Controlled release nitrogen fertilizer use in potato production systems of eastern Canada

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Abstract
Nitrogen (N) is the most limiting essential nutrient for potato (*Solanum tuberosum* L.) and its management is important from both economic and environmental standpoints. Controlled-release N fertilizers, such as polymer-coated urea (PCU), could reduce N losses and increase N use efficiency (NUE) by matching the release of N with potato N uptake. During the last 10 years, different studies were conducted in eastern Canada (Quebec and New-Brunswick) to evaluate the effectiveness of PCU in potato production. A total of nine site-years were conducted between 2006 and 2012 to compare the PCU to the most used conventional N sources. Their effects were assessed on various parameters including yield, specific gravity, NUE, chlorophyll meter readings nitrate (NO_3) leaching, and nitrous oxide (N_2O) emissions along with soil nitrate availability during growing seasons and at harvest. Our results showed that PCU can maintain or increase marketable tuber yield and quality, increase NUE, and reduce NO_3 leaching, particularly in excessively wet years. However, higher N availability from PCU may have implications for N_2O emissions and non-growing season N losses. Evidence of the overall economic advantages of using the PCU in potato production, if any, will be needed to influence a more widespread adoption of PCU by producers.

Key Words
Nitrogen fertilizers, urea, controlled release, potato, NUE.

Introduction
Potato (*Solanum tuberosum* L.) crops frequently require high applications of fertilizer nitrogen (N) to achieve high tuber yield and quality. In eastern Canada, general fertilizer N recommendations vary between 125 to 200 kg N ha^{-1} (NBDAFA 2001; CRAAQ 2010). The apparent recovery of applied fertilizer N by the growing crop, however, may average less than 50% (Cambouris et al. 2016; Ziadi et al. 2011). Management of this fertilizer N is important from both economic and environmental standpoints (Zebarth et al. 2009). Nitrogen deficiency results in poor crop growth, small tuber size, and low tuber yield (Bélanger et al. 2000; Cambouris et al. 2016), while excessive N can lead to poor tuber quality, delayed crop maturity, increased N_2O emissions, and excessive nitrate leaching (Ojala et al. 1990; Bélanger et al. 2000; Burton et al. 2008). However, the optimal fertilizer N rate can vary widely among fields and years (Cambouris et al. 2015), due to different factors including crop N demand, soil N supply and climatic conditions.

Controlled-release N fertilizers, such polymer-coated urea (PCU), are a management strategy intended to increase NUE while maintaining or improving crop yield (Shoji et al., 2001; Wilson et al., 2009). Contrasting results, however, are reported in the literature regarding the benefits of PCU on crop yield and quality over traditional N fertilizers. Shoji et al. (2001) reported increased tuber yield and NUE with controlled-release N compared to urea. Similarly, total and marketable yield gains with PCU urea averaged 3.9 and 3.3 Mg ha^{-1}, respectively, over urea in the study by Zvomuya and Rosen (2001). Conversely, other studies reported lower yield with controlled-release N compared to soluble-N sources (Maynard and Lorenz 1979; Waddell et al. 1999). Under conditions conducive to NO_3 leaching, Zvomuya et al. (2003) reported a 12 to 19% increase in total and marketable tuber yields with polyolefin-coated urea compared to urea. These findings clearly indicate that the effect of controlled-release N products on potato yield and quality probably depends on local conditions.
In this paper, we summarize the effectiveness of PCU on potato yields, NUE and NO_2 emissions under the humid temperate conditions of eastern Canada.

Methods
Three studies with a total of nine sites-years were used during different growing seasons (2006 to 2012) in two provinces of eastern Canada (Quebec and New-Brunswick). The PCU used in these experimental sites was ESN (44-0-0) "Environmentally smart nitrogen" developed by Agrium (Agrium Advanced Technologies, Calgary, AB, Canada, www.agriumat.com), which is characterized by a semi-permeable membrane that

enables water to inter the urea granule by dissolving nitrogen inside. The gradual release of N is dependent on soil temperature and moisture.

