Plant Density and Hybrid Influence on Corn Forage Yield and Quality

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ABSTRACT

Corn (*Zea mays* L.) hybrid selection and plant density are important management considerations for successful forage production in dairy and livestock operations. The objectives of this study were (i) to determine the effect of plant density on high- and low-quality corn hybrids and (ii) to describe the economic trade-off between plant density and forage yield and quality. Two adapted hybrids selected for high and low quality characteristics were grown in the field at five plant densities ranging from 44 500 to 104 500 plants ha^{-1} at six locations in Wisconsin during 1994, 1995, and 1996. Forage quality response among hybrids was similar across the range of plant densities evaluated. As plant density increased, dry matter yield increased 1.7 to 4.1 Mg ha^{-1}, depending on location. Maximum dry matter yields were observed at 97 300 to 102 200 harvested plants ha^{-1}. In vitro true digestibility decreased 16 to 23 g kg^{-1} as plant density increased. Crude protein decreased 6 to 8 g kg^{-1} as plant density increased. Neutral-detergent fiber increased 20 to 35 g kg^{-1}, and acid-detergent fiber increased 19 to 29 g kg^{-1} with increasing plant density. A trade-off exists between yield and quality for corn forage. Milk Mg^{-1} decreased 98 to 143 kg milk Mg^{-1} with increasing plant densities, but milk ha^{-1} increased 926 to 2176 kg milk ha^{-1} until about 75 000 to 85 000 harvested plants ha^{-1}, and did not change with higher plant densities.

CORN is a high-yield, high-energy forage produced with lower labor and machinery requirements than other forage types (Roth et al., 1995). Corn is a primary source of energy in the Wisconsin dairy industry, and its nutritive value is related to digestibility (Carter et al., 1991). Many environmental, cultural, and genetic factors influence corn forage yield and quality.

Deinum and Bakker (1981) found digestibility differences among corn hybrids. In France, Barriére et al. (1995) found a variation of 1.0 to 2.0 kg of milk per day when dairy cows (*Bos taurus*) were fed genotypes with low and high digestibility values.

Corn hybrids respond differently to high plant density (Phipps and Weller, 1979; Pinter et al., 1994). Nafziger (1994) suggested that newer hybrids have greater grain yield at higher plant densities than older hybrids. Newer hybrids seem to be more tolerant to plant stress at higher plant density than older hybrids (Tollenaar, 1992).

The relationship between corn forage yield and plant density is not established. Total dry matter increases 6 to 40% when plant density increases from about 55 000 to 88 000 plants ha^{-1} (Rutger and Crowder, 1967; Karlen et al., 1985). Olson and Sander (1988) indicated that optimum plant density may differ between corn grain and forage production with higher plant densities favoring forage rather than grain yield. Cox and Otis (1993) reported maximum dry matter yield at 81 500 plants ha^{-1} and maximum grain yield at 74 100 plants ha^{-1}. However, maximum forage yields have also been reported at 79 000 plants ha^{-1} (Graybill et al., 1991) and 100 000 plants ha^{-1} (Sparks, 1988).

Even though corn forage yield may have a greater optimum plant density than corn for grain, forage quality losses at high plant density have been reported (McAllan and Phipps, 1977). As plant density increases from 18 500 to 143 300 plants ha^{-1}, in vitro true digestibility decreases (Sanderson et al., 1995; Jones et al., 1995). The negative relationship between plant density and corn forage quality makes it difficult to recommend plant density for optimum animal performance based on yield. The objectives of this study were (i) to determine the effect of plant density on high- and low-quality corn hybrids and (ii) to describe the economic trade-off between plant density and forage yield and quality.

MATERIALS AND METHODS

Experiments were conducted from 1994 to 1996 at six locations in Wisconsin. The locations were grouped into three production zones. In the southern zone, the soil at Lancaster was a Rozetta silt loam (fine-silty, mixed, mesic Typic Hapludalf), and the soil at Arlington was a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll). In the central zone, the soil at Marshfield was a Withee silt loam (fine-loamy, mixed, mesic Aquic Glossoboralf), and at Valders the soil was a Kewaunee clay loam (fine, mixed, mesic Typic Hapludalf). In the northern zone, the soil at Spooner was an Antigo silt loam (fine-silty over sandy or sandy skeletal, mixed Typic Glossoboralf), and the soil at Ashland was Manistee loamy sand (sandy over clayey, mixed, frigid Alfic Haplorthod).

