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Article *in* Crop Science · September 2006

DOI: 10.2135/cropsci2005.06-0141

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Published online July 25, 2006

Response of a Leafy and Non-Leafy Maize Hybrid to Population Densities and Fertilizer Nitrogen Levels

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ABSTRACT

Optimum plant population density (PPD) of maize (*Zea mays* L.) for grain and/or silage production depends on hybrid type, soil fertility and agronomic management. Limited information exists on the yield response of Leafy maize hybrids to different PPD under varying N application rates. A field study was conducted during 2003 and 2004 in Ottawa, Canada to evaluate grain and silage yields of a Leafy hybrid ('Maizex LF850 RR') with a conventional hybrid ('Pioneer 3893'), under three PPD (60 000, 75 000, and 90 000 plants ha^{-1}) and four N fertilizer (0, 75, 150, and 225 kg N ha^{-1}) regimes. Canopy light interception, plant dry matter (DM), silage, and grain yield were measured. The Leafy hybrid had 20 to 25% more leaf area, on an individual plant basis, and produced significantly greater silage DM (21.1 vs. 20.0 Mg ha^{-1}), but had a significantly smaller grain yield (9.4 Mg ha^{-1}) than the conventional hybrid (9.7 Mg ha^{-1}). The Leafy hybrid was more sensitive to high density and low N stresses, resulting in more barren plants (up to 15%), lower harvest index (HI), thus significantly lower grain yield than the conventional hybrid in 2003. Grain yield reached to a maximum with 225 kg N ha^{-1} followed by 75 and 150 kg N ha^{-1}, but silage DM was not different between 150 and 225 kg N ha^{-1}. Plant population density had no effect on grain yield but silage yield increased linearly as PPD increased from 60 000 to 90 000 plants ha^{-1}. Within the tested range of PPD, no differential response of hybrids was observed in terms of grain yield or silage DM, and N treatments had no effect on response of hybrids to PPD. We conclude that the Leafy hybrid was more sensitive to high PPD and low N stresses than the conventional hybrid especially for grain production. The optimum PPD for silage production may be beyond 90 000 plants ha^{-1} for both types of hybrids.

Plant population density (the number of plants per unit area) is one of the most important yield determinants of maize. As crop growth rate depends on the amount of intercepted photosynthetically active radiation (PAR), the leaf area per unit ground area (i.e., leaf area index [LAI]) plays an important role in DM production. The LAI attains its maximum value shortly after silking (Allison, 1969), and variation in maximum LAI is due to plant density, genotype architecture and environment (Tollenaar, 1977; Stewart et al., 2003). The ways to increase LAI are through increased planting density and adequate N supply. The PPD affects the post-flowering source/sink ratio through its effects on plant leaf area, the amount of light intercepted per plant and kernel number per plant (Borrás et al., 2003). All these traits decrease in response to increased PPD (Westgate et al., 1997; Andrade et al., 2002). Borrás et al. (2003) reported that increased PPD promoted an enhanced light attenuation within the canopy, increased post-flowering source/sink ratio and decreased grain protein content. Generally, higher density would enable capturing more PAR initially but crowding increases after canopy closure.

Plant population density ultimately affects yield through altering yield components. At high PPD, ear and kernel abortion occur because of interplant competition for assimilates during the flowering period (Tollenaar, 1977). Andrade et al. (1999) suggested that PPD has an important effect on partitioning of DM between vegetative and reproductive sinks, and kernel set responded to the amounts of resources available for each individual plant. Grain yield per unit area increases with PPD until the increase in yield attributable to plants is offset by decline in mean yield per plant (Tollenaar and Wu, 1999). At supra-optimal PPD, the number of kernels per ear, mean kernel weight, and cob length were reduced (Bavec and Bavec, 2002). On the other hand, lower than optimum PPD delayed canopy closure with reduced interception of seasonal incident solar radiation (Westgate et al., 1997), leading to greater number of grains per plant, but lower grain yield per unit area (Andrade et al., 1999). Westgate et al. (1997) suggested that rapid canopy development may be especially critical in the relatively cool, short growing regions, typical of the Northern Corn Belt.

There are numerous studies on the effects of PPD (Begna et al.,1997; Sangoi et al., 2002; Bavec and Bavec, 2002), planting pattern or row spacing (Farnham, 2001; Andrade et al., 2002; Ma et al., 2003), combinations of row spacing (row width) and PPD (Westgate et al., 1997; Cox and Cherney, 2001; Widdicombe and Thelen, 2002), N by PPD (Blumenthal et al., 2003; Monneveux et al., 2005), and N by hybrid (Costa et al., 2002; Ma et al., 2005; Subedi and Ma, 2005a,b; Monneveux et al., 2005) on the grain yield and forage production of maize. However, in most of the cases, there was a single rate of N and/or hybrids used were of similar types.

There has been continuous genetic improvement in maize during the last 50 yr. Yield improvement in newer maize hybrids is attributed to their abilities to withstand high PPD stresses (Tollenaar and Wu, 1999). Accordingly, periodic reassessment of optimal plant density, row width, and N responses of newer maize hybrids is

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Published in Crop Sci. 46:1860–1869 (2006).
Crop Ecology, Management & Quality
doi:10.2135/cropsci2005.06-0141

Abbreviations: DM, dry matter; HI, harvest index; LAI, leaf area index; LRS, Leafy reduced-stature; NDVI, normalized difference vegetation index; NLRS, non-Leafy reduced stature; PAR, photosynthetically active radiation; PM, physiological maturity; PPD, plant population density.

required. A single density may not be optimum for all types of hybrids because maize hybrids differ in their response to PPD (Tollenaar and Wu, 1999; Sangoi et al., 2002). Genotypes with different leaf architecture and stature may respond differently to PPD and N supply as they vary in the number of leaves, plant height, leaf area per plant, and vertical leaf angle distribution along the main stem (Edmeades and Laffite, 1993). Maize hybrids tolerant to crowding have been obtained as a result of selecting for yields in dense stands under a wide range of testing environments (Sangoi et al., 2002). The current hybrids perform better under supra-optimal PPD because of lower DM in the tassel, more compact canopy structure and lower ear placement. The Leafy hybrids, with extra leaves above the ear (Shaver, 1983), contain a Leafy (*lfy*) gene, which results in more leaves per plant, and, overall, more leaf area and leaf DM than the non-Leafy (i.e., conventional) hybrids (Subedi and Ma, 2005a). The optimum PPD requirement for silage maize may be different from grain maize, and that of a Leafy type may not be suitable for the conventional types. Roth (2003) evaluated the Leafy and non-Leafy hybrids for dual purpose and observed that the grain hybrids were superior in yield but sound grain could be produced from the Leafy hybrids as well. Begna et al. (1997) evaluated the performance of Leafy reduced-stature (LRS), non-Leafy reduced-stature (NLRS), and non-Leafy (i.e., conventional) hybrids at a range of PPD and found that at low PPD, all hybrids had the highest yield per plant while at higher PPD yield of the conventional hybrid declined more than the Leafy types (i.e., LRS and NLRS). Cox (1997) recommended that forage maize be planted at 7.5% higher PPD than a grain crop. Roth (2003) observed that yields of Leafy hybrids were less responsive to PPD than those of non-Leafy hybrids. Subedi and Ma (2005c) observed that the Leafy maize (Maizex LF850 RR) had a 25 to 40% greater leaf area and plant DM at silk stage, but there was no difference in grain yield and total DM at physiological maturity stage than the conventional hybrid (Pioneer 3893).These results indicate that hybrid selection and PPD are important management considerations for forage and grain production (Cusicanqui and Lauer, 1999).

