Influence of population density, row spacing and hybrid on forage corn yield and nutritive value in a cool-season environment

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Baron, V. S., Najda, H. G. and Stevenson, F. C. 2006. **Influence of population density, row spacing and hybrid on forage corn yield and nutritive value in a cool-season environment.** Can. J. Plant Sci. **86**: 1131–1138. Increasing yield for silage and grazing in cool, short-season areas may be possible by planting corn (*Zea mays* L.) at high population densities and at narrow row spacing. The objective was to determine how population density (75 000, 100 000, and 125 000 plants ha^{-1}) and row spacing (standard: 76 cm and narrow: 38 cm) affected whole-plant yield, yield-related parameters, and nutritive value of two corn hybrids grown at Brooks and Lacombe, Alberta during 2 yr. The hybrids (Pioneer 39F45 and 39N03) were rated at 2000 Ontario corn heat units (CHU). Trial, hybrid, population density and row spacing interacted to influence whole-plant yield. Population density had a greater impact on whole-plant yield than row spacing and hybrid choice. Generally, yield leveled off at 100 000 plants ha^{-1} when the interaction of all effects was considered. Leaf area index (LAI) and whole-plant yield at this density were 2.68 and 12.0 Mg ha^{-1}, respectively. Narrow compared with standard row spacing had positive effects on whole-plant yield of one hybrid, but not the other and improved LAI at 75 000 plants ha^{-1}, but not at the other plant densities. Increasing plant density and reducing row spacing had only minor effects on whole-plant nutritive value. Growing corn in narrow rows to accommodate prevalent planting equipment should have no adverse effects on whole-plant corn production in short-season areas of Canada. However, when considering changes in corn management to maximize whole-plant yield narrow row spacing is not as important as achieving a plant density of approximately 100 000 plants ha^{-1}.

Key words: Corn, *Zea mays* L., nutritive value, population density, row width, silage yield

Baron, V. S., Najda, H. G. et Stevenson, F. C. 2006. **Influence de la densité du peuplement, de l'écartement des rangs et de la variété sur le rendement et la valeur nutritive du maïs fourrager cultivé en saison fraîche**. Can. J. Plant Sci. **86**: 1131–1138. On pourrait accroître la récolte d'ensilage et améliorer la paissance du maïs (*Zea mays* L.) dans les régions caractérisées par une courte période végétative et une saison fraîche en augmentant la densité de peuplement et en réduisant l'espacement entre les rangs. L'étude devait établir comment la densité du peuplement (75 000, 100 000 et 125 000 plants par hectare) et l'écartement des rangs (normal, 75 cm, et réduit, 38 cm) affectent le rendement en plants entiers, les paramètres du rendement et la valeur nutritive de deux hybrides cultivés à Brooks et à Lacombe (Alberta) pendant deux ans. Les deux variétés utilisées (Pioneer 39F45 et 39N03) étaient cotées à 2 000 unités thermiques du maïs. L'essai, la variété, la densité du peuplement et l'écartement des rangs interagissent pour modifier le rendement en plants entiers. La densité du peuplement agit plus sur ce facteur que l'écartement des rangs et le choix du cultivar. En général, quand on prend en compte les différents effets et leur interaction, on constate un plafonnement du rendement à 100 000 plants par hectare. À cette densité, l'indice foliaire et le rendement en plants entiers s'établissent respectivement à 2,68 et à 12,0 Mg par hectare. L'écartement réduit a eu une incidence positive sur le rendement en plants entiers d'une variété mais pas sur celui de l'autre cultivar. L'indice foliaire était également supérieur à la densité de 75 000 plants par hectare, mais pas aux autres densités. Accroître la densité de peuplement et rapprocher les rangs n'ont qu'une incidence mineure sur la valeur nutritive du plant entier. La culture du maïs en rangs rapprochés pour accommoder le matériel de plantation prévalent ne devrait avoir aucune incidence négative sur la production de plants de maïs entiers dans les régions du Canada connaissant une courte période végétative. Toutefois, lorsqu'on envisage la modification des pratiques culturales pour maximiser le rendement en plants entiers, on se rappellera qu'un écartement réduit ne revêt pas autant d'importance qu'une densité de peuplement d'environ 100 000 plants par hectare.

Mots clés: Maïs, *Zea mays* L., valeur nutritive, densité de peuplement, espacement des rangs, rendement en ensilage

Interest in growing corn for silage and grazing is increasing in areas of less than 2300 CHU (Dwyer et al. 1999). This interest has spawned from the introduction of corn hybrids that mature prior to 2100 CHU, warmer than normal temperatures on the Canadian prairies over the decade of 1990s, and increasing use of corn for fall and winter grazing (Willms et al. 1993; Baron et al. 2003).

Winter grazing of beef cows can reduce costs associated with harvesting, hauling, and storage of feed, and manure removal (McCartney et al. 2004). Further savings are achieved if cows go into confined feeding in good, rather

Abbreviations: **ADF**, acid detergent fiber; **CHU**, corn heat units; **IVDOM**, in vitro digestible organic matter; **LAI**, Leaf area index; **NDF**, neutral detergent fiber than poor body condition (Willms et al. 1993). For example, a savings of \$0.70 per feeding day accrued for swath-grazed cows compared with cows fed in winter confinement (McCartney et al. 2004). Also, \$47.00 was saved per cow wintered during traditional winter feeding in southern Alberta after cows fall-grazed standing corn and winter wheat compared to native range (Willms et al. 1993).

