Variability in corn yield response to nitrogen fertilizer in Quebec

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Abstract

Optimizing nitrogen (N) fertilization is important to improve corn yield and to reduce N losses to the environment. The economic optimum nitrogen rate (EONR) is variable and depends on many factors, including weather conditions and crop management. The main objective of this study was to examine how grain corn yield response to N varies with planting date, soil texture and spring weather across sites and years in Monteregie, which is the most important with 64% of total area and 69% of total harvested grain for this crop in Quebec province. This experiment was conducted during 8 years (2002 to 2004 and 2006 to 2010), at 11 sites with 23 hybrids and four N applications rates, for a total of 45 site-years. Each six year involved five and six rates ranging from 80-90 to 240 kg N ha^{-1}. Trials were separated into two groups based on optimal and late planting dates. Grain yield response to N varied among site-years. Significant differences in grain yield among the applied N rates were observed in all of the site-years planted at optimal dates (from 8.8 to 14.7 Mg ha^{-1}), and in most of those planted late (8.5 to 12.8 Mg ha^{-1}). Overall, optimal planting window increased grain yield compared to late planting. EONR ranged less widely for site-years planted on optimal dates (180 to 237 kg N ha^{-1}) than for those planted late (132 to 237 kg N ha^{-1}). Soil textural classes and rainfall affected the EONR. The average EONR was 193 and 204 kg N ha^{-1} for fine-textured soil and coarse-textured soil, respectively. Response to fertilizer N was higher for early planted corn combined with wet conditions. These results suggest that the current N guideline may need to increase for the optimal

planting window and should be based on soil texture and weather.

Keywords. Corn yield, variability in corn yield response, economic optimum nitrogen rate, planting date, soil texture, rainfall

Introduction

This is a report of a 8 yr-study of corn nitrogen fertilization on high-yielding fields in Québec-Eastern Canada. Data and analyses presented in this report have been published in Kablan et al (2017).

Nitrogen fertilizer rates needed for corn vary largely among fields and also within fields (Scharf et al. 2002), due to variations in crop uptake demand, soil N supply and losses from the soil. Identifying the EONR is very important in high N-demanding crops such as corn, in order to maximize profitability and to reduce N losses to the environment (Wang et al. 2003; Kyveryga et al. 2009). However, EONR is variable and depends on many other factors, including weather conditions and crop management (Coulter and Nafziger 2008; Nyiraneza et al. 2010), and genetics, soil landscape position and their dynamic interactions (Tsai et al., 1992; Sogbedji et al. 2001; Miao et al. 2006).

Soil texture is another important factor that influences EONR. In a study conducted in Québec, Ziadi et al. (2013) demonstrated that EONR was higher in clay soil than in fine sandy loam soils. The average EONR across years was 181, 161 and 125 kg N ha^{-1} for clay, clay loam, and fine sandy loam soils, respectively. Tremblay et al. (2012) also showed that corn response to added N was significantly greater in fine-textured soils than in medium-textured ones. These authors demonstrated that abundant and well-distributed rainfall (AWDR) enhanced N response.

Timely planting is critical for maximizing grain corn yield. Coulter et al. (2010) demonstrated that planting dates between 21 April and 6 May in southwestern Minnesota resulted in high grain corn yield. However, when planting was delayed until 30 May, yield was only 80% of the maximum.

The impact of these factors, however, has not been documented specifically for the Montérégie region, which is one of the most important corn producing areas in Quebec, accounting for 64% of provincial corn acreage and 69% of the total amount of corn produced in the province (La financière agricole du Québec 2015). There is a need to refine N recommendations compared to the current standard N recommendation (170 kg ha^{-1}, CRAAQ 2003), and to develop specific recommendations for different soil types in this region. The objective of this study was therefore to examine how grain corn yield response to N varied according to date of planting, soil texture, and rainfall across years and sites in Montérégie region.

Materials and Methods

Site Description

Field experiments were conducted from 2002 to 2004 and 2006 to 2010, on high-yielding fields located at La Coop Research farm in Saint-Hyacinthe and farmers' fields, for a total of 11 sites. All fields were located within a 10-km radius (lat. 45°35`33"-45°40`42", long. 72°50`53"-72°56`5"). Soil textures were grouped into three categories based on clay content, using the approach of Ziadi et al. (2013). Four fields with soils mostly of clay textural class were located on the research farm. Two fields with clay soils, three fields with fine sandy loam and two fields with loam textural class were located on farmers' land and managed by the research farm. Because of the limited size of the sample and based on the approach of Tonitto et al. (2006), clay and clay loam were grouped in a fine-textured soil category and fine sandy loam was considered as coarse texture. A total of 45 site-years were managed.