Nitrogen fertilizer affects maize DM production by influencing leaf area development, leaf area maintenance and photosynthetic efficiency (Muchow, 1998), and thus grain yield. The need for N is related with the hybrid type, purpose of crop production, PPD, and soil and environmental conditions. Monneveux et al. (2005) observed that in tropical maize, grain yield was negatively correlated with kernel abortion rate under low N stress. Under high PPD and low N conditions, final kernel number depended on abortion rate.

The effect of N on maize yield is one of the most studied areas. However, studies on N rates with different PPD for diverse purpose hybrids are limited. So far, most of the PPD, row spacing, and N studies have been focused on grain production. Subedi and Ma (2005b), in a pot experiment, observed that there was no differential N uptake, or remobilization and partitioning between the conventional and Leafy maize hybrids. To what extent maize hybrids with diverse morphological characteristics respond to different PPD at varying N application rates for grain and silage production is not studied. The objectives of this study were to (i) determine how the contrasting maize hybrids differ in response to N and PPD for grain and silage production, and (ii) assess if the hybrid responses to N and PPD are consistent across years.

MATERIALS AND METHODS

A field experiment was conducted for two growing seasons (2003 and 2004) in Ottawa, Canada (45°22′ N, 75°43′ W) under rainfed conditions on a loam-silt to loam textured soils (Eutrochepts) in both years. The previous crop in the rotation was wheat (*Triticum aestivum* L.) in 2003 and soybean [*Glycine max* (L.) Merr.] in 2004. The soil in 2003 contained 4.6 μg NO_3–N g^{-1}, 12.7 μg P (Bray P) g^{-1}, 175 μg test K g^{-1}, and had a water pH of 6.9. In 2004, it contained 7.6 μg NO_3–N g^{-1}, 34.7 μg Bray P g^{-1}, 95.5 μg test K g^{-1}, with a water pH of 6.7. Two maize hybrids with distinct genetic and morphological characteristics were used. Pioneer 3893 is a popular commercial hybrid in the region with a favorable response to higher planting rates, with a 2700 Crop Heat Units (CHU rating; Brown and Bootsma, 1993). Maizex LF850 RR is a Leafy silage hybrid with "Round-up Ready" trait but with a similar maturity (≈2–4 d) as Pioneer 3893 (Subedi and Ma, 2005c).

The study consisted of four N fertilizer rates (0, 75, 150, and 225 kg N ha^{-1}) and three PPD (60 000, 75 000, and 90 000 plants ha^{-1}), as a factorial experiment, was arranged in a split plot design with four replications. Nitrogen rates were assigned to the main plots, and combination of hybrids and densities were randomized in subplots. Each subplot consisted of eight rows of maize spaced 0.76 m with 9 m length. Fertilizer P and K were applied preplanting according to soil test recommendations. All N fertilizer was broadcast preplant as calcium ammonium nitrate (CAN; 27.5% N) as per treatment's requirement. Seed rates were calibrated to achieve the targeted PPD. Planting of maize was done on 17 May 2003 and 13 May 2004. No hand thinning was done so as to adjust the existing PPD. Herbicide, Primextra II (S-metolachlor/benoxacor/atrazine) at a rate of 3.3 L ha^{-1} was applied preplanting. Manual weeding was performed to remove weeds that escaped the herbicide treatment.

Time taken to reach different phenological events was recorded. At the three-leaf collar stage (V3; Ritchie et al., 1993), the number of plants in the third and fourth rows was counted for each plot. Leaf greenness (SPAD–502 Chlorophyll Meter, Minolta Camera Co. Ltd., Tokyo, Japan) and canopy reflectance as determined by a hand-held multi-spectral radiometer (MSR-16; CropScan Inc., Rochester, MN) were simultaneously measured at V12 and silking. Leaf greenness (SPAD) was measured in the upper most fully expanded leaf at V12 and on the ear-leaf at silking stage from five random plants of the second row. The spectral readings from the CropScan were used to derive a normalized difference vegetative index (NDVI) as $NDVI = (IR_{813} - R_{613})/(IR_{813} + R_{613})$ (Ma et al., 1996). Destructive leaf area was measured from three plants of the seventh row at silking using a LI-COR Leaf Area Meter (Model- LI-300; LI-COR Inc., Lincoln, NE). After leaf area measurement, all leaves and the stalks were dried at 80°C for >72 h and dry weights were determined. Similarly, nondestructive LAI was measured twice at V12 and silking using a LI-COR Plant Canopy Analyser (Model: LI-2000; LI-COR Inc.).

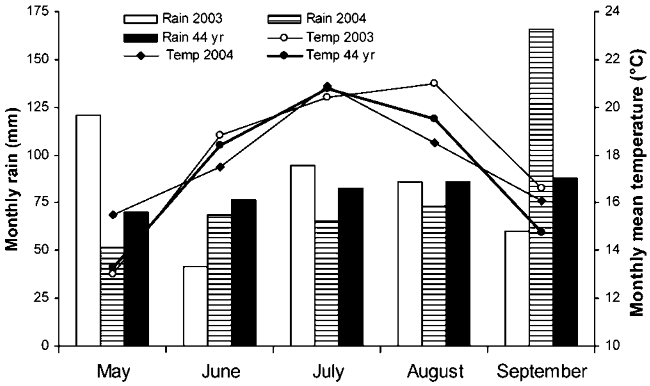

Fig. 1. Monthly mean temperatures (°C) and total monthly rain (mm) during the growing seasons (May to September) of 2003 and 2004 as compared to the long-term (1961–2004) average values in the experimental site at Ottawa.