Until recently, growing corn for silage was limited to areas above 2100 to 2200 CHU, because the earliest corn hybrids were rated for grain maturity at approximately 2300 CHU (Daynard 1978; Major and Hamilton 1978). Corn hybrids requiring 2300 CHU often failed to reach 300 g kg^{-1} whole plant dry matter concentration prior to the first fall frost when grown under cool conditions (Daynard 1978). The last pertinent literature review (Daynard 1978) indicated that feeding immature corn silage had negative effects on voluntary intake and ensiling it in tower silos resulted in excessive seepage losses and even freezing.

The best management options for short-season corn producers are to choose large and vigorous hybrids and grow them at plant densities greater than ideal for grain production (Daynard 1978). The optimum population density for short-season corn production is determined by plant size and leaf area per plant (Hunter 1980; Daynard and Muldoon 1981). Plant size and leaf area have been reduced as hybrids are selected for early silking dates in an attempt to arrive at grain maturity within short growing seasons (Daynard and Muldoon 1981). Thus, higher densities are required for smaller, earlier-maturing hybrids than for taller, later and leafier ones to maximize yield (Daynard and Muldoon 1981; Duncan 1984).

Increasing plant density (e.g., 40 000 to 100 000 plants ha^{-1}) in corn is a method used to increase grain and whole-plant yield, because in the process, LAI, light interception and crop growth rate are increased (Tollenaar and Bruulsema 1988; Cox 1996). Studies conducted using standard (76-cm) row spacing resulted in whole-plant yield increases of 25% in southern Manitoba (Baron et al. 1987), 9 to 33% in Wisconsin (Cusicanqui and Lauer 1999) and 10 to 26% in New York (Cox 1996; Cox et al. 1998) as plant population densities increased over a range from 45 000 to 105 000 plants ha^{-1}. However, Daynard and Muldoon (1981) observed a 10% increase in whole-plant yield as plant densities increased from 50 000 to 63 000 plants ha^{-1} in south-central Ontario.

A smaller (2 to 8%) and possibly less reliable improvement in corn whole-plant yield may be obtained by growing corn in narrow rows (Hunter et al. 1970; Cummins and Dobson 1973; Cox et al. 1998; Cox and Cherney 2001). This practice is thought to be more of an advantage in northern compared with southern areas of North America (Cox et al. 1998). In areas where corn is adapted, there are concerns about costs of equipment conversion when moving to narrower (e.g., 30- or 50-cm rows) from standard row spacing, when yield improvement is small and uncertain (Stewart 2003). However, on the northern fringes of the corn-growing region of the Canadian Prairies, small grain seeding equipment has row spacing ranging from 15 to 30 cm. While adapting harvesting equipment may be important for silage production, this equipment does not play a role in grazing. Thus, a more critical concern in short-season areas is whether corn might yield less whole-plant dry matter when planted in narrow than in conventional row widths.

Increasing plant densities increase whole-plant fiber concentrations and slightly decrease digestibility, resulting in lesser animal production such as reduced milk yield per cow compared with the lower population densities used for grain production (Cox et al. 1998; Cusicanqui and Lauer 1999). This may offset the potential gain in whole-plant yield with increasing plant density.

The objective of the present study was to determine the impact of row spacing and population density on whole-plant yield and nutritive value with two ultra-early corn hybrids at two short-season locations in Alberta.

MATERIALS AND METHODS

Research sites were established on a loamy Black Orthic Chernozem soil at Lacombe, AB (52° 28′N; 113° 45′W; 847 m) in 2002 and 2003 and on a silt loam Brown Orthic Chernozem soil at Brooks, AB (50° 33′N; 111° 51′W; 747 m) in 2001 and 2002.

Hybrid, population density, and row spacing treatments were randomized within each of three replicates. Plots were 3.05 × 6 m. The two early corn hybrids were Pioneer 39N03 and Pioneer 39F45 (Pioneer Hi-Bred Ltd., Chatham, ON), both rated at 2000 CHU maturity. Corn was planted on 2001 May 09 and 2002 May 15 at Brooks, and on 2002 May 16 and 2003 May 21 at Lacombe. Population densities were 75 000, 100 000 and 125 000 plants ha^{-1}. Each plot had four rows for standard (76-cm) and eight rows for the narrow (38-cm) row spacing.

Prior to planting, fertilizer was broadcast and incorporated at 200 kg N ha^{-1}, 40 kg P_2O_5 $ha^{-1}$and 40 kg K_2O ha^{-1}. Seed was double-planted by hand and plants were thinned to the target population just prior to the six-leaf stage. Weeds were controlled chemically, with a pre-formulated mixture of 640 g ha^{-1} a.i. bentazon [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] plus 640 g ha^{-1} a.i. atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] applied in-crop at a rate of 3.2 L ha^{-1} of product. Surviving weeds not controlled with herbicides were hand-weeded to keep plots weed-free.

