maximum dry matter yields at one-half milkline or approximately 650 g kg^{-1} moisture with no significant increases in yield with later maturity. Although

Table 3. Regression equations for fresh forage, ensiled forage, and fresh stover yield and quality at Arlington, WI (1998 and 1999). Data were pooled across year, hybrid, and replication ($n = 48$) and regressed against growing degree units (GDUs) ($n = 8$).

Trait†	Regression equation	r^2 or R^2
	Fresh forage	
DM yield, Mg ha^{-1}	$-9.93 + 0.03x$‡	0.98
CP, g kg^{-1}	$287 - 0.35x + 1.42 \times 10^{-4}x^2$	0.99
ADF, g kg^{-1}	$-1\,151 + 5.97x - 0.007x^2 + 2.84 \times 10^{-6}x^3$	0.99
NDF, g kg^{-1}	$-1\,656 + 9.26x - 0.01x^2 + 4.40 \times 10^{-6}x^3$	0.99
IVTD, g kg^{-1}	$2\,143 - 6.07x + 0.008x^2 - 3.10 \times 10^{-6}x^3$	0.95
CWD, g kg^{-1}	$70.5 + 1.12x - 7.70 \times 10^{-4}x^2$	0.93
Milk, kg Mg^{-1}	$9\,549 - 37.7x + 0.047x^2 - 1.85 \times 10^{-5}x^3$	0.99
Milk, kg ha^{-1}	$215\,000 - 834x + 1.04x^2 - 3.91 \times 10^{-4}x^3$	0.99
	Ensiled forage	
DM yield, Mg ha^{-1}	$-6.14 + 0.026x$	0.98
CP, g kg^{-1}	$286 - 0.366x + 1.59 \times 10^{4}x^2$	0.96
ADF, g kg^{-1}	$-1\,163 + 5.70x - 0.007x^2 + 2.28 \times 10^{-6}x^3$	0.99
NDF, g kg^{-1}	$-1\,611 + 8.33x - 0.01x^2 + 3.41 \times 10^{-6}x^3$	0.99
IVTD, g kg^{-1}	$1\,328 - 2.63x + 0.003x^2 - 1.13 \times 10^{-6}x^3$	0.99
CWD, g kg^{-1}	$64.2 + 1.12x - 8.76 \times 10^{-4}x^2$	0.96
Milk, kg Mg^{-1}	$7\,110 - 25.7x + 0.029x^2 - 1.07 \times 10^{-5}x^3$	0.99
Milk, kg ha^{-1}	$134\,000 - 491x + 0.56x^2 - 1.94 \times 10^{-4}x^3$	0.99
	Fresh stover	
DM yield, Mg ha^{-1}	NS§	–
CP, g kg^{-1}	$159 - 0.078x$	0.95
ADF, g kg^{-1}	$271 + 0.10x$	0.90
NDF, g kg^{-1}	$598 + 0.08x$	0.82
IVTD, g kg^{-1}	$894 - 0.32x$	0.95
Ear/stover ratio, g kg^{-1}	$-2\,770 + 5.50x - 22.7 \times 10^{-4}x^2$	0.99

† DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTD, in vitro true digestibility; CWD, cell wall digestibility.
‡ x = GDUs (base 30/10°C).
§ NS, no significant ($P < 0.05$) coefficients.