Crop Management and Fertility

Fields that had not received any manure applications the previous 5 years and worked with annual fall moldboard plow tillage were retained. Starter fertilizer applications were banded at planting, including 40 to 50 kg N ha^{-1} as ammonium nitrate, and P and K fertilizers according to the soil test, as per CRAAQ recommendations (CRAAQ 2003). The rest of the N fertilizer for each N treatment was either broadcast and incorporated before planting corn or applied as UAN at sidedress and injected at 5 cm when corn was at V3 to V5 growth stage. The experimental design at each site-year was a randomized complete block with four replications. Each experimental plot was four rows (3 m) wide and 7 m long.

Trials were planted in 76 cm row spacing with a seeding rate of 79,000 seed ha^{-1}. Herbicides were used for weed control and applied before corn emergence or soon after emergence. Grain corn yield was determined by harvesting the two center rows from each plot after maturity. Yields were calculated on a basis of 155 g kg^{-1} moisture content.

Rainfall Data and Related Parameters

The monthly rainfall from May to September and the 30-yr average rainfall were recorded at the La Providence weather station, which is located within 10 km from the research farm (45°36‘59”N, 72°57’15”W). Two rainfall parameters were retained for this study. May and June rainfall was considered for the site-years with N applied at preplant, while AWDR was considered for the site-years with N applied at sidedress (Tremblay et al., 2012).

Data Analysis

Since the period between late April and mid-May represents the optimum planting period for corn in this region (La Financière agricole du Québec 2015), the data were separated into two groups according to the planting dates. The first group contains trials with planting dates between late April and mid-May. The second group contains trials with planting dates after mid-May.

Differences in grain yield among treatments were analyzed for all data using SPSS version 24. A two-way ANOVA was performed within each of the 45 site-yr. When the F-test for the N fertilizer rate effect was significant ($P<0.05$) for a site-year (37 of 45 site-yr), five response models (Quadratic, Quadratic-plateau, Mitscherlich, Linear-plateau, Spherical plateau) were fit to data using the Crop Nutrient Response Tool V 4.5 (Bruulsema 2015). Ultimately, the quadratic-plateau model was chosen for most of the site-years, since it showed the best fit to the data in these trials and in other response trials reported in the literature (Bélanger et al. 2000; Schmidt et al. 2011). The linear-plateau was used to estimate the EONR for 6 of 37 site-yr, where it fit better than the quadratic-plateau.

The EONR was calculated by taking into account the price ratio between fertilizer (1.20 CAN \$ kg^{-1} of N) and corn (0.23 CAN \$ kg^{-1}).

A descriptive statistics analysis was calculated where EONR was considered a dependent variable, and independent variables were soil texture, planting date, and rainfall. The relationship between these parameters was also evaluated using subgroup combinations.

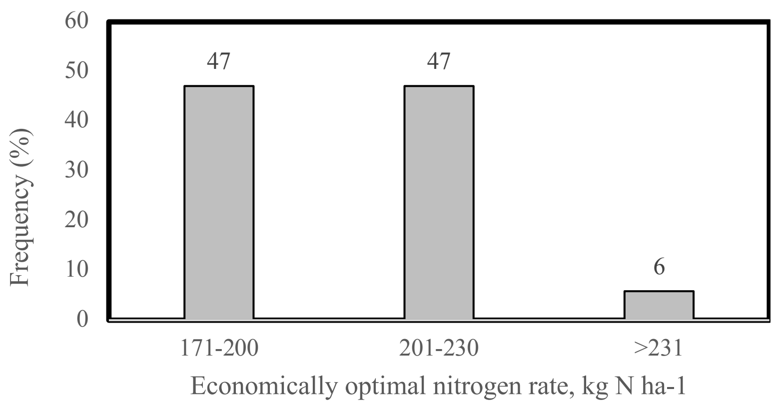
Results and discussion

Planting Date, Corn Yield Response and EONR

As weather permitted, 17 site-yr were planted between 27 April and mid-May and 28 site-yr were planted from 22 May to 2 June. Grain yield response to increasing N rates varied across the site-years. A two-way ANOVA revealed that fertilizer N improved grain yield in all of the 17 site-yr planted between late April and mid-May. Observed average grain yield for those site-years ranged from 8.8 to 14.7 Mg ha^{-1}. Considering the site-years where corn was planted after mid-May, a significant effect of fertilizer N was observed on 20 out of 28 site-yr. Average grain yield ranged from 8.5 to 12.8 Mg ha^{-1}. Site-years planted between late April and mid-May yielded higher than site-years planted after mid-May (11.4 compared to 10.3 Mg ha^{-1}). This is consistent with the results of Lauer et al. (1999) who reported that grain corn yields decreased with later planting date.