Plants were counted within a pre-designated row for silk emergence and were monitored every 2 to 3 d to determine the date at which 50% of silks had emerged. Leaf area index was determined within 2 wk of silking using a LAI-2000 plant canopy analyzer (Li-COR Ltd. Lincoln, NE.). Ten readings were taken at least 1 m from the edge of the plot.

Corn was harvested on 2002 Sept. 26 and 2003 Sep. 08 at Lacombe, and on 2001 Sep. 12 and 2002 Sep. 13 at Brooks. Eight plants from each plot were clipped at ground level at harvest time and weighed fresh. Five of these eight plants were separated into stover and ear components and each component was weighed fresh. The five-plant stover and ear samples were chopped mechanically, and a 250-g subsample of each weighed fresh and after drying for 96 h at 50°C to determine dry matter percentage of the respective components. Dry matter yields of the ear and stover components were added, and adjusted for population density of the plots, to determine whole-plant dry matter yield. Whole-plant and ear dry matter concentrations were calculated from the fresh and dry weights of respective components described above. Dried sub-samples were retained for forage quality assays.

Forage Quality Assays

Dried sub-samples of stover and ear were ground, with a Wiley mill (Model no. 4; Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen prior to quality determination. Total N concentration of samples was measured using the Dumas combustion method (Etheridge et al. 1998) with a Leco carbon and N determinator (Model CN 2000, Leco Corp., St. Joseph, MI). Crude protein was estimated by multiplying N concentration by 6.25. In vitro digestible organic matter concentration (IVDOM) was measured with direct acidification during a 24-h second-stage pepsin digestion (Marten and Barnes 1980). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined separately (Van Soest and Robertson 1980). The IVDOM, NDF, and ADF procedures were modified for a filter bag system (ANKOM Technology Corporation; Fairport, NY) similar to that described by Vogel et al. (1999). Alpha amylase (ANKOM Technology – FAA) and sodium sulfite (ANKOM Technology – FSS) were used in determination of NDF as described in ANKOM Technology 8/98. Whole-plant quality was estimated from a weighted concentration of the stover and ear concentrations.

Statistical Analyses

Data were analyzed in accordance with the randomized complete block design using the PROC MIXED procedure of SAS software (Littel et al. 1996). The hybrid, population density, row spacing management, and trial (location × year combinations) were considered to be fixed effects, and replicate was considered to be a random effect. Model fit criteria (Littel et al. 2002) indicated that a model with a common variance estimate for all trials was best for the variables analyzed in this study. Thus trials were combined in the statistical analyses. Treatment effects were declared significant at $P < 0.05$. The Least significant difference (LSD) is used to determine differences between two designated means after declaration of significance within analyses of variance. When shown in the text or tables it has been determined at the 5% level of significance.

RESULTS AND DISCUSSION

Climate

Rainfall was well below average for three trials and near normal at Brooks in 2002 (Table 1). Irrigation is a common practice in the Brooks area and carried out in both years (Table 1). During 2002 at Lacombe low rainfall early in the season probably reduced whole-plant yield. During 2003, at Lacombe, spring rainfall and timely rains in August resulted in satisfactory growing conditions despite low season-long rainfall. Corn heat unit accumulations between planting and harvest were near average (Table 1). The late planting date in 2003 at Lacombe was offset by higher than average maximum temperatures in July and August, and by higher than average minimum temperatures during June and August.

Whole-Plant Yield

A significant trial × hybrid × row spacing × population density interaction and some lower order interactions were significant for whole-plant yield (Table 2). A major component of the interaction was reduced yields and lack of response to population density for narrow row spacing at Lacombe in 2002 compared with the other trials (Table 3). Whole-plant yield was 11.3, 12.0 and 12.8 Mg ha^{-1} at 75 000, 100 000 and 125 000 plants ha^{-1}, respectively, with each density significantly different from the other (LSD = 0.4 Mg ha^{-1}), when averaged over row spacing, hybrids and trials. Whole-plant yield increased from 75 000 to 100 000 plants ha^{-1} in two of four trials, from 100 000 to 125 000 plants ha^{-1} in two of four trials and from 75 000 to 125 000 plants ha^{-1} in all trials when averaged over hybrids and row spacing.

The narrow row spacing had 4.2% greater whole-plant yield than standard row spacing (12.3 compared with 11.8 Mg ha^{-1}; LSD = 0.4 Mg ha^{-1}), averaged over plant density, hybrids and trials. Whole-plant yield consistently increased up to 100 000 plants ha^{-1} when planted in either narrow or standard row spacing, when averaged over hybrids. This occurred in three of four trials for narrow row spacing and all trials for standard row spacing.

Pioneer 39F45 out-yielded Pioneer 39N03 by 7.2% (12.4 compared with 11.6 Mg ha^{-1}; LSD = 0.4 Mg ha^{-1}), averaged over plant densities, row spacings and trials. Both hybrids increased whole-plant yield above 75 000 plants ha^{-1} when planted in standard row spacings in half of the trials. Pioneer 39F45 increased whole-plant yield above 75 000 plants ha^{-1} in three of four trials when planted in narrow rows, compared with one of four trials for Pioneer 39N03.