The experimental design was a randomized complete block in a split-plot treatment arrangement with four replications. Experiments were planted on different land areas between years. Main plots were target plant densities of 44 500, 59 500, 74 500, 89 500, and 104 500 plants ha^{-1}. Split-plots were two corn hybrids of known quality characteristics (J.G. Coors, personal communication, 1994) and adapted to one of the corn production zones. Pioneer '3921' and Pioneer '3902' were planted in the northern zone, Pioneer '3757' and Jacques '4120' in the central zone, and Cargill '4327' and Pioneer '3417' in the southern zone. Hybrids selected for lower fiber and higher in vitro digestibility (high quality) characteristics were Pioneer 3921, Pioneer 3757, and Cargill 4327. Split-plot size was 3.1 by 7.6 m with four rows per plot. Plots were planted at 125 000 plants ha^{-1} and hand-thinned to target plant densities. Farming practices for the experiment in each location were similar to those of the surrounding area (Table 1).

The two center rows of each plot were harvested when kernel milkline was between 50 and 75% (Wiersma et al., 1993), or following the occurrence of a killing frost. At harvest, a sample of five consecutive plants was collected, weighed, chopped, and mixed. A 1-kg subsample was dried at 75°C for 7 d and retained for quality analysis. The remaining plants

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Published in Agron. J. 91:911–915 (1999).

Abbreviations: ADF, acid-detergent fiber; NDF, neutral-detergent fiber.

Table 1. Field characteristics and cultural practices for six Wisconsin locations (1994–1996) where the corn hybrid by plant density study was conducted.

Location	Year	Previous crop†	Soil test pH	Soil test P	Soil test K	N fertilizer rate	Planting date	Harvest date	Frost date (<0°C)
				— mg kg^{-1} —		kg ha^{-1}			
				Southern Wisconsin					
Lancaster	1994	corn	7.1	90	275	94	4 May	20 Sept.	27 Oct.
	1995	corn	7.1	31	190	166	6 May	12 Sept.	23 Sept.
	1996	corn	7.1	90	275	185	6 May	25 Sept.	3 Oct.
Arlington	1994	soybean	6.5	72	195	39	21 Apr.	4 Sept.	10 Oct.
	1995	soybean	6.4	47	185	80	1 May	11 Sept.	22 Sept.
	1996	soybean	6.7	62	205	78	26 Apr.	10 Oct.	2 Oct.
				Central Wisconsin					
Marshfield	1994	corn	6.9	31	145	394‡	7 May	23 Sept.	10 Oct.
	1995	alfalfa/hay	6.8	35	118	63	5 May	25 Sept.	22 Sept.
	1996	corn	6.8	35	128	25	22 May	15 Oct.	2 Oct.
Valders	1994	corn	7.7	26	145	111	6 May	19 Sept.	27 Oct.
	1995	barley	7.6	21	160	270‡	12 May	17 Sept.	23 Sept.
	1996	alfalfa	7.3	53	179	270‡	15 May	4 Oct.	8 Oct.
				Northern Wisconsin					
Spooner	1994	alfalfa	5.8	17	103	116	6 May	16 Sept.	9 Oct.
	1995	corn	6.6	12	55	57	11 May	13 Sept.	21 Sept.
	1996	corn	6.6	22	68	54	10 May	2 Oct.	2 Oct.
Ashland	1994	alfalfa	7.1	192	300	52	10 May	5 Oct.	2 Oct.
	1995	corn	6.8	175	148	77	18 May	20 Sept.	23 Sept.
	1996	corn	6.8	175	148	103	13 May	3 Oct.	2 Oct.

† Alfalfa: *Medicago sativa* L.; soybean: *Glycine max* (L.) Merr.; barley: *Hordeum vulgare* L. Wheat: *Triticum aestivum* L.; corn: *Zea mays* L.
‡ Manure application.

in each plot were hand-harvested and weighed to determine forage yield.