The EONR for the site-years planted before mid-May ranged from 180 to 237 kg N ha^{-1}. All of the EONR were greater than the current N recommendation for the province of Quebec (170 kg N ha^{-1}; CRAAQ 2003) (Fig.1a). Considering the site-years planted after mid-May, the EONR ranged from 132 to 237 kg N ha^{-1}. Nine site-years had EONRs lower than the current N fertilizer recommendation for corn in Quebec (170 kg N ha^{-1}; CRAAQ 2003), which represented 45% of the sites, whereas eleven site-years (55%) showed EONR values above the Quebec recommendation (Fig. 1b).

A



B

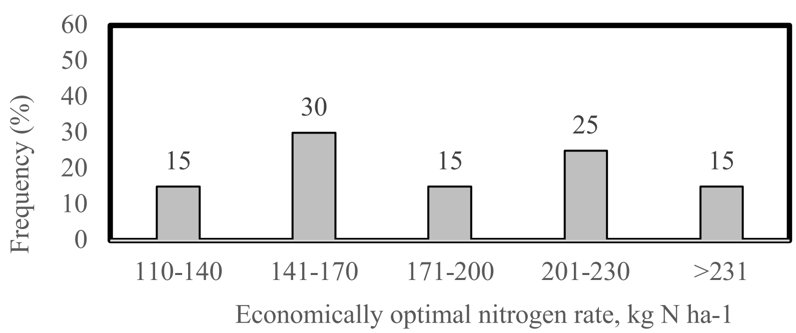


Figure 1. The frequency distribution of economically optimal rate for (A) planting date between late April and mid-May and (B) late-planted corn

Estimated grain yield at EONR in this study ranged from 10.0 to 15.3 Mg ha^{-1} for corn planted between late April and Mid-May and from 8.8 to 13.1 Mg ha^{-1} after mid-May. The highest grain yield at EONR (15.3 Mg ha^{-1}) was obtained with 213 kg N ha^{-1} on corn planted before mid-May. After mid-May, the highest yield at EONR (13.1 Mg ha^{-1}) was reached with 168, 175 and 199 kg N ha^{-1} (3 sites).

EONR as Affected by Soil Textural Class

The EONR of fine-textured soils varied across the years with a minimum and maximum of 132 and 237 kg N ha^{-1}, respectively. For coarse-textured soils, the minimum and maximum EONR were 175 and 225 kg N ha-^{1}, respectively. Fine-textured soils sometimes have lower N requirements than coarse-textured soils and Quebec fertilizer recommendations reflect this. However, other reports from Canada have found that the opposite occurs (Tremblay et al. 2012; Ziadi et al. 2013). Although both soil texture and planting date influence EONR, few reports have examined both effects together.

Table 1 shows the effects of soil texture and planting date classes on EONR. For both soil texture categories, the EONR tended to be lower for late planting than early planting. In fine-textured soils, early planting required an additional 22 kg N ha^{-1} to obtain optimum yield compared to late planting. This could be explained by the fact that delayed planting reduces the corn capacity to respond to greater N rates.

For late-planted corn, EONR was slightly lower on fine-textured soils (183 kg N ha^{-1}) compared to coarse-textured soils (199 kg N ha^{-1}). In an optimal planting window, both textural classes presented similar EONR, which is greater than provincial recommendations from CRAAQ. This result suggests that in the optimal window, additional N is needed to optimize corn grain yield on both fine- and coarse-textured soils.

Table 1. Relationship between EONR, soil texture and planting date

Subgroup	*N*	EONR kg ha^{-1}	Min	Max	Yield at EONR Mg ha^{-1}	Min	Max
Subgroup for texture							
Fine texture	30	193±33.6	132	237	11.6±1.8	8.8	15.3
Coarse texture	7	204±15.4	175	225	12.6±0.9	10.9	13.5
Subgroup for combined texture and planting date							
Fine texture − early planting	14	205±18.4	180	237	12.8±1.7	10	15.3
Fine texture − late planting	16	183±38.9	132	237	10.6±1.3	8.8	13.1
Coarse texture − early planting	3	210±12.9	201	225	12.0±1.1	10.9	13.1
Coarse texture − late planting	4	199±17.2	175	212	13.0±0.4	12.7	13.5

N − number of site-years in each subgroup, EONR− economic optimum N rate, mean ± standard deviation

EONR as Impacted by Interaction of Planting Date, Rainfall and Soil Texture

It has been reported that rainfall amounts observed in May right before N fertilizer applications and in June just after N applications are the most interesting, because fertilizer nitrate content is subject to mobilization by water (Kyveryga et al. 2011). Another reason for interest is the fact that the few days before and right after the N application, rainfall has a positive effect on N response (Tremblay et al. 2012). May and June rainfall was also used because of preplant treatments. Since the N application in 2002, 2003 and 2006 was done late, between June 20 and July 7, and most of the sites received a sidedress application, we have considered the AWDR index to better evaluate the effect of rainfall on applied fertilizers.