Averaged over trials, whole-plant yield increased above 75 000 plants ha^{-1} at both row spacings for Pioneer 39F45, while yield increased above 75 000 plants ha^{-1} only at the standard row spacing for Pioneer 39NO3 (Table 3). Pioneer 39F45, with narrow row spacing, yielded 22% more when planted at 100 000 plants ha^{-1} than when planted at 75 000 plants ha^{-1} and with standard row spacing. Pioneer 39N03 yielded 18% more when planted at 125 000 plants ha^{-1} than at 75 000 plants ha^{-1}, at standard row spacing.

Cox et al. (1998) found only the main effects of hybrid, row spacing and population density affected whole-plant yield. They also observed a slight yield advantage with narrower row spacing when data were averaged over hybrids and densities, which was similar to the advantage we observed (i.e., 4.2%). In New York State (Cox 1996; Cox et al. 1998) and Wisconsin (Cusicanqui and Lauer 1999) optimum population density for whole-plant yield was about 100 000 plants ha^{-1}. In areas with less than 3000 CHU in Canada (south-central Ontario) maximum whole-plant yields were achieved with densities just above 63 000 plants per ha^{-1} (Daynard and Muldoon 1981). Baron et al. (1987),

Table 1. Average monthly maximum and minimum temperature, monthly precipitation and accumulated corn heat units[z] during 2 yr and long-term averages[y] for Lacombe and Brooks, AB, and irrigation water applied at Brooks, AB

Month	Max. temp. (°C)	Min. temp. (°C)	Precip. (mm)	Max. temp. (°C)	Min. temp. (°C)	Precip. (mm)	Max. temp. (°C)	Min. temp. (°C)	Precip. (mm)
Lacombe	2002			2003			Long-term		
May	15.0	0.5	11.4	15.0	2.3	64.4	16.8	2.9	55.6
June	23.3	7.0	11.9	20.2	8.2	44.2	20.3	7.2	77.6
July	25.2	9.7	38.9	25.3	8.5	10.6	22.3	9.0	91.9
August	20.9	6.5	71.6	25.3	8.9	36.2	21.7	7.7	70.5
September	16.3	2.8	27.4	16.6	3.3	5.0	17.0	3.1	44.1
Total			161.2			160.4			339.7
	Accumulated corn heat units								
	16 May to 26 Sep.			21 May to 8 Sep.			Long-term		
	1827			1987			1855		
Brooks	2001			2002			Long-term		
May	21.3	4.8	9.4	17.1	1.7	2.4	18.7	3.5	41.7
June	22.6	8.3	43.6	22.8	9.5	111.6	23.0	9.8	57.6
July	27.8	11.9	13.8	28.1	11.6	23.2	25.9	11.8	39.0
August	29.8	10.2	1.4	23.0	6.3	53.4	25.2	10.9	37.9
September	22.8	5.7	16.6	18.6	5.2	28.0	18.9	5.8	34.3
Total			84.8			218.6			210.5
	Accumulated corn heat units								
	9 May to 12 Sep.			15 May to 13 Sep.			Long-term		
	2362			2373			2353		
	Irrigation water applied (mm)								
	330			225					

[z] Accumulated corn heat units according to Dwyer et al. (1999).
[y] Long-term averages were determined from the years 1972 to 2002.

Table 2. Analyses of variance results for hybrid, row spacing, population density, trial effects and their interactions

Source	Whole-plant yield	LAI[z]	Ear of whole-plant	Silking date	Whole -plant	Ear	IVDOM	NDF	ADF	Protein
					Dry matter		Concentration			
					P value					
Hybrid (H)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	NS	NS	<0.01
Row spacing (R)	<0.01	<0.01	NS	NS	NS	<0.05	NS	NS	NS	<0.05
H × R	NS[Y]	NS	NS	NS	NS	NS	NS	NS	NS	NS
Density (D)	<0.01	<0.01	<.01	<0.01	<0.01	<0.01	NS	<0.05	NS	NS
H × D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
R × D	NS	<0.05	NS	<0.01	<0.01	NS	NS	NS	NS	NS
H × R × D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Trial (T)	<0.01	<0.01	NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01
T × H	NS	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	<0.01	<0.05	NS
T × R	NS	NS	NS	NS	NS	NS	<0.05	NS	<0.05	NS
T × D	<0.01	<0.05	NS	<0.05	<0.01	NS	<0.05	NS	NS	NS
T × H × R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × H × D	NS	NS	NS	NS	NS	NS	<0.05	NS	NS	NS
T × R × D	<0.01	NS	NS	<0.01	NS	NS	NS	NS	NS	NS
T × H × R × D	<0.01	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] LAI is leaf area index; IVDOM is in vitro digestible organic matter; NDF and ADF are neutral and acid detergent fiber, respectively.
[y] NS is probability for a significant *F* value ≥ 0.05.

on the other hand, found that whole-plant yield was consistently maximized at a population density of 75 000 plants ha^{-1} at sites having CHU typical of the southern part of the Prairie Provinces. However, there is no all-encompassing recommendation for plant population density for all regions and environments within regions, because it is dependent on environmental factors such as soil moisture, and management factors such as soil fertility, hybrid selection and time of planting and harvest (Duncan 1984; Modarres et al 1998) including row spacing (Duncan 1984) and use as grain or silage (Daynard 1978; Daynard and Muldoon 1981).