The incoming and intercepted PAR were measured in the control plots (i.e., 0 N and 75 000 plant ha^{-1}) of both hybrids using a 1-m Line Quantum Sensor (LICOR LI-191SB) starting at V12 until 4 wk after silking. The sensor bars were placed at the soil surface at a 45° angle between the third and fourth rows. Incident PAR above the canopy and at ground level was recorded continuously for 24 h each day and data were stored in a Delta-logger (DeltaTRAK Inc., Pleasanton, CA). The observations recorded only during the day time (between 0900 and 1700 h) were used for the calculation of the percentage of PAR intercepted. The percentage of PAR intercepted by the canopy was derived as the fraction of the difference between the total incident PAR above the canopy and PAR at the ground level over the total above-canopy PAR.

During the 2004 growing season, the incoming and intercepted PAR was also measured at V12 and silking stages using a Decagon AccuPAR (Model: PAR-80; Decagon Devices, Inc.). The sensors were placed at a slanting position (45° angle) between rows 3 and 4 in a pre-determined spot, and the percentage of PAR intercepted by the canopy was determined as described above with the Line Quantum Sensor.

At the 50% kernel milk-line stage (whole plant moisture of ≈65%), five plants from row 7 were harvested and fresh and dry weights and moisture contents of the forage biomass (silage) were measured after drying the samples at 80°C until a constant weight. The nonfermented silage yield was expressed as DM silage yield (Mg ha^{-1}) calculated based on the number of plants at harvest in each treatment. At physiological maturity (PM), total number of plants, number of ears and number of barren plants (plants without ears or filled kernels) were counted in the third and fourth rows of each plot. Five plants from the seventh row were harvested and ears and other parts were separated for the determination of HI. Ears and stover was oven dried at 80°C for >72 h, and DM weights were recorded. Finally, rows 3 and 4 were combine harvested for grain yield. Grain yields were corrected to a 155 g kg^{-1} water basis.

The experimental data with common variables and homogenous variances in both years were subjected to combined analysis of variance (ANOVA) using the general linear model procedure (SAS Institute, 1996). While some variables that were not common in both years were analyzed separately. Treatment mean differences were separated using the least significant difference ($LSD_{0.05}$) test, if the F-tests were significant ($P \leq 0.05$).

RESULTS AND DISCUSSIONS

Growing Conditions

Growing conditions for both years were normal in terms of rainfall and mean air temperatures (Fig. 1). Rainfalls were generally evenly distributed throughout the growing seasons, and the crops did not experience moisture stress. There were almost double of the 44 yr average (1961–2004) rain in May of 2003 and September of 2004. The 2004 growing season received slightly more rain than 2003, especially during the later part of the grain filling period. Mean air temperatures were between 15 and 22°C from planting to PM. However, May of 2004 was slightly warmer than in 2003, while August and September were warmer in 2003 than 2004 or the long-term average. In both years, the accumulated CHU were >2900; adequate for the maturity of the hybrids tested.

Number of Plants and Ears at Harvest

The levels of significance of main effects of year, N, PPD, and hybrid, and interactions between them for various parameters measured over 2 yr are presented in Table 1.

The actual number of plants at V3 and at harvest (R6) for each of the three PPD in 2 yr is summarized in Table 2. There was an obvious difference in the number

Table 1. Levels of significance and corresponding degrees of freedom (df) for the main effects and interactions between year (Y), nitrogen (N), hybrid (H) and plant population density (PPD) for various parameters measured in 2 yr.

Source	df	Plants at V3	Plants at harvest (R6)	LAI with LI-COR†	Leaf area per plant‡	SPAD at silking	Grain moisture	Grain yield	Silage DM
Year (Y)	1	0.837	0.480	<0.001	<0.001	<0.001	<0.001	<0.001	0.642
Block (B)	3	<0.001	<0.001	0.011	0.675	0.267	0.486	0.440	0.651
Nitrogen (N)	3	0.099	0.123	<0.001	<0.001	<0.001	0.139	<0.001	<0.001
Error A	9								
Hybrid (H)	1	0.742	0.111	<0.001	<0.001	<0.001	<0.001	0.012	0.005
Density (PPD)	2	<0.001	<0.001	<0.001	<0.001	<0.001	0.727	0.156	0.018
N × H	3	0.794	0.991	0.521	0.202	0.072	0.065	0.345	0.861
N × PPD	6	0.930	0.982	0.512	0.304	0.375	0.439	0.837	0.434
H × PPD	2	0.703	0.795	<0.001	0.347	0.811	0.106	0.198	0.210
Y × N	3	0.065	0.345	0.068	0.008	<0.001	0.851	0.023	0.429
Y × H	1	0.902	0.114	<0.001	0.002	0.004	<0.001	0.004	0.095
Y × PPD	2	<0.001	<0.001	0.714	0.099	0.264	0.998	0.872	0.759
N × H × PPD	6	0.985	0.456	0.566	0.588	0.075	0.463	0.276	0.516
Y × N × H × PPD	17	0.998	0.622	0.905	0.314	0.639	0.438	0.533	0.266
Error B	132								

† Leaf area index (LAI) measured nondestructively using the LI-COR Plant Canopy Analyser (LI-2000) at silking (R1) stage.
‡ Leaf area of individual plant measured destructively using LI-COR Leaf Area Meter (LI-3000) at silk stage.

Table 2. Plant population density of two maize hybrids at the seedling stage (V3) and at physiological maturity (R6), averaged over four N rates and three plant population density levels in 2003 and 2004 in Ottawa.

	Actual plant population density							
	At emergence (V3)				At harvest (R6)			
	2003		2004		2003		2004	
Designated plant population density	P 3893†	LF 850†	P 3893	LF 850	P 3893	LF 850	P 3893	LF 850
	plants ha^{-1}							
60 000 plants ha^{-1}	55 029†	54 163	59 661	60 472	54 756	55 986	59 435	59 886
75 000 plants ha^{-1}	75 027	74 753	73 855	74 576	73 524	76 667	73 224	74 306
90 000 plants ha^{-1}	88 511	90 925	85 571	85 436	85 914	91 609	83 904	83 228

† P3893 and LF 850 are Pioneer 3893 and Maizex LF 850 RR, respectively.

of plants at emergence and PM stages among the three PPD levels, but no effects of N, hybrid or their interactions were significant. There was no difference in plant stands in 2 yr. Stand counts at V3 and R6 corresponded to the targeted PPD, except in the 60 000 plants ha^{-1} treatment in 2003, which had almost 10% less plant stand compared to about 5% less in the 75 000 and 90 000 plants ha^{-1} treatments (Table 2). There was always a slight reduction in the number of plants from V3 to R6, and actual PPD at harvest were from 2 to 9% lower than the targeted number of plants (Table 2). There was an exception that in 2003, the Leafy maize had slightly greater number of plants at PM than at V3, possibly because of delayed emergence of some plants.