Study #1 (St-Ubalde Site, Quebec)
The experiment was conducted over three growing seasons (2006-2008) in St-Ubalde, Quebec, Canada (46°45′00″ N, 72°16′00″ W) as reported by Ziadi et al. (2011). Each year, treatments consisted of an unfertilized control (0 N), calcium ammonium nitrate (27-0-0) (CAN) applied at 150 kg N ha^{-1} (150CAN) and 200 kg N ha^{-1} (200CAN), and PCU applied at 150 kg N ha^{-1} (150PCU). A new experimental area was selected each year to avoid the effects of residual N from previous years. Three replicates in a randomized complete block design were used each year. Nitrogen fertilizers were applied in bands at planting, 5 cm below and 5 cm on both sides of the seed. At harvest, marketable yield was estimated from the middle two rows (5 m long) in each experimental unit. Tubers were graded into various size classes and weighed. Other parameters including NUE, soil NO_3, and specific gravity were measured but not reported in this paper.

Study #2 (Ste-Catherine-de-la-Jacques-Cartier, Quebec)
The experiment was conducted over five growing seasons (2008-2012) in Ste-Catherine-de-la-Jacques-Cartier (46°51'N, 71°37'W), near Quebec City, Canada as reported by Cambouris et al. (2016). The experiment included 13 treatments arranged in a randomized complete block design with four replications of each treatment in each year. Treatments were a factorial of four N rates (60, 120, 200, and 280 kg N ha^{-1}) and three N sources [ammonium nitrate (AN; 34-0-0), ammonium sulphate (AS; 22-0-0) and a polymer-coated urea (PCU)] plus an unfertilized control. The effect of N fertilizer source and rate on total and marketable tuber yield, total plant N accumulation, specific gravity, culls (unmarketable tubers) and apparent fertilizer N recovery (ANR) were determined. The ANR data will be presented in this paper.

Study #3 (Fredericton, New-Brunswick)
The study was conducted over three growing seasons (2008-2010) at Fredericton, New-Brunswick, Canada (45° 85'N; 66° 36 'W) as reported by Zebarth et al. (2012). Briefly, a randomized complete block design with the following four N treatments, in four replications, was used: (1) a control, which received no fertilizer N; (2) conventional fertilizer N management for Atlantic Canada, which consists of all N banded at planting as diammonium phosphate (DAP) plus (AN); (3) split N application with 60% of N banded at planting as DAP plus AN and 40% of N broadcast and incorporated at final hilling as AN; and (4) all N banded at planting as PCU. The fertilizer N application rate was 193 kg N ha^{-1} for all three N sources, the recommended rate for this site with barley as a preceding crop (Zebarth et al. 2012). At harvest, total tuber yield and tuber specific gravity were determined from each plot. In addition, N_2O and CO_2 flux measurements (Burton et al. 2008) a long with soil mineral N concentrations were made during each growing season. Soil N_2O flux will be presented.

Results
Results obtained from study #1 indicated that marketable yield varied from 17.2 to 29.3 Mg ha^{-1}, which is in same range as other studies conducted in eastern Canada (Bélanger et al. 2000). The 150PCU treatment increased marketable yield and the yield of medium-size tubers by an average of 12% compared with the 150CAN and 200CAN treatments (Table 1). The increased potato yields obtained with the PCU in the present study are in line with the results of previous studies (Shoji et al. 2001; Zvomuya and Rosen 2001). These results provide evidence that PCU is a promising N source for increasing potato tuber yield, presumably because of the closer synchrony between potato N uptake and N release.

Table 1. Effects of N fertilization treatments and cultivars on marketable yield and yields of three potato size classes (adapted from Ziadi et al. 2011)

	Marketable yield	Potato size classes		
		Jumbo	Medium	Small
	Mg ha^{-1}			
Treatments †				
Control	17.2	3.0	7.5	6.8
150CAN	26.0	7.4	10.9	7.3
150PCU	29.3	8.6	14.6	6.8
200CAN	26.3	8.0	11.3	6.9

† 150CAN and 200CAN: 150 kg N ha^{-1} and 200 Kg N ha^{-1}as calcium ammonium nitrate, respectively; 150PCU: 150 kg N ha^{-1} as controlled-release.