We found that population densities of 100 000 plants ha^{-1} or greater often were required to maximize whole-plant yield with these earlier-maturing hybrids under Alberta con-

Table 3. Whole-plant dry matter yield for two corn hybrids planted at three plant densities and two row widths at Brooks (2001 and 2002) and Lacombe (2002 and 2003), AB in two years

Hybrid^{Z}	Row spacing (cm)	Population density (plants ha^{-1} × 1000)					
		75	100	125	75	100	125
		Mg ha^{-1}					
		Brooks					
		2001			2002		
Pioneer	38	12.2	12.5	14.0	12.1	14.4	15.3
39F45	76	11.7	14.3	12.7	12.3	12.4	14.4
Pioneer	38	12.1	11.9	12.6	12.5	11.8	15.0
39N03	76	11.5	12.8	13.4	13.1	12.7	14.9
		Lacombe					
		2002			2003		
Pioneer	38	11.0	11.2	10.1	12.0	15.9	14.8
39F45	76	8.3	8.8	11.7	12.3	12.8	12.2
Pioneer	38	9.4	9.2	9.4	12.0	12.8	11.8
39N03	76	9.5	7.6	10.5	8.9	11.4	12.9
LSD^{z}		2.0					

		Population density (plants ha^{-1} × 1000) Average of trials			Significance of population density^{y}
		75	100	125	
		(Mg ha^{-1})			*P*
Pioneer	38	11.8	13.5	13.5	0.001
39F45	76	11.1	12.1	12.8	0.006
Pioneer	38	11.5	11.4	12.2	0.239
39N03	76	10.8	11.1	12.7	< 0.001
LSD^{x}		1.0			

[z] LSD is least significant difference between two means among trials, population densities, row spacings and hybrids at $P < 0.05$.

[y] *P* value for the contrast testing the overall effect of population density for each combination of hybrid and row spacing.

[x] LSD is least significant difference between two means among plant population densities, row spacings and hybrids at $P < 0.05$.

ditions. Short-season hybrids, such as those used in this study, may require greater population densities to maximize yield because of small stature and leaf area per plant (Daynard and Muldoon 1981). Modern corn hybrids such as those used in this study may also have greater population tolerance than those used in previous studies (e.g., Baron et al. 1987). Dwyer et al. (1991) observed improved leaf photosynthetic rates and leaf areas for hybrids released during the 1980s compared with the 1950s and 1960s, which resulted in higher optimum plant densities for yield.

Percentage ear of whole-plant (percent ear) was affected by hybrid, population density, and the hybrid × trial interaction (Table 2). Percent ear decreased as population density increased; percent ear of 75 000, 100 000 and 125 000 plants ha^{-1} densities were 47.3, 43.1 and 41.5%, respectively (LSD = 2.3%). Row spacing had no effect on ear percentage in the present study (Table 2).

Leaf Area Index

The main effects, plant density, row spacing and hybrid, and the interactions, row spacing × plant density, hybrid × trial and plant density × trial were significant for LAI (Table 2). Averaged over row spacing, hybrid and trial, LAI increased from 2.36 at 75 000 plants ha^{-1} to 2.94 at 125 000 plants ha^{-1} and from 2.58 to 2.77 for standard and narrow row spacing, respectively, when averaged over the other factors. Thus, there was an increase in LAI of 25% for plant density and 6% for row spacing. However, the plant density × row spacing interaction was due to a relatively higher increase for LAI to narrow rows at 75 000 plants ha^{-1} (15%) than at 100 000 (4.5%) and 125 000 plants ha^{-1} (2.4%) (Table 4); narrow and standard rows were significantly different at the lowest plant density, only. Significant differences between 75 000 and 100 000 plants ha^{-1} were shown at all trials and between each plant density at two of four trials, averaged over row spacing and hybrid. Pioneer 39NO3 had a 9% higher LAI than Pioneer 39F45 (2.77 vs. 2.54) averaged over plant density, row spacing and trials. This trend was prevalent in three of four trials and significant difference occurred in two of four trials.