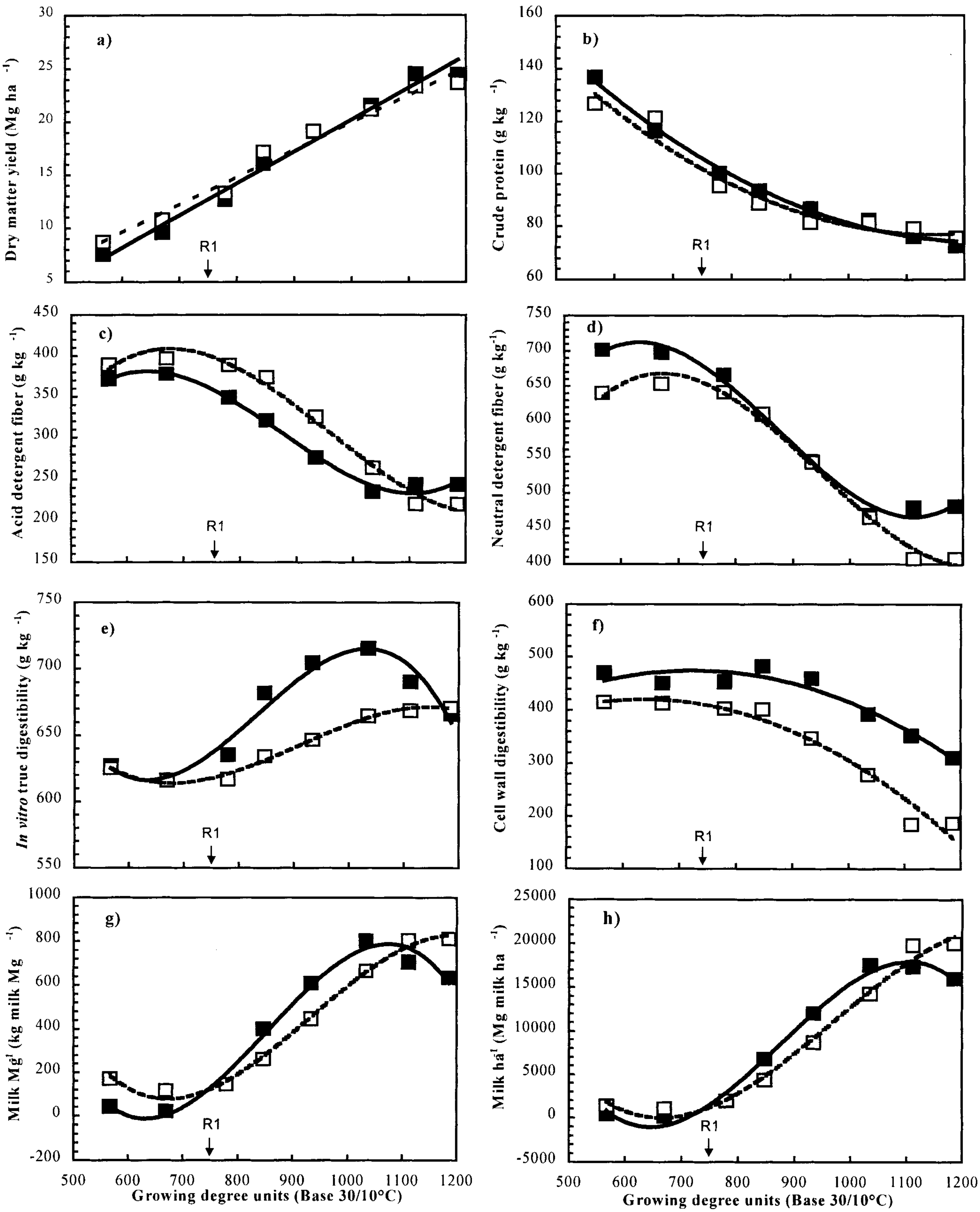

Fig. 1. Relationship between whole-plant (a) dry matter yield, (b) crude protein (CP) concentration, (c) neutral detergent fiber (NDF) concentration, (d) acid detergent fiber (ADF) concentration, (e) in vitro true digestibility (IVTD) concentration, and (f) cell wall digestibility (CWD) concentration and (g) milk per megagram and (h) milk per hectare on growing degree units (GDUs). Data are reported for unfermented forage (■—) and silage (□ - - -). Each data point is the mean across four hybrids, four replicates, and 2 yr. Equations and coefficients of determination (R^2) for Fig. 1 are reported in Table 3. R1 refers to the growth stage of corn when silks were emerged on at least 50% of the plants.

the linear response suggests higher yield could be obtained as GDUs continued to accumulate, other studies report that dry matter yield will level off after 650 g kg^{-1} moisture (Wiersma et al., 1993).

Forage and Silage Quality

Cubic models best explained the relationship between forage and silage quality parameters and GDUs, with the exception of CP and CWD, which exhibited a quadratic relationship with GDUs.

In agreement with Wiersma et al. (1993), the highest concentrations of CP were observed at earlier harvest dates and declined quadratically with GDUs (Fig. 1b). Concentrations of CP ranged from 138 to 72 g kg^{-1} across all harvest dates. Crude protein has previously been shown to decline with increasing maturities (Johnson and McClure, 1968; Sheperd and Kung, 1996).

A cubic model best described the regression of ADF and NDF concentrations on GDUs for forage and silage (Table 3). Generally, after R1 (Ritchie et al., 1996), concentrations of fiber decreased as the season progressed (Fig. 1c and 1d). The concentration of ADF decreased at a rate of 0.30 g kg^{-1} GDU^{-1} and NDF at a rate of 0.50 g kg^{-1} GDU^{-1} from the second to the seventh harvest date and then began to increase as corn approached black layer. Increases in whole-plant fiber content as corn approaches black layer have been reported by Bal et al. (1997) and Wiersma et al. (1993). Concentrations of ADF in forage ranged from 235 to 377 g kg^{-1} and NDF from to 479 to 701 g kg^{-1}. A decline in fiber concentration with increasing maturity can be attributed to the dilution effect created by the increasing content of grain as corn matures (Coors et al., 1997).