Forage was analyzed for in vitro true digestibility (Goering and Van Soest, 1970) as modified by Coors et al. (1997). Crude protein was calculated by multiplying total Kjeldahl N (Bremner and Breitenbeck, 1983) by 6.25. Neutral-detergent fiber (NDF) and acid-detergent fiber (ADF) were determined by the procedure of Robertson and Van Soest (1981). Neutral-detergent fiber and in vitro true digestibility (IVTD) were used to calculate cell wall digestibility (CWD) (Van Soest, 1994) by the following equation:

$$CWD = \left[\frac{NDF - (1000 - IVTD)}{NDF}\right] \times 1000 \quad [1]$$

Although animal feeding trials are the best methods for evaluating silage value, these are expensive and are not practical when evaluating a large number of hybrids and/or agronomic treatments. Therefore, alternative methods to evaluate economic value of forages have been developed by many researchers (Shenk, 1975; Rohweder et al., 1978; Miller, 1988; Lippke and Herd, 1994). The performance indices of milk Mg^{-1} (kg milk Mg^{-1} of corn forage) and milk ha^{-1} (kg milk ha^{-1} of corn forage) were used to evaluate the economic tradeoff between treatments (Undersander et al., 1993). Milk Mg^{-1} was predicted using in vitro true digestibility, crude protein, and NDF values from equations for feed intake and animal requirements for a standard dairy cow with 613 kg of body weight producing 36 kg of milk per day at 3.8% fat. Milk ha^{-1} is the product of milk Mg^{-1} and dry matter yield of corn forage.

Since different hybrids were used in each production zone, data were analyzed across locations and years within a production zone. All data were analyzed using analysis of variance where location and year were considered random effects within each production zone. Analysis of variance for each zone was calculated using the General Linear Model procedure of SAS (SAS Inst., 1982). 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 ($P < 0.05$). Regression analysis was used to examine the relationship plant density at harvest and dry matter yield, quality traits, and performance indices. Regression coefficients were described when significant ($P < 0.05$).

RESULTS AND DISCUSSION

Within a production zone, no location or year interactions with treatment effects were observed in this study. Few interactions were observed between treatment effects. A plant density × hybrid interaction for dry matter yield in the northern zone was observed. Pioneer 3902 achieved a maximum yield at 86 800 plants ha^{-1} and declined as plant density increased further, while dry matter yield of Pioneer 3921 increased through the entire range of plant density treatments. Plant density × hybrid interactions for dry matter yield have been observed previously by Graybill et al. (1991), Cox (1996), and Pinter et al. (1994). A plant density × hybrid interaction was observed for ADF in the southern zone.

Since few interactions were found, and when detected were minimal in relation to main effects, we suggest that differences for hybrid quality varied in a similar manner across this range of plant densities. This coincides with Cummins and Dobson (1973), who reported no plant density × hybrid maturity interaction for in vitro dry matter digestibility. Graybill et al. (1991) likewise found no plant density × hybrid interaction for NDF, ADF, and crude protein.

Coors et al. (1994) reported that forage dry matter yield and quality traits are genetically variable in corn germplasm. Hybrid differences in dry matter yield have been documented (Fairey, 1980; Deinum, 1988). In this study, no hybrid differences for dry matter yield were

Table 2. Corn hybrid forage yield and quality response in Wisconsin (1994–1996).†

Hybrid	Harvested plant density	DM yield	IVTD	CP	NDF	ADF	Cell wall digestibility	Milk Mg^{-1}	Milk ha^{-1}
	plants ha^{-1}	Mg ha^{-1}	g kg^{-1}					kg Mg^{-1}	kg ha^{-1}
				Southern Wisconsin‡					
Cargill 4327	75 800	19.5	772	71	443	221	485	1023	19 980
Pioneer 3417	73 200	19.3	763	72	471	232	497	937	17 949
LSD (0.05)	1 420	NS	6	1	12	6	6	43	1 103
				Central Wisconsin					
Pioneer 3757	73 600	14.7	812	75	417	199	524	1192	17 694
Jacques 4120	71 900	14.7	796	70	452	212	546	1071	15 747
LSD (0.05)	1 520	NS	5	2	10	6	8	34	837
				Northern Wisconsin					
Pioneer 3921	73 700	17.1	735	68	511	265	480	768	13 073
Pioneer 3902	74 400	17.2	730	68	513	268	474	749	12 825
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

† DM, dry matter; HI, harvest index; IVTD, in vitro true digestibility; CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber.
‡ Southern Wisconsin: Lancaster and Arlington. Central Wisconsin: Marshfield and Valders. Northern Wisconsin: Spooner and Ashland.

measured (Table 2). Differences were detected for quality, and were similar to previously described characteristics of the hybrids.