The relatively low LAI at 100 000 plants ha^{-1} observed (2.62 and 2.74 for standard and narrow row spacing, respectively) in this study (Table 4) is due to small per plant LAI of the early-maturing hybrids that are required in this short-season area (Hunter 1980). Hunter (1980) suggested that LAI in the range of 2.0 to 2.7 intercepts about 75% of full sunlight. It has been demonstrated that later-maturing and larger hybrids have greater LAI at optimum plant density than earlier ones, and this explains why whole-plant yield is higher (Daynard and Muldoon 1981; Fairey 1982). In many cases, the higher LAI is at optimum plant density, the greater is the expected whole-plant dry matter yield, because crop growth rate is a function of light interception and carbon exchange rate (Hunter 1980; Tollenaar and Aguilera 1991; Cox 1996). Daynard and Muldoon (1981), in Ontario, observed a maximum yield of 14 Mg ha^{-1} at 63 000 plants

Table 4. Leaf area index (LAI), silking date and whole-plant dry matter concentration of short-season corn as influenced by population density and row spacing at Brooks (2001 and 2002) and Lacombe (2002 and 2003), AB

	Population density (Plant ha^{-1} × 1000)		
Row spacing (cm)	75	100	125
		LAI	
38	2.52	2.74	2.97
76	2.20	2.62	2.90
LSD^{z}		0.15	
		Silking date	
		day of year	
38	214	214	215
76	211	217	215
LSD		1.6	
		Whole-plant dry matter concentration	
		g kg^{-1}	
38	344	336	308
76	347	309	307
LSD		14	

^{z}LSD is least significant difference between two means among population densities and row spacings at $P < 0.05$.

ha^{-1} with an LAI of 3 to 4. Cox (1996), in New York, had a maximum yield of 16.5 Mg h^{-1} with an LAI of 4.35 in a dry year and a yield of 20.8 Mg ha^{-1} with LAI of 5.15 in a wet year; optimum plant density in both years was 90 000 plants ha^{-1}. Leaf area index was higher in narrow compared with standard row spacings at 75 000 plants ha^{-1} in the current study (Table 4). Thus, narrow row spacing may be a means of increasing yield slightly at population densities under 100 000 plants ha^{-1}. However, only one of the two hybrids used responded consistently to narrow row width for whole-plant yield (Table 3).

Maturity

Plant density, row spacing and hybrid, and the density × row spacing interaction were significant for silking date, and trial interacted significantly with row spacing × density and with hybrid (Table 2). Silking date was delayed more as plant density increased in standard than narrow row spacing as plant density increased, but corn planted in standard row spacing silked 3 d earlier than narrow row spacing at 75 000 plants ha^{-1} and the reverse at 100 000 plants ha^{-1} (Table 4). The delayed silking date for narrow rows at the lower plant density may be explained by increased shading (i.e., higher LAI), but this does not explain the reversal in silking date at 100 000 plants ha^{-1}, which occurred in two of four trials. Pioneer 39F45 silked approximately 3 d earlier than Pioneer 39N03; the effect was significant in two of four trials.

Whole-plant dry matter concentration was affected by plant density, hybrid and the plant density × row spacing interaction; trial interacted with hybrid and plant density (Table 2). General trends for effect of plant density, row spacing and hybrid on whole-plant dry matter concentration followed those for silking date. Whole-plant material was generally drier with lower plant density; row spacings were similar for whole-plant dry matter concentration at the highest and lowest plant densities, but narrow was significantly drier than standard row spacing at 100 000 plants ha^{-1} (Table 4). Whole-plant dry matter concentration of Pioneer 39F45 was significantly lower than Pioneer 39N03 in two of four trials.

Table 5. In vitro digestible organic matter (IVDOM), neutral (NDF) and acid (ADF) detergent fiber and protein concentration as affected by population density at Brooks (2001 and 2002) and Lacombe (2002 and 2003), AB

	Population density (Plant ha^{-1} × 1000)			LSD^{z}
	75	100	125	
		g kg^{-1}		
IVDOM	712	713	709	NS^{y}
NDF	485	496	498	11
ADF	270	277	280	NS
Protein	73	72	73	NS

^{z}LSD is least significant difference between two means among population densities at $P < 0.05$.

^{y}NS indicates that population density was not significant at the main effect level (Table 2).

Ear dry matter concentration was affected by plant density, row spacing and hybrid and the trial × hybrid interaction (Table 2). Ear dry matter concentration decreased with increased plant density; ear dry matter concentrations for 75 000, 100 000 and 125 000 plant ha^{-1} densities were 435, 404 and 384 g kg^{-1}, respectively (LSD = 13 g kg^{-1}). Reduction of row spacing increased ear dry matter concentration to 414 g kg^{-1} from 400 g kg^{-1} (LSD = 11 g kg^{-1}). There was a trend for Pioneer 39F45 to have slightly drier ears than Pioneer 39N03, but this was significant in only one of four trials.

In the current study, increasing plant density above 75 000 plants ha^{-1} delayed maturity as shown by delayed silking dates (Table 4) and lower whole-plant and ear dry matter concentrations. However, whole-plant dry matter concentrations averaged over trials and hybrids were never below 300 g kg^{-1}. Also in this study, narrow row spacing did not delay maturity as plant density increased, and in fact, had higher whole-plant dry matter concentration than standard row spacing at 100 000 plants ha^{-1}. The problems associated with production of immature corn silage with whole-plant dry matter concentrations less than 300 g kg^{-1} were outlined previously (Daynard 1978). For whole-plant production Fairey (1982) recommended planting short-season corn at 100 000 plants ha^{-1} in spite of low dry matter concentrations. The storage and feeding problems associated with low whole-plant dry matter concentration are associated with silage production (Daynard 1978) and are not necessarily known to limit grazing potential.