In agreement with the findings of Johnson and McClure (1968), IVTD was lowest at R1 and increased until about 1025 GDUs (700 g kg^{-1} moisture) (Fig. 1e). Unlike the data reported by Wiersma et al. (1993) and Cummins (1970), IVTD did not plateau after the maximum but declined approximately 80 g kg^{-1}. The relationship between forage and silage CWD and GDUs was best explained using a quadratic model (Table 3 and Fig. 1f). The CWD was highest (478 g kg^{-1}) between the growth stages of R1 and R2 at 727 GDUs and declined until the last harvest date. This suggests that lignification of the cell wall occurred as harvest dates progressed through the growing season (Jung and Deetz, 1993).

Different relationships were observed for fresh forage and silage in regressions of whole-plant yield or quality parameters on GDUs (Table 3). Differences in relationships can be attributed to dry matter losses during fermentation (Danley and Vetter, 1973). In agreement with observations made by Hunt et al. (1993) and Danley and Vetter (1973), silage was generally lower in CP, NDF, IVTD, and CWD (Fig. 1b, 1d, 1e, and 1f, respectively) and higher in ADF (Fig. 1c). Cell wall digestibility declined most severely due to ensiling.

At earlier harvest dates, the risk of effluent loss is greater, which probably contributes to any quality losses associated with early harvest of immature corn (Gummer et al., 1988). Normal fermentation of silage produces some dry matter loss that is associated with respiration of sugars. This causes increases in concentrations of fiber components and CP and concurrent decreases in digestibility (Dewars et al., 1963).

Potential Milk Yield Indices for Forage and Silage

Cubic relationships between potential milk yield indices and GDUs were observed for forage and silage (Table 3 and Fig. 1g and 1h). After R1, milk per megagram of forage and milk per hectare of forage increased until maxima of 794 kg milk Mg^{-1} forage and 19 049 Mg milk ha^{-1} forage were obtained when corn was harvested between 1075 and 1105 GDUs (670 and 630 g kg^{-1} moisture). Milk per hectare was still within 95% of the maximum values if corn was harvested as early as 700 g kg^{-1} moisture and as late as 580 g kg^{-1} moisture.

Stover Yield and Quality

No relationship was observed between stover dry matter yield and GDUs (Table 3 and Fig. 2a). This suggests that maximum stover yield is reached by the time reproductive development in corn has begun (Fairey, 1980; Wiersma et al., 1993). Linear models best described relationships that were observed between the quality characteristics of stover and GDUs (Table 3 and Fig. 2). Stover quality decreased as harvest dates progressed through the growing season. Crude protein ranged from 100 to 67 g kg^{-1} between the first and the last harvest date. Acid detergent fiber and NDF exhibited a positive linear relationship with GDUs. A negative linear model best described the relationship between IVTD and GDUs. Concentrations of IVTD were 644 g kg^{-1} on the first harvest date and decreased at a rate of 0.32 g kg^{-1} GDU^{-1} throughout the season. Ratios of ear to stover increased quadratically from the first to the last harvest date where a maximum of 560 g kg^{-1} ear/stover ratio was observed (Table 3 and Fig. 2f).

CONCLUSION

Few hybrid × harvest date interactions were observed for forage, silage, or stover quality traits, suggesting that hybrid quality differences would be similar across the range of harvest times. There were no hybrid differences for yield, quality, and estimated animal performance indices for fresh and ensiled whole-plant corn and stover.

The relationship between dry matter yield and GDUs was linear, with maximum production of about 25 Mg ha^{-1}. The nutritive value of unfermented forage and silage increased and stover quality decreased as harvest time progressed through the growing season. Generally, forage quality was always lowest when harvest time coincided with flowering (R1). Fiber constituents were lowest between 1100 and 1110 GDUs (650 g kg^{-1} moisture). In vitro true digestibility was maximized at 1025 GDUs (700 g kg^{-1} moisture). Milk per megagram and milk per hectare were optimized at 1075 and 1105 GDUs (670 and 630 g kg^{-1} moisture), respectively. The ensiling