The number of ears and barren plants were recorded only in 2003. There were large differences in these components due to N, hybrid, and PPD. Irrespective of N and PPD, Pioneer 3893 had more number of ears than the Leafy hybrid (Table 3). The lower number of ears for the Leafy maize was primarily associated with the large number of plants without ears (i.e., barrenness). Regardless of N treatments and PPD, only 1.6% of total plants of Pioneer 3893 were without ears as compared to 5.2% of the Leafy maize (Table 2).

Nitrogen treatment had an apparent effect on the number of ears and barren plants in 2003. The 0 N treatment (control) had fewer ears (69 303 ha^{-1}) than the other three N treatments, which were similar (72 613 ears ha^{-1}). The 0 N treatment had the greatest number of barren plants (5254 ha^{-1}); the other three N treatments were not different (overall average of 1712 plants ha^{-1}). However, there was a strong N × hybrid interaction for the number of barren plants (Fig. 2A). For Pioneer 3893, there was no difference in the number of barren plants among N treatments but for the Leafy maize, there were about 10% of the plants without ears under the 0 N treatment compared to only 2.6% in Pioneer 3893. There was also an N × PPD interaction for the number of barren plants. Irrespective of hybrids, the highest PPD (90 000 ha^{-1}) had the greatest number of barren plants under 0 N (Fig. 2B).

The number of barren plants increased with increased PPD (Fig. 2C). However, there was also a strong hybrid × PPD interaction, such that at the lowest PPD (60 000 plants ha^{-1}), both hybrids had a similar number of barren plants (<1.5%), but the number of barren plants increased sharply (up to 7.2%) with increased PPD only in the Leafy hybrid (Fig. 2D). This clearly indicated that the Leafy hybrid was sensitive to high density stress compared to the conventional hybrid, such that the effect of overcrowding was expressed as many plants without ears.

A significant hybrid × PPD × N interaction for the number of barren plants indicated that the conventional hybrid responded similarly to all N and PPD (Fig. 2E), but the Leafy hybrid had an escalated number of barren plants at 75 000 (11.8%) and 90 000 plants ha^{-1} (14.8%) when grown with 0 N (Fig. 2F). The number of barren plants increased as PPD increased, even at the highest rate of N supply (225 kg N ha^{-1}), indicating overcrowd-

Table 3. Differences in yield and other parameters between two maize hybrids in two growing seasons averaged across four N and three density levels.

	2003		2004	
Parameters	Pioneer 3893	Maizex LF850 RR	Pioneer 3893	Maizex LF850 RR
No. of plants ha^{-1} at V3	72856a§	73281a	73165a	73360a
No. of plants ha^{-1} at harvest (R6)	71398b	74754a	72323a	72338a
No. of cobs ha^{-1}	72659a	70912b	NR¶	NR
No. of barren plants ha^{-1}	1139b	4039a	NR	NR
Leaf area at silking, cm^2 plant^{-1}†	4000b	4786a	4820b	6020a
LAI at silking‡	2.91b	3.36a	3.74a	3.77a
Grain dry weight per plant, g	125.2a	111.1b	132.1a	130.9a
Grain yield, Mg ha^{-1}	9.0a	8.4b	10.3a	10.4a
Silage DM, Mg ha^{-1}	20.4a	20.9a	19.6b	21.4a
Harvest index (HI)	0.54a	0.49b	0.51a	0.47b
Grain moisture at harvest,%	23.5a	22.5a	22.9b	29.4a
Silage moisture at harvest, %	52.8b	58.8a	64.9a	62.8b
SPAD readings at silking	57.9a	50.7b	58.6a	53.8b

† Destructive leaf area measured in three plants per plot at silking stage.
‡ LAI measured at silking stage nondestructively using LI-COR Plant Canopy Analyser (Model: LI-2000).
§ Values followed by different letters within a row are significantly different at $P \leq 0.05$.
¶ NR, not recorded.