Nutritive Value

Influences of plant density, row spacing and hybrid on parameters affecting nutritive value were minor. For IVDOM there was a trial × hybrid × plant density interaction, and each of the main effects interacted significantly with trial (Table 2). There was a trend for reduced IVDOM with increasing plant density (Table 5), but it was not consistent across trials and IVDOM was not significantly different at the main effect level. There were also trends for higher IVDOM with narrow compared with standard row spacing (Table 6) and Pioneer 39F45 compared with Pioneer 39N03

Table 6. In vitro digestible organic matter (IVDOM), neutral (NDF) and acid (ADF) detergent fibre and protein concentration as affected by row spacing or corn hybrid at Brooks (2001 and 2002) and Lacombe (2002 and 2003), AB

	Row spacing (cm)			Hybrid		
	38	76	LSD[z]	Pioneer 39F45	Pioneer 39NO3	LSD[y]
			($g\ kg^{-1}$)			
IVDOM	712	710	NS[x]	716	707	7
NDF	491	495	NS	493	493	NS
ADF	272	279	NS	275	276	NS
Protein	72	74	2	71	75	2

[z] LSD is least significant difference between two means for row spacing at $P < 0.05$.

[y] LSD is least significant difference between two means for hybrid at $P < 0.05$.

[x] NS indicates that row spacing or hybrid was not significant at the main effect level (Table 2).

(Table 6), but in both cases the differences were significant in one of four trials.

Plant density affected NDF, but not ADF concentration (Table 5). Neutral detergent fiber was significantly lower for 75 000 than 125 000 plants ha^{-1}; 100 000 plants ha^{-1} was intermediate. Row spacing and hybrid produced no significant differences at the main effect level, and interactions with trial resulted in no consistent responses for NDF and ADF.

Protein concentration was not affected by plant density; however, corn grown at standard row spacings was marginally higher than corn grown at narrow ones (Table 6). Pioneer 39N03 had greater protein concentrations than Pioneer 39F45 (Table 6), but the differences were small.

In the current study IVDOM decreased 4 g kg^{-1} and NDF increased 17 g kg^{-1} as plant density increased from 75 000 to 125 000 plants ha^{-1}. Others have found similar trends for nutritive value as plant density increased. Cox et al. (1998) observed that in vitro true digestibility decreased by 24 g kg^{-1} and NDF increased by 31 g kg^{-1} as plant density increased from 45 000 to 100 000 plants ha^{-1} and Cusicanqui and Lauer (1999) observed that in vitro true digestibility decreased 16 to 23 g kg^{-1} and NDF increased from 20 to 35 g kg^{-1} as plant density increased from 45 000 to 105 000 plants ha^{-1}. Thus, estimated milk yield per dairy cow declined and milk yield per ha^{-1} levelled off prior to the highest plant density in these studies (Cox et al. 1998; Cusicanqui and Lauer 1999) with increasing plant density. However, gestating beef cows at mid-pregnancy have relatively low energy requirements for maintenance (National Research Council 1996), which means that lower digestibility and greater fiber concentrations are of less consequence for winter grazing of cows. Cox et al. (1998) and Cox and Cherney (2001) found no significant effects of row spacing on nutritive value parameters. The nutritive value shown in the present study appears comparable to semi-dwarf barley, which is an alternative for grazing and animal feeding (Baron et al. 2000).

CONCLUSIONS

Increasing population density remains the most effective way to increase whole-plant yield in short-season corn (13%) compared with narrow row spacing (4%). Averaged over trials, row spacing and hybrids whole-plant yield increased up to 125 000 plants ha^{-1}, but interactions occurred among all main effects, so that a more conservative estimate of best population density is approximately 100 000 plants ha^{-1} (Table 3). Both LAI and whole-plant yield at 100 000 plants ha^{-1} were smaller compared with yield and LAI at optimum plant density of later maturing hybrids grown in longer season environments (e.g., Daynard and Muldoon 1981; Cox 1996).

Narrow row spacing had no negative effects on whole-plant yield and nutritive value. Lack of equipment with standard row spacing per se should not prevent corn production for grazing in this short-season area. However, more research is needed on the impacts of unconventional planting equipment on whole-plant corn yield for grazing and silage.

Two very early corn hybrids were used in this study. This number of hybrids used is insufficient to make generalized statements about ideal types for this region or for corn management involving narrow rows and higher plant populations. However, one hybrid, Pioneer 39F45, appeared to respond more readily to increasing plant density when grown in narrow rows compared with the other hybrid, suggesting that hybrid might be a factor worth considering in future research involving population density and row spacing to increase whole-plant yield in these short-season areas.

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Baron, V. S., Daynard, T. B., Dupuis, G., Fairey, N. A., Major, D. J., Muldoon, J. F. and White, R. P. 1987. Evaluation of early-maturing European and Canadian corn hybrids for grain and forage production in Canada. Maydica **32**: 33–48.

Baron, V. S., Najda, H. G., McCartney, D. H., Bjorge, M. and Lastiwka, G. W. 2003. Winter weathering effects on corn grown for grazing in a short-season area. Can. J. Plant Sci. **83**: 333–341.