In vitro true digestibility differences between hybrids were detected in the southern and central zones (Table 2). This confirms earlier findings of hybrid differences for digestibility (Vattikonda and Hunter, 1983; Allen et al., 1991; Deinum and Bakker, 1981; Hunt et al., 1993). Our results were in the range reported by Vattikonda and Hunter (1983), who found that digestibility variation among 28 hybrids was from 772 to 818 g kg^{-1}.

Carter et al. (1991) stated that protein is not considered a major factor for corn forage evaluation, due to the low protein concentration of corn compared with legume forages. In this study, protein concentration was low in all zones. Significant crude protein differences between hybrids were found in the southern and central zones (Table 2).

Hybrids with the greatest in vitro true digestibility concentrations in the southern and central zone also had the least NDF and ADF concentrations (Table 2). In the northern zone, no hybrid differences were detected for in vitro true digestibility, nor for NDF and ADF concentrations. In general, these NDF and ADF values are in the range of those reported by Allen et al. (1991), who observed variations from 364 to 455 g kg^{-1} for NDF and from 174 to 220 for ADF among 32 hybrids. Hunt et al. (1992) found that forage NDF varied from 417 to 490 g kg^{-1} and ADF from 239 to 283 g kg^{-1}. Hybrids with greater in vitro true digestibility had less cell wall digestibility in the southern and central zones.

The previously identified high-quality hybrids, Cargill 4327, Pioneer 3757, and Pioneer 3921, produced 86, 121, and 19 more kg milk Mg^{-1} than corresponding low-quality hybrids in the southern, central, and northern zones, respectively (Table 2). Barriére et al. (1995) found a 480 kg milk Mg^{-1} variation when dairy cows were fed genotypes with low and high digestibility. Likewise, these hybrids yielded 2286, 1947, and 248 more kg milk ha^{-1} in the southern, central, and northern zones, respectively, even though they had similar forage yields. The conclusion that yield and quality should be taken in consideration when selecting hybrids for forage, as reported by Deinum and Bakker (1981), Deinum (1988), and Roth (1994), was also supported by this study.

Numerous workers have found that dry matter yield is maximized from 80 000 to 100 000 plants ha^{-1} (Fairey, 1982; Cox, 1996, 1997; Pinter et al., 1990, 1994; Graybill et al., 1991). Dry matter yield increased as plant density increased in a linear fashion in the central zone and in a quadratic fashion in the southern and central zones (Table 3). High R^2 values in all zones indicates a close relationship between dry matter yield and plant density.

Table 3. Regression equations for corn forage yield and quality in Wisconsin (1994–1996). Data were pooled across year, location within a production zone, hybrid, and replication (n = 48) and regressed against harvested plant density (n = 5).