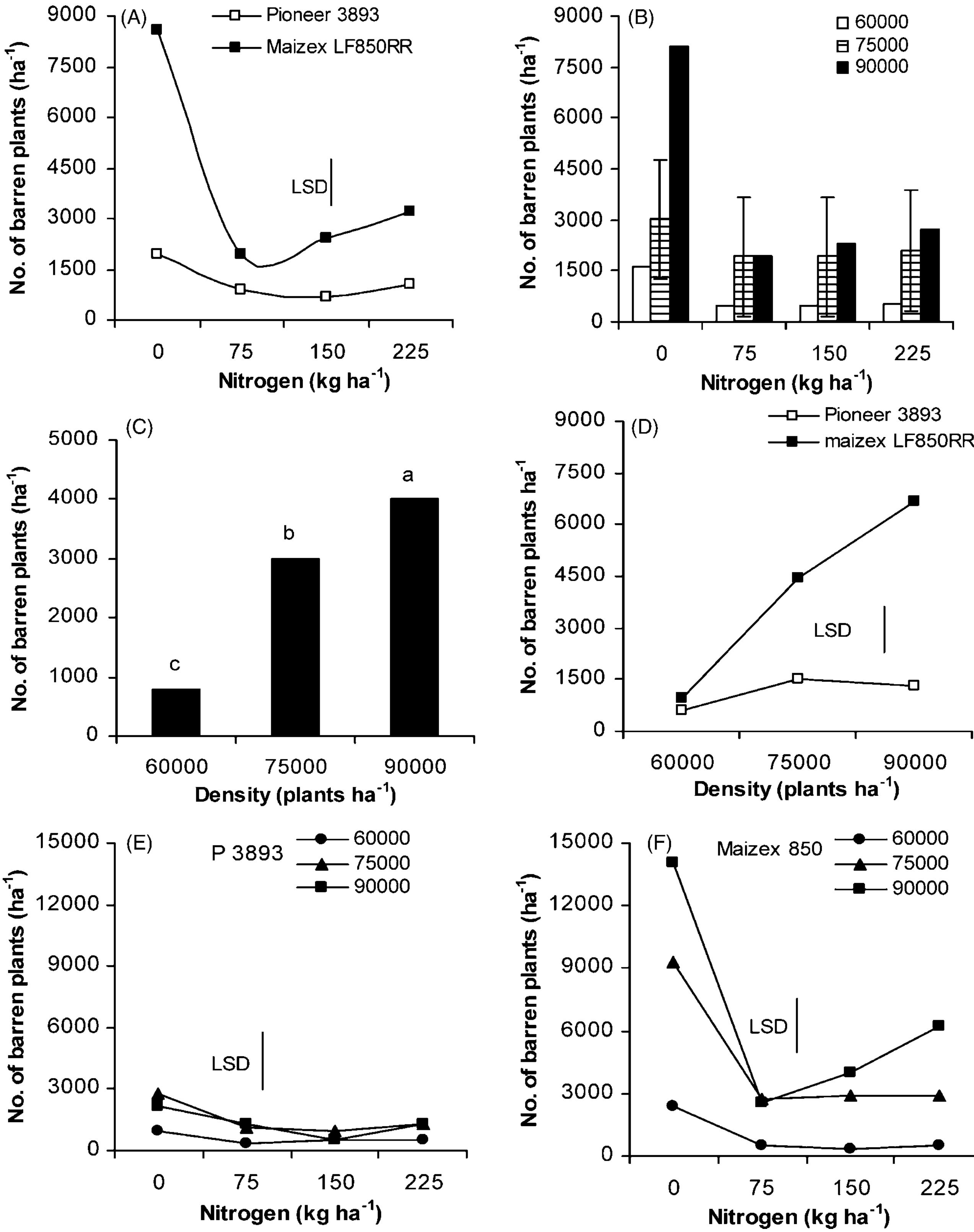

Fig. 2. The number of barren plants as affected by (A) hybrids in each N treatment, (B) N × plant population density (PPD), (C) PPD alone, (D) PPD × hybrids, (E) N × PPD for Pioneer 3893, and (F) N × PPD for Maizex LF850 RR in 2003 growing season. The vertical bar is the $LSD_{0.05}$ value.

ing in the canopy affecting ear development at higher PPDs for the Leafy hybrid.

Leaf Area, Canopy Development, and Light Interception

The Leafy hybrid had 20 leaves per plant compared to 16 for Pioneer 3893, in both years, and there were no hybrid × N or PPD × N interactions. There were 10 leaves above the ear in the Leafy hybrid as compared to only five in Pioneer 3893. The overall leaf area per plant was greater in 2004 than in 2003 (Table 3). The leaf area of individual plants, measured destructively at silking stage revealed that all the three factors tested affected leaf area (Table 1). Plants of the Leafy maize had 20 to 25% more leaf area than Pioneer 3893, which is consistent with the previous study using the same hybrids (Subedi and Ma, 2005c). The 0 N treatment had the smallest leaf area than the other N treatments in 2003, while the 0 and 75 kg N ha^{-1} had smaller areas than other two higher N rates in 2004 (Fig. 3A). In 2003, leaf area of the individual plant decreased significantly as the PPD increased to 75 000 and 90 000 plants ha^{-1} (Fig. 3B). However, in 2004, 75 000 and 90 000 plants ha^{-1} had a similar leaf area but smaller than with 60 000 plants ha^{-1}.

Leaf area indices measured at silking stage were different among hybrid, N, and PPD treatments. The LAI was greater in 2004 than in 2003, which agrees with the other observations above. Irrespective of N and PPD, the Leafy hybrid had a greater average LAI than the Pioneer 3893 (Table 3). In 2003, the values were larger in all N fertilized treatments than the unfertilized control treatment, whereas in 2004, the highest N applied treatment (225 kg N ha^{-1}) produced the largest LAI and other treatments had a similar LAI (Fig. 3C). Generally, LAI values increased linearly with the increase in PPD (Fig. 3D). A strong hybrid × PPD interaction was observed in 2004 because under low PPD, both hybrids had a similar LAI, but as PPD increased to 75 000 plants ha^{-1} and above, the LAI values increased continuously only for the Leafy maize.

Quantum sensor measurement indicated that about 85 to 95% of the total PAR was intercepted at and after the silking stage by the canopies of both hybrids at 75 000 plants ha^{-1} grown without added N. However, there was a larger difference between the two hybrids in 2003 (Fig. 4A) than in 2004 (Fig. 4B). This was mainly

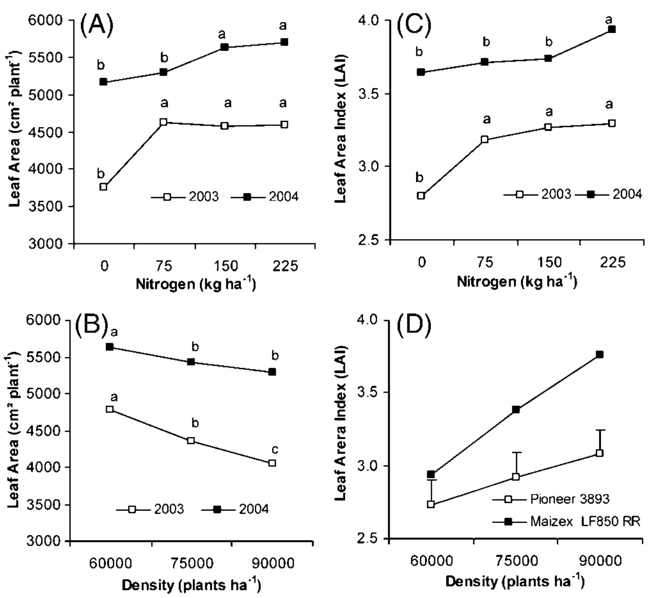

Fig. 3. Leaf area per plant measured destructively using LI-COR Plant Canopy Analyser at the silking stage as affected by (A) N treatment (N), (B) plant population density (PPD), and (C) leaf area index (LAI) as affected by N, and (D) interaction between hybrids and PPD for the LAI in 2003. The points on the line associated with different letters are significantly different at $P \leq 0.05$, and the error bars (D) is $LSD_{0.05}$.