Results obtained from study #2 showed that a one-time application of PCU significantly increased ANR above that of AN and AS in one of five growing seasons (2008, Table 2). On average, the ANR in whole plants (vines and tubers) ranged from 33 to 69%, with a mean of 55% (Table 2). Nitrogen source significantly influenced ANR (Table 2). There was a decreasing trend in ANR with increasing N fertilizer application rate in each year, except in 2010 (Cambouris et al. 2016).In 2008, ANR was 25 and 30% higher with PCU than AN and AS, respectively (Table 2). In 2010, ANR was 33% greater ($P < 0.05$) with AN than AS, even though total plant N accumulation in 2010 was only 9% greater ($P = 0.058$) for AN than AS (Cambouris et al. 2016). On average across the five growing seasons, ANR was 10% lower ($P < 0.05$) for AS than AN and PCU (Table 2). It is likely that the greater ANR for PCU than AN and AS in 2008 was due in part to greater NO_3 leaching below the root zone during the growing season in the AN and AS plots due to the timing and intensity of rainfall, and better synchrony between plant N demand and N supply in the PCU plots. Total rainfall in 2008 was 31% above normal, including 153 and 38% above normal in June and July, respectively, which corresponds to the time during and immediately after the second N application for AN and AS was made.

Table 2. Effect of N fertilizer source and application rate on apparent N recovery in potato tubers and vines (adapted from Cambouris et al. 2016)

	2008	2009	2010	2011	2012	Mean‡
			%			
N source†						
AN	55b§	68a	44a	63a	56a	57
AS	53b	63a	33b	55a	55a	52
PCU	69a	62a	40ab	58a	58a	57

† AN, ammonium nitrate; AS, ammonium sulphate; PCU, polymer-coated urea.‡ Average across years.
§ Means within a column for N source followed by different lowercase letters are significantly different at $P < 0.05$.

Results obtained from Fredericton site indicated that N_2O emissions varied among the growing seasons, with greater cumulative values in 2010 than in 2008 and 2009 (Zebarth et al. 2012). The N_2O emissions were relatively uniform throughout 2008 regardless of N fertility treatment or row location (Fig. 1). On average, N_2O emissions were greater for the fertilized treatments than for the unfertilized control, and greater for the PCU treatment than for the split N treatment. The N_2O emissions were numerically higher for the PCU treatment than for the other fertilized treatments in 2009; however, this difference was not statistically significant (Zebarth et al. 2012). This suggests that substitution of conventional fertilizer products with a PCU product when the risk of NO_3 leaching is limited will not necessarily reduce N_2O emissions, and may in some cases increase the risk of N_2O emissions. It may be necessary to reduce applications rates with PCU products in order to achieve benefits in terms of reduced N_2O emissions. Further research is required.

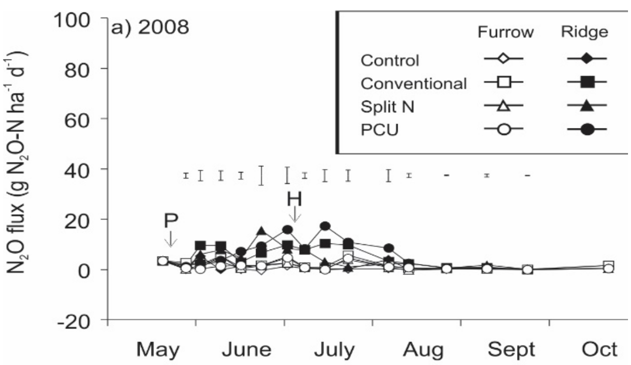

Fig. 1: Soil N_2O flux for four N fertility treatments, measured separately from the potato ridge and furrow locations, over the growing season of 2008. Errors bars indicate ± 1 SE. The time of planting (P) and final hilling (H) when fertilizer was applied are indicated by arrows (adapted from Zebarth et al. 2012).

Conclusion

Our results show that PCU can maintain or increase marketable tuber yield and quality, increase NUE, and potentially reduce NO_3 leaching, particularly in excessively wet years. However, higher N availability from PCU may have implications for N_2O emissions and non-growing season N losses.

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