The impact of planting date category along with soil texture and rainfall were assessed. The early planting / fine texture / May + June rainfall subgroup showed a similar EONR for high and low rainfall (206 and 214 kg N ha^{-1}, respectively (Table 2). When corn was planted late on fine-textured soils, high AWDR gave lower EONR (148 kg N ha^{-1}) than low AWDR (190 kg N ha^{-1}). Our data suggest that AWDR classes have an inverse effect on fine-textured soils (i.e., high AWDR gives a lower EONR than low AWDR). Subgroups for combined planting date, timing of N fertilization, and rainfall showed that for late planting EONR was slightly higher for low AWDR than for high AWDR with sidedressing. During wet growing seasons, the EONR for sidedressed corn was raised by 24 kg ha^{-1} for early planting versus late planting.

Table 2. Relationship between EONR, planting date, soil texture and rainfall

Subgroup	*N*	EONR kg ha^{-1}	Min	Max	Yield at EONR Mg ha^{-1}	Min	Max
Subgroup for combined planting date, soil texture and rainfall							
Early planting − fine texture − High May + June rainfall	8	206±17.0	185	228	14.0±1.0	12.5	15.3
Early planting − fine texture − Low May + June rainfall	4	214±22.1	190	237	10.8±0.7	10	11.6
Early planting − fine texture − High AWDR	2	188±11.3	180	196	12.2±0.8	11.6	12.7
Early planting − coarse texture − High May + June rainfall	0	-	-	-	-	-	-
Early planting − coarse texture − Low May + June rainfall	1	-	-	-	-	-	-
Early planting − coarse texture − High AWDR	2	213±17.0	201	225	12.6±0.7	12.1	13.1
Late planting − fine texture − Low May + June rainfall	2	197±43.1	166	227	11.1±0.6	10.6	11.5
Late planting − fine texture − High AWDR	3	148±16.6	132	165	9.5±0.6	8.8	10.1
Late planting − fine texture − Low AWDR	11	190±39.6	134	237	10.8±1.3	9.1	13.1
Late planting − coarse texture − High AWDR	4	199±17.2	175	212	13.0±0.4	12.7	13.5
Subgroup for combined planting date, timing of N fertlization and rainfall							
Early planting − preplant − High May + June rainfall	8	206±16.7	185	228	14.0±1.0	12.5	15.3
Early planting − preplant − Low May + June rainfall	5	212±19.5	190	237	10.8±0.6	10	11.6
Early planting − sidedress − High AWDR	4	201±18.6	180	225	12.4±0.7	11.6	13.1
Late planting − preplant − Low May + June rainfall	2	197±43.1	166	227	11.1±0.6	10.6	11.5
Late planting − sidedress − High AWDR	7	177±31.6	132	212	11.5±2.0	8.8	13.5
Late planting − sidedress − Low AWDR	11	190±39.6	134	237	10.8±1.3	9.1	13.1

AWDR − abundant well distributed rainfall, *N* − number of sites-years in each subgroup, EONR − economic optimum N rate, mean ± standard deviation

This analysis indicated that soil texture, planting date and precipitation affected the EONR. During wet spring, responses to N fertilizer were more pronounced for sidedress application on coarse-textured soils over fine ones. In years where corn was planted late, N response was also greater in coarse-textured soil with high rainfall. This suggests that on coarse-textured soil, additional N is needed to optimize grain yield in years with wet growing season due to considerable losses from leaching. It has been reported that sandy soils are the most vulnerable to nitrate loss, with large losses occurring primarily from leaching. Our findings confirmed those of Scharf (2015), who reported that fertilizer N loss is usually irregular during wet weather and results in a high optimal N rate.

Summary and Conclusion

In this 8-yr (45 site-yr) study of corn N fertilization rates on high-yielding fields, it was observed that grain yields and EONR varied across site-years. Overall, optimal planting window increased grain corn yields compared to late planting. Averaged across textures, planting date, and weather, EONR was 195 kg N ha^{-1}, which is above the current N recommendation for this region (170 kg N ha^{-1}).

The EONR was affected by soil textural classes, planting date and rainfall. The results from our study indicated that N rate guidelines may need to be increased for the optimal planting window, and should be based on soil texture and weather conditions.

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