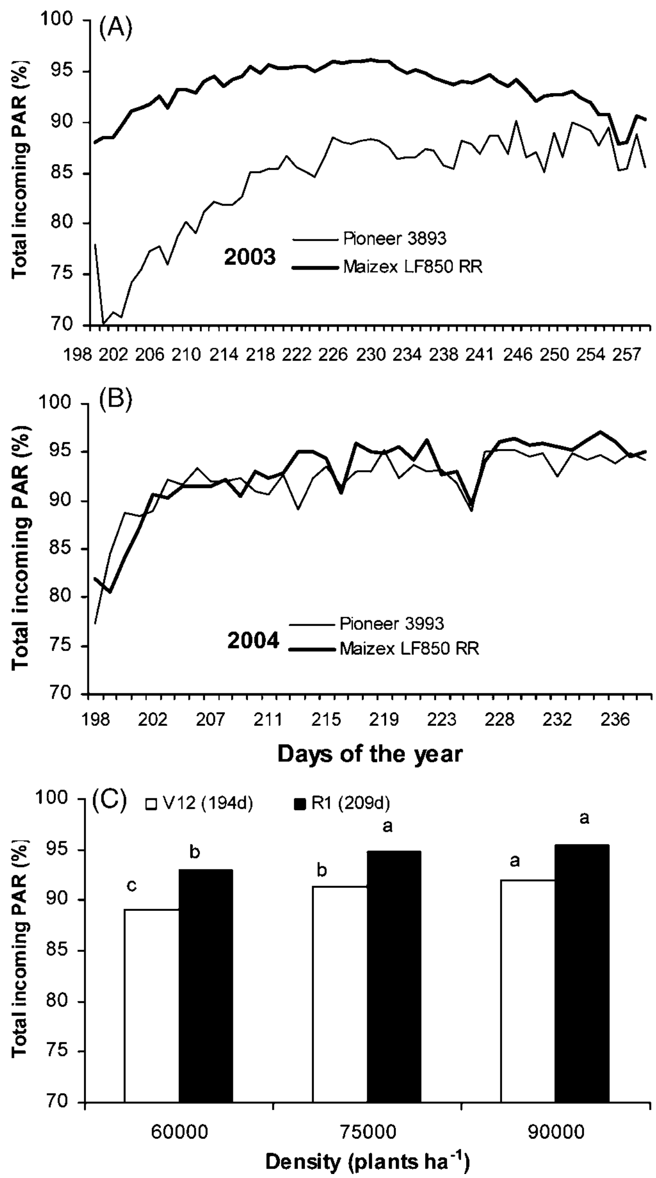

Fig. 4. Total photosynthetically active radiation (PAR) intercepted (%) by the canopy during the period from 0900 to 1700 h each day from V12 to 4 wk after silking in the two maize hybrids grown with 0 kg N ha^{-1} at a plant population density of 75 000 plants ha^{-1} (A) in 2003, (B) in 2004, and (C) effect of plant population at V12 and silking (R1) stages measured by Decagon AccuPAR in 2004. The bars associated with different letters in (C) are significantly different at $P \leq 0.05$ for each stage of measurement.

because in 2003, there was a difference in LAI or leaf area per plant between the hybrids (Table 3); therefore, the Leafy hybrid intercepted a consistently larger proportion of incoming PAR than the conventional hybrid, especially before the silking stage.

Measurements of PAR from the Decagon AccuPAR in 2004 agreed with observations made with the Quantum Sensor in that the percentage of PAR intercepted was similar in magnitude (around 94%) averaged across PPD and N levels, and there was no difference between the two hybrids. Nitrogen had an effect, but the difference was only between 0 N (93%) and the other N treatments (95%). Density had a greater effect such that the percentage of PAR intercepted in the canopy increased as the PPD increased (Fig. 4C). This is obvious as high PPD had larger LAI, thus intercepting more light in the canopy with less light penetrating to ground level. There were no hybrid × N or N × PPD interactions for the percentage of PAR interception.

Despite the differences in plant architecture (i.e., leaf area density and LAI), there was no difference between the two hybrids for the percentage of PAR intercepted by the canopy, possibly due to mutual shading of leaves for the Leafy hybrid. Moreover, the lack of difference in grain yield between the two hybrids indicates that although there was greater foliage biomass in the Leafy hybrid, its efficiency in trapping and utilization of incident PAR was low. As light travels downward through a canopy, it suffers a reduction in its photosynthetic photon flux density and significant alteration in its spectral composition (Borrás et al., 2003).

Leaf Greenness and Canopy Reflectance

The measurement of leaf greenness, using SPAD, at V12 and R1 stage differentiated the hybrid, N treatments, and densities. Pioneer 3893 had consistently greater SPAD values than the Leafy maize (Table 3). Nitrogen and PPD both had independent effects on SPAD readings and there were no hybrid × N or hybrid × PPD interactions. The difference in SPAD readings between the two hybrids at all N rates is shown in Fig. 5. The SPAD values were slightly smaller at V12 than at silking but the difference between the hybrids and effects of N and PPD were the same as at silking stage (data not shown). The observations on SPAD totally agree with the previous study by Subedi and Ma (2005a) that the Leafy hybrid always had lower SPAD readings than the conventional hybrids irrespective of N levels and stage of measurement. The SPAD reading also differentiated the effect of PPD on leaf greenness that the highest PPD (90000 ha^{-1}) had the smallest SPAD values and vice versa. Similar to SPAD, the measurement of canopy reflectance (NDVI) at silking differentiated hybrid and N effects but did not differentiate PPD effects in either year.

Grain Yield and Harvest Index

Grain moisture content at harvest was greater in 2004 (26.1%) than in 2003 (22.9%), and the Leafy hybrid had higher grain moisture (26.2%) than in the Pioneer 3893 (22.8%). Nevertheless, there was an interaction between the year and hybrid such that there was no difference between the hybrids in 2003 but the Leafy hybrid had greater grain moisture concentration (23 vs. 29%) in 2004. There were no effects of N and PPD on grain moisture and no other interactions were significant. There was no significant difference (2–3 d), to reach PM of the two hybrids. Harvesting for grain yield was at least 2 wk after PM, the reason for higher grain moisture of the Leafy hybrid in 2004 is not known.

Grain DM of individual plant was greater in 2004 than 2003 for both hybrids (Table 3). The Pioneer 3893 had significantly greater grain DM per plant than the Leafy maize in 2003, but there was no difference between the hybrids in 2004 (Table 3). Nitrogen treatment had also a highly significant effect on individual plant's grain DM. However, the responses of grain DM to N treatment were different in 2 yr (Fig. 6A). In 2003, grain DM for N treatments from 75 to 225 kg N ha^{-1} were similar, but in 2004, 150 kg N ha^{-1} treatment had the greatest grain DM per plant followed by 225 and 75 kg N ha^{-1} treatments. The 0 N treatment had the lowest grain DM in both years. There was also a strong effect of PPD on grain DM in both years. Grain yield of individual

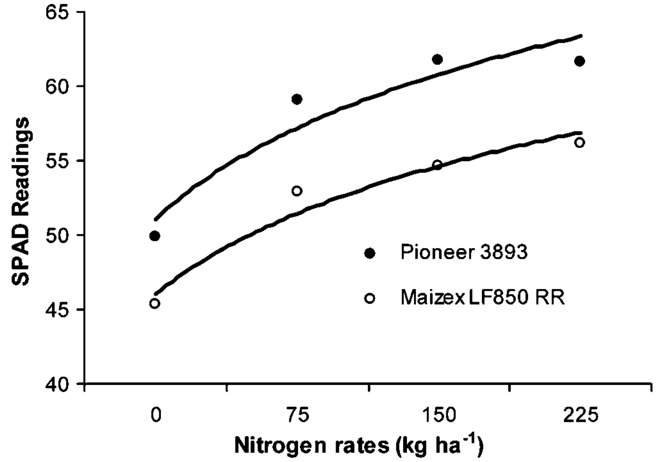

Fig. 5. Effect of N treatment on the leaf greenness (SPAD) measured at silking stage in two hybrids averaged over two growing seasons.