Baron, V. S., Okine, E. and Dick, A. C. 2000. Optimizing yield and quality of cereal silage. J. Kennelly, ed. Proc. of the Western Canadian Dairy Seminar, Red Deer, AB. Advances in Dairy Technology. 12: 351-357. University of Alberta, Edmonton, AB.

Cox, W. J. 1996. Whole-plant physiological and yield responses of maize to plant density. Agron. J. **88**: 489–496.

Cox, W. J. and Cherney, D. R. 2001. Row spacing, plant density and nitrogen effects on corn silage. Agron. J. **93**: 597–602.

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

Cummins, D. G. and Dobson, J. W. 1973. Corn for silage as influenced by hybrid maturity, row spacing, plant population and climate. Agron. J. **65**: 240–243.

Cusicanqui, J. A. and Lauer, J. G.1999. Plant density and hybrid influence on corn forage yield and quality. Agron. J. **91**: 911–915.

Daynard, T. B. 1978. Practices affecting quality and preservation of whole-plant corn silage. Can. J. Plant Sci. **58**: 651–659.

Daynard, T. B. and Muldoon, J.F. 1881. Effects of plant density on the yield, maturity and grain content of whole-plant maize. Can. J. Plant Sci. **61**: 843–849.

Duncan, W. G. 1984. A theory to explain the relationship between corn population and grain yield. Crop Sci. **24**: 1141–1145.

Dwyer, L. M., Stewart, D. W., Carrigan, L., Ma, B. L., Neave, P. and Balchin, D. 1999. Guidelines for comparisons among different maize maturity rating systems. Agron. J. **91**: 946–949.

Dwyer, L. M., Tollenaar, M. and Stewart, D. W. 1991. Changes in plant density dependence of leaf photosynthesis of maize (*Zea mays* L.) hybrids, 1959 to 1988. Can. J. Plant Sci. **71**: 1–11.

Etheridge, R. D., Pesti, G. M. and Foster, E. H. 1998. A comparison of nitrogen values obtained utilizing the Kjeldahl nitrogen and Dumas combustion methodologies (Leco CNS 2000) on samples typical of animal nutrition analytical laboratory. Anim. Feed Sci. Technol. **73**: 21–28.

Fairey, N. A. 1982. Influence of population density and hybrid maturity on productivity and quality of forage maize. Can. J. Plant Sci. **62**: 427–434.

Hunter, R. B. 1980. Increased leaf area (source) and yield of maize in short-season areas. Crop Sci. **20**: 571–574.

Hunter, R. B., Kannenberg, L. W. and Gamble, E. E. 1970. Performance of five maize hybrids in varying populations and row widths. Agron. J. **62**: 255–256.

Littel, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R.D. 1996. SAS system for mixed models. SAS Institute, Inc., Cary, NC. 656 pp.

Littel, R. C., Stroup, W. W. and Freund, R.J. 2002. SAS for linear models. 4th ed. SAS Institute, Inc., Cary, NC.

Major, D. J. and Hamilton, R. I. 1978. Adaptation of corn for whole-plant silage in Canada. Can. J. Plant Sci. **58**: 643–650.

Marten, G. C. and Barnes, R. F. 1980. Prediction of energy digestibility of forages and fungal enzyme systems. Pages 61–71 *in* W. J. Pigden et al., eds. Standardization of analytical methodology for feeds. IDRC-134e, Ottawa, ON.

McCartney, D., Basarab, J. A., Okine, E. K. Baron, V. S. and Depalme, A. J. 2004. Alternative fall and winter feeding systems for spring calving cows. Can. J. Anim. Sci. **84**: 511–522.

Modarres, A. M., Hamilton, R. I., Dijak, M., Dwyer, L. M., Stewart, D. W., Mather, D. E. and Smith, D.L. 1998. Plant population density effects on maize inbred lines grown in short-season environments. Crop Sci. **38**: 104–108.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th ed. National Academy Press, Washington, DC.

Stewart, G. 2003. Narrow row one more. Growing Ontario's corn – Ontario Field Crop Report, April 23, 2003. [Online] Available: http://www.gov.on.ca/omafra/english/crops/field/news/index

Tollenaar, M. and Aguilera, A. 1992. Radiation use efficiency of an old and a new maize hybrid. Agron. J. **84**: 536–541.

Tollenaar, M. and Bruulsema, T. W. 1988. Efficiency of maize dry matter production during periods of complete leaf area expansion. Agron. J. **80**: 580–585.

Van Soest, P. J. and Robertson, J. B. 1980. Systems analyses for evaluation of fibrous feeds. Pages 49–60 *in* W. J. Pigden et al., eds. Standardization of analytical methodology for feeds. IDRC-134e, Ottawa, ON.

Vogel, K. P., Pedersen, J. F, Masterson, S. D. and Toy, J. T.1999. Evaluation of a filter bag system for NDF, ADF and IVDMD forage analysis. Crop Sci. **39**: 276–279.

Willms, W. D., Rode. L. M. and Freeze, B. S. 1993. Performance of Hereford cows on fescue prairie and in drylot as influenced by fall grazing. Can. J. Anim. Sci. **73**: 881–889.