Trait†	Regression equation‡	R^2
	Southern Wisconsin§	
DM yield, Mg ha^{-1}	$y = 6.55 + 0.287x‡ - 0.00144x^2$	0.99
IVTD, g kg^{-1}	$y = 792 - 0.333x$	0.95
CP, g kg^{-1}	$y = 796 - 0.111x$	0.88
NDF, g kg^{-1}	$y = 426 + 0.411x$	0.88
ADF, g kg^{-1}	$y = 199 + 0.375x$	0.94
CW digestibility, g kg^{-1}	$y = 513 - 0.291x$	0.86
Milk, kg Mg^{-1}	$y = 1120 - 1.89x$	0.93
Milk, kg ha^{-1}	$y = 9850 + 225x - 1.29x^2$	0.97
	Central Wisconsin	
DM yield, Mg ha^{-1}	$y = 12.4 + 0.0318x$	0.89
IVTD, g kg^{-1}	no significant coefficients	—
CP, g kg^{-1}	no significant coefficients	—
NDF, g kg^{-1}	$y = 401 + 0.465x$	0.60
ADF, g kg^{-1}	no significant coefficients	—
CW digestibility, g kg^{-1}	no significant coefficients	—
Milk, kg Mg^{-1}	$y = 1270 - 1.89x$	0.93
Milk, kg ha^{-1}	no significant coefficients	—
	Northern Wisconsin	
DM yield, Mg ha^{-1}	$y = 5.25 + 0.267x - 0.00134x^2$	0.99
IVTD, g kg^{-1}	$y = 760 - 0.363x$	0.88
CP, g kg^{-1}	$y = 78 - 0.135x$	0.91
NDF, g kg^{-1}	$y = 468 + 0.599x$	0.92
ADF, g kg^{-1}	$y = 230 + 0.494x$	0.92
CW digestibility, g kg^{-1}	no significant coefficients	—
Milk, kg Mg^{-1}	$y = 933 - 2.35x$	0.92
Milk, kg ha^{-1}	$y = 6720 + 166x - 1.03x^2$	0.96

† DM, dry matter; HI, harvest index; IVTD, in vitro true digestibility; CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; CW digestibility, cell wall digestibility.
‡ x = 1000 plants ha^{-1}.
§ Southern Wisconsin: Lancaster and Arlington. Central Wisconsin: Marshfield and Valders. Northern Wisconsin: Spooner and Ashland.

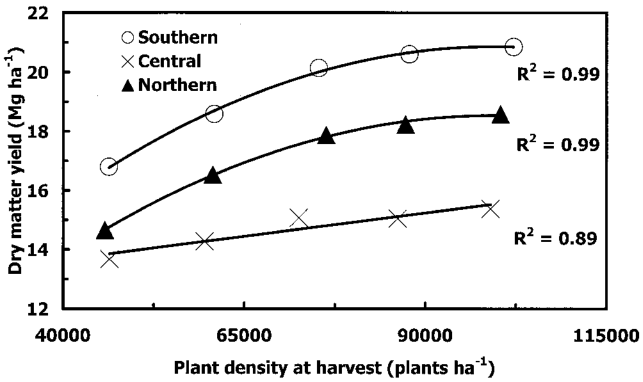

Fig. 1. Relationship between corn forage dry matter yield and plant density at harvest in three Wisconsin production zones (1994–1996). Data are averaged across year, location, hybrid, and replication; each point is the mean of 48 plots. For regression equations, see Table 3.

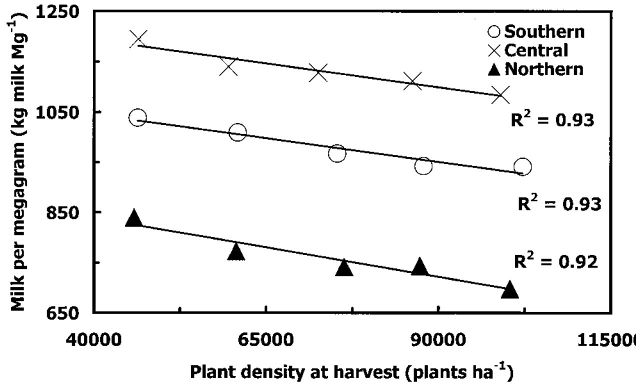

Fig. 2. Relationship between corn forage milk Mg^{-1} and plant density at harvest in three Wisconsin production zones (1994–1996). Data are averaged across year, location, hybrid, and replication; each point is the mean of 48 plots. For regression equations, see Table 3.

Plant densities of 97 300 to 102 200 were found to maximize dry matter yield in all zones (Fig. 1), although the linear response for the central zone indicates that greater dry matter yield would have been obtained if greater plant densities were included in the study. However, yield increased at a slower rate for plant densities above 75 300 and 76 300 plants ha^{-1} in the southern and northern zone, respectively.

Linear responses best explained the relationship between most forage quality parameters and plant density in the southern and northern zones (Table 3). Only NDF exhibited a linear relationship in the central zone.