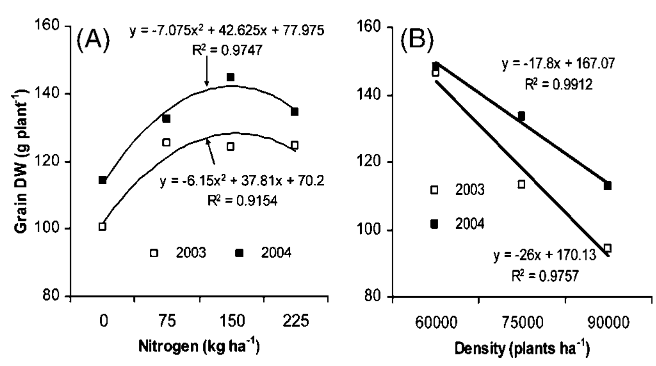

Fig. 6. Effect of (A) N treatment and (B) plant population density on the grain dry weight per plant (g) in two growing seasons averaged over two maize hybrids.

plant declined linearly as PPD increased from 60 000 to 90 000 plants ha^{-1} (Fig. 6B). There were no interactions between PPD and hybrid or PPD and N for the grain DM of individual plant.

Overall grain yield was greater in 2004 (10.4 Mg ha^{-1}) than in 2003 (8.7 Mg ha^{-1}). The combined analysis of variance over 2 yr revealed that Pioneer 3893 had significantly greater yield (9.7 Mg ha^{-1}) than the Leafy maize (9.4 Mg ha^{-1}). There was a significant year $\times$ hybrid interaction because the Pioneer 3893 produced greater yield in 2003 than the Leafy hybrid but there was no yield difference between them in 2004 (Table 3). Nitrogen treatment affected grain yield significantly. Irrespective of hybrid and PPD, grain yield increased exponentially to a maximum with the 225 kg N ha^{-1} treatment (Fig. 7). Nitrogen at 75 and 150 kg N ha^{-1} produced similar grain yields, which were significantly greater than the 0 N but were smaller than the 225 kg N ha^{-1} treatments. A year $\times$ N interaction was also significant for grain yield (Fig. 8). In 2003, N treatments at 75 and 150 kg N ha^{-1} produced similar grain yields which were greater than 0 N, but smaller than 225 kg N ha^{-1}. However, in 2004, all N treatments from 75 to 225 kg N ha^{-1} produced a similar yield which was greater than the 0 N treatments. There was also a hybrid $\times$ N interaction for grain yield in 2003 due to smaller yields of the Leafy hybrid than the non-Leafy hybrid under the 0 and 75 kg N ha^{-1} treatments (data not shown). The smaller yield of the Leafy hybrid at the lower N treatments was attributed, at least in part, to the larger number of barren plants. Therefore, it was evident that the Leafy hybrid was less tolerant to low-N stresses than the conventional hybrid. The soil fertility and growing conditions both were better in 2004 than 2003; as a result, the overall crop was better in 2004. The effect of low-N stress was minimal in 2004 than in 2004.

Although, individual plant yield decreased linearly as PPD increased (Fig. 6B), there was no effect of PPD on

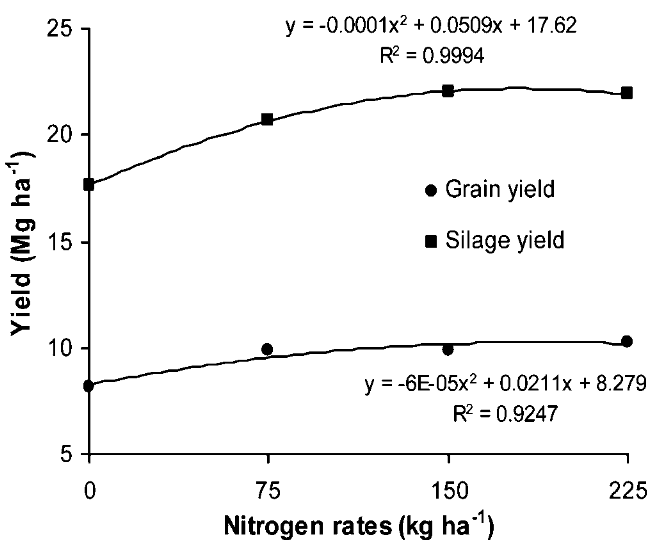

Fig. 7. Response of grain and silage yields (Mg ha^{-1}) of maize to different N treatments averaged over two hybrids and 2 yr.

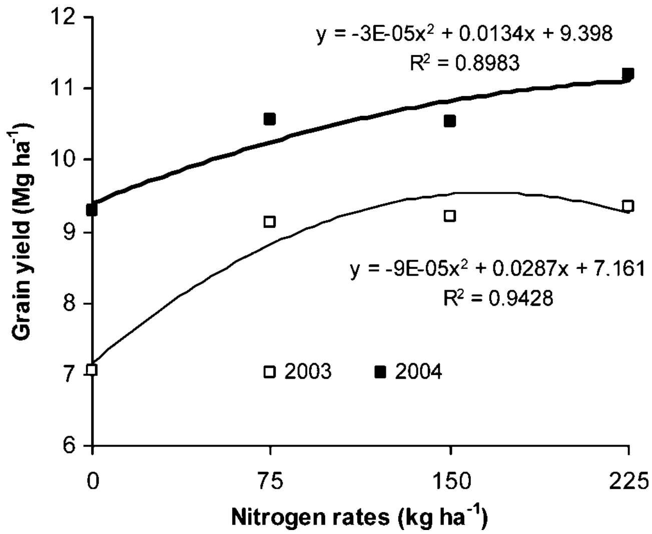

Fig. 8. Response of grain yield (Mg ha^{-1}) of maize to N treatments in 2 yr averaged over two maize hybrids.

the grain yield. There were also no interactions between PPD and hybrid or PPD and N for grain yield. Despite the small yield of individual plant at higher PPD, the overall grain yield was not reduced as the larger number of plants per hectare compensated for the smaller grain DM per plant.

The Leafy hybrid had a lower average HI than the conventional hybrid in both years (Table 3). However, the response of HI to PPD changes was different between the two hybrids in both years (Fig. 9). It was noted in both years that at the low PPD, both hybrids had similar HI values, whereas, as PPD increased, HI decreased in the Leafy hybrid, but it remained unchanged in the conventional hybrid. This pattern was primarily associated with the increased number of barren plants in the Leafy hybrid at the higher PPD, especially in 2003, thus producing more biomass without grain or reduced grain mass per plant (Table 3). Another possible contributing factor could be that in the Leafy hybrid, the amount of stover per plant was not reduced much, but ear size and grain mass per ear were reduced to a substantial degree with increased PPD. The consistently lower HI of the Leafy hybrid than the non-Leafy hybrid, especially under high PPD also suggests that as the PPD rises, the ear size and grain mass per plant was reduced in relation to stover biomass, which also indicates that this hybrid was more sensitive to high PPD than its non-Leafy counterpart.