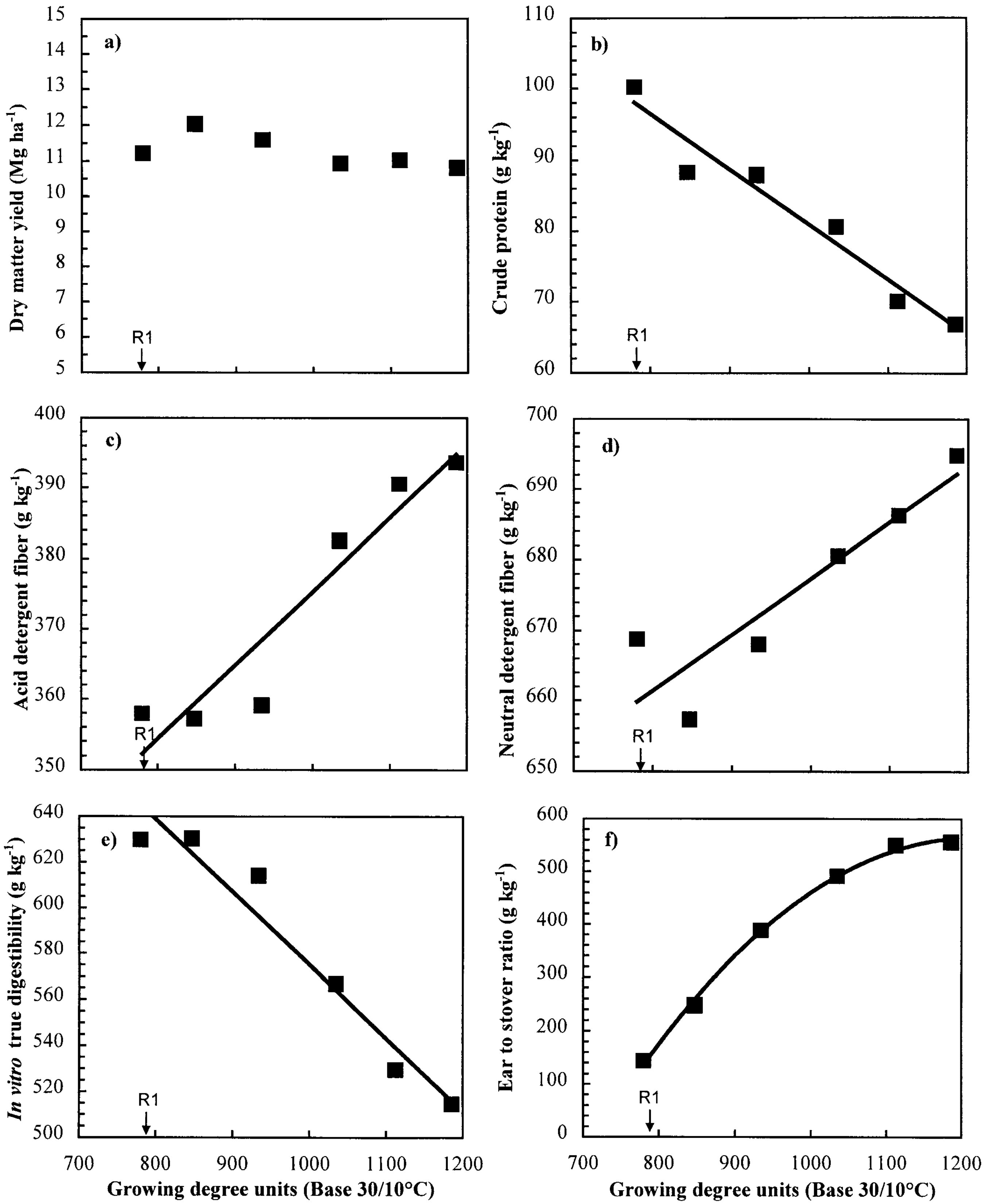

Fig. 2. Relationship between stover (a) dry matter yield, (b) crude protein (CP) concentration, (c) neutral detergent fiber (NDF) concentration, (d) acid detergent fiber (ADF) concentration, (e) in vitro true digestibility (IVTD) concentration, and (f) ear/stover ratio and growing degree units (GDUs). Each data point is the mean across four hybrids, four replicates, and 2 yr. Equations and coefficients of determination (R^2) for Fig. 2 are reported in Table 3. R1 refers to the growth stage of the corn when silks were emerged on at least 50% of the plants.

process affected the chemical composition of the forage plants, and quality was lower compared with fresh forage.

The results from this experiment suggest that yield, quality, and performance indices will remain at 95% of optimum if corn forage is harvested between 700 and 600 g kg^{-1} moisture, which encompassed a time interval of 15 d or 134 GDUs. Milk per hectare and yield were still at 95% of maximum when the concentration of moisture declined below 600 g kg^{-1} moisture.

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