A negative linear relationship between forage in vitro true digestibility and plant density was observed in the southern and northern zones (Table 3). Similar to Sanderson et al. (1995), forage in vitro true digestibility was greater at lower plant densities in all zones. Averaged across zones and years, in vitro true digestibility decreased about 0.35 g kg^{-1} for each 1000 plant ha^{-1} increase in plant density. Cell wall digestibility decreased as plant density increased in the southern zone, but was not affected by plant density in the central and northern zones.

Crude protein had a negative linear response in the southern and northern zones (Table 3). The crude protein range was 65 to 78 g kg^{-1} across plant densities. Depending on the zone, crude protein decreased at the rate of 0.11 to 0.13 g kg^{-1} for each 1000 plants ha^{-1} increase, which is consistent with findings of Sanderson et al. (1995).

A positive linear relationship between NDF and plant density in all zones and between ADF and plant density in the southern and northern zones (Table 3) suggest that increasing plant density lowers quality by increasing fiber content in the plant. Plant density has been previously shown to affect NDF (Sanderson et al., 1995; Graybill et al., 1991). Phipps and Weller (1979) reported that ADF content increased with higher plant densities.

Milk Mg^{-1} decreased 98 to 143 kg milk Mg^{-1} as plant density increased (Fig. 2). Milk ha^{-1} increased 926 to 2176 kg milk ha^{-1} up to about 75 000 harvested plants ha^{-1}, and did not change with higher plant densities (Fig. 3). A close relationship between plant density and milk Mg^{-1} was observed (Fig. 2 and Table 3). Milk Mg^{-1} decreased linearly at the rate of 1.89 kg milk Mg^{-1} in the southern and central zones, and 2.35 kg milk Mg^{-1} in the northern zone for each 1000 plants ha^{-1} increase in plant density. The relationship between plant density and milk ha^{-1} was best explained using a quadratic model ($R^2 = 0.96$) in both southern and northern zones (Table 3). Maximum milk ha^{-1} was produced at plant densities of 75 000 to 85 000 plants ha^{-1} in these two zones. No relationship was observed between milk ha^{-1} and plant density in the central zone.

CONCLUSIONS

Plant density × hybrid interactions were not observed for most quality traits in all zones, suggesting that hybrid quality response would be similar across the range of plant densities. Differences were observed between hybrids for quality traits in the southern and central zones. In contrast, both of the hybrids used in the northern zone had similar quality traits.

The response of dry matter yield to plant density was quadratic with maximum dry matter production between 97 300 and 102 200 plants ha^{-1}. Forage quality decreased as plant density increased. In vitro true digestibility and crude protein were greatest at the lowest

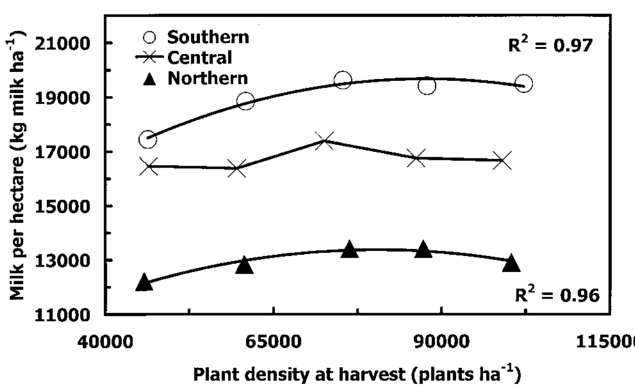

Fig. 3. Relationship between corn forage milk ha^{-1} and plant density at harvest in three Wisconsin production zones (1994–1996). Data are averaged across year, location, hybrid, and replication; each point is the mean of 48 plots. For regression equations, see Table 3.

plant densities, and NDF and ADF increased with increasing plant densities. Maximum milk Mg^{-1} was obtained at the lowest plant density in all zones. Since yield increased and quality decreased with increasing plant density in this study, an economic tradeoff existed between forage production and animal performance. Maximum milk produced per unit land area occurred at plant densities of 75 000 to 85 000 harvested plants ha^{-1} and would be desirable for corn forage production in Wisconsin. These plant densities are approximately 6000 plants ha^{-1} greater than current recommendations for corn grain production.

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