In most cases, significant differences occurred between fertilized and unfertilized treatments. However, the yield improvement due to added N was rather small. The crop without added N treatment produced 7.1 Mg ha^{-1} grain yield in 2003 and 9.3 Mg ha^{-1} in 2004, which were 75% and 83%, respectively, of the highest N application rate (i.e., 225 kg N ha^{-1}). There was always a small yield difference between the zero N and highest N applied treatments. This observation is consistent with the other field studies in the same environment (Ma et al., 2005). Similarly, the observation that the Leafy and conventional maize hybrids do not have differential

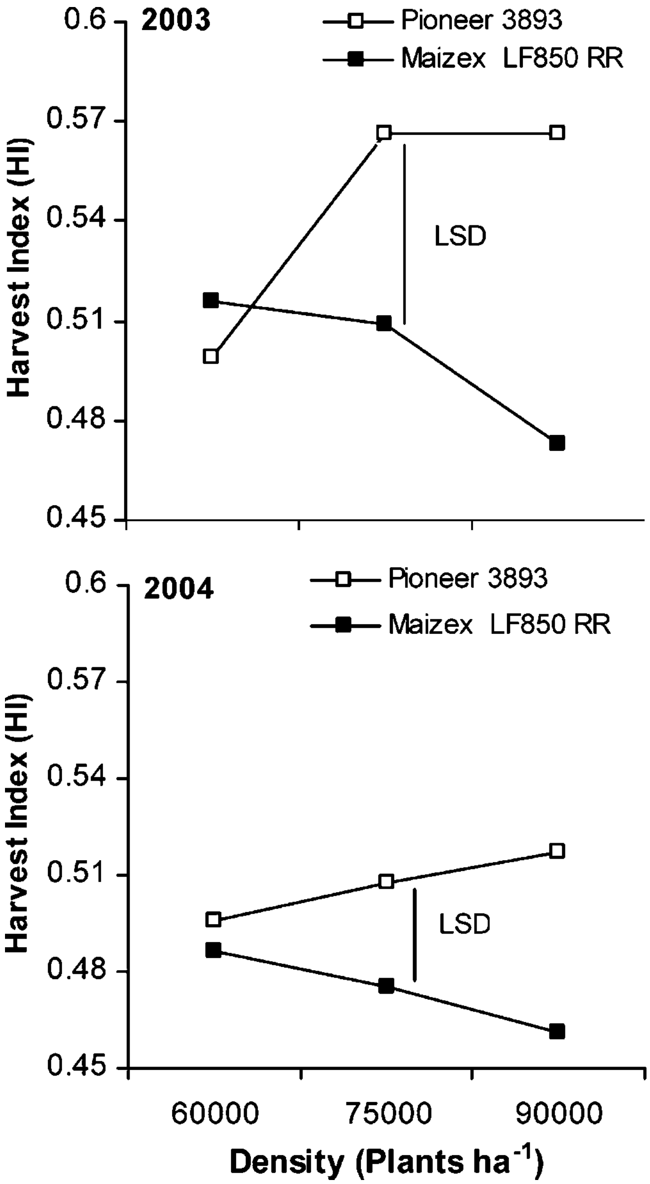

Fig. 9. Effect of plant population density on the harvest index (HI) of two maize hybrids in (A) 2003 and (B) 2004, averaged over four N treatments.

N requirements also agrees with the findings of Subedi and Ma (2005b).

Silage Dry Matter

The silage (i.e., unfermented forage biomass) yields were similar in both years and were affected by hybrid, N, and PPD individually, and there were no interactions between the factors tested. The Leafy hybrid produced greater silage DM (21.1 Mg ha^{-1}) than Pioneer 3893 (20.0 Mg ha^{-1}). Silage moisture contents at harvest ranged from 53 to 59% in 2003 and between 63 and 65% in 2004. The lower moisture content in 2003 resulted from a slightly delayed harvesting due to unfavorable weather conditions at harvesting time.

Nitrogen had large effects in both years, and there were no interactions of N with hybrids or PPD. Silage yield increased linearly up to 150 kg N ha^{-1} and plateaued thereafter (Fig. 7). The PPD also had a strong effect on silage yield. Irrespective of N and hybrid, silage yield increased linearly ($R^2 = 0.988$) with the increase in PPD from 60000 to 90000 plants ha^{-1}.

The silage yield tended to increase beyond the tested PPD range for both hybrids. This indicates that the optimum PPD for silage is higher than for grain production, which is consistent with the previous observations on dual purpose hybrids by Cox (1997) such that maize can be planted at higher PPD as forage than as a grain crop. Whether or not the silage quality is affected at higher PPD was not evaluated in this study. Cusicanqui and Lauer (1999) suggested that a trade-off exists between yield and quality of maize silage. Our results are not in agreement with the findings of Begna et al. (1997) that the LRS hybrids were more tolerant to higher PPD than the conventional ones. Possibly, because the LRS hybrids possess both the Leafy and reduced stature traits, which resulted in reduced height so that the canopy architecture was different. Tall plants with large leaf area results in reduced light utilization efficiency as light penetration is affected in the deeper canopies, or the intercepted PAR was poorly utilized in the Leafy hybrids.

In summary, our study, involving contrasting maize hybrids with various rates of N and PPD, demonstrated that the two types of maize hybrids differed in various morphological parameters, yield, and yield components. It is not surprising that two hybrids with contrasting genetic and morphological backgrounds differed significantly in a number of parameters. However, it is interesting that the Leafy hybrid produced a large portion of leaf biomass (silage yield) and greater LAI, but it had overall smaller grain yield than the conventional hybrid. The response of a conventional hybrid to grain and silage yields was consistent across years but the Leafy hybrid had a lower grain yield in 2003 under a situation of low N and high PPD. Grain yield was not affected by the three levels of PPD but silage yield tended to increase further beyond 90000 plants ha^{-1} for both types of hybrids. There was no evidence that the Leafy hybrid requires different PPD and N rates than the non-Leafy counterpart, but it was clearly shown that the Leafy hybrid was more sensitive to high PPD and low N stresses as occurred in 2003, for grain production. It was evident from the 2003 results that the number of barren plants of the Leafy maize at high PPD can be reduced substantially with increased rates of N application. Regardless of hybrid, PPD for grain yield was different than for silage production. Nevertheless, although the Leafy hybrid was more sensitive to low N stress than the conventional hybrid, there was no difference between the hybrids at higher N supply for the grain yield or silage production. The study added new information such that there was no difference in maize leaf architecture in response to PPD and N supply to achieve a similar grain or silage yield. It has also demonstrated that the Leafy maize was less tolerant to high PPD at low-N stress than the conventional hybrid.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the excellent technical assistance of L. Evenson, D. Balchin and V. Deslauriers of Agriculture and Agri-Food Canada. ECORC contribution No: 05-535.

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