Effect of nitrogen source and rate on potato tuber external and internal physiological disorders

Athyna N. Cambouris[1], Mervin St. Luce[1], **Noura Ziadi[1]**, Bernie J. Zebarth[2] and Isabelle Perron[1]

[1]Agriculture and Agri-Food Canada, 2560 Hochelaga Boulevard, Quebec City, QC, Canada, G1V 2J3, Noura.Ziadi@agr.gc.ca
[2]Agriculture and Agri-Food Canada, 850 Lincoln Road, PO Box 20280, Fredericton, NB, Canada, E3B 4Z

Abstract
Potato (*Solanum tuberosum* L.) tuber quality is an important factor that can affect its market value. We investigated the impact of nitrogen (N) fertilizer source and rate on external and internal defects of potato tubers across five growing seasons (2008 – 2012) under irrigated conditions on sandy soils in Quebec, Canada. The treatments included an unfertilized control, and three N sources [ammonium nitrate (AN), ammonium sulphate (AS) and polymer-coated urea (PCU)] applied at four rates (60, 120, 200 and 280 kg N ha^{-1}). The PCU was applied 100% at planting and the AN and AS were applied 40% at planting and 60% at hilling. Yield of misshapen tubers was greater and there was a lower incidence of rhizoctonia at higher N rates. Conversely, common scab and brown spot were more prevalent at higher N rates. Yield of misshapen tubers and the presence of hollow heart were greater for AN and PCU than AS. There was also a greater occurrence of common scab for PCU as compared to AN and AS. Additionally, brown spot tended to be more prevalent when PCU was used. Our results suggest that while PCU may give similar potato tuber yields to AN and AS, there may be a slightly greater tendency for increased common scab when PCU is applied. Overall, this study showed that N fertilizer rate and source are important factors that can influence the occurrence of external and internal physiological disorders of potato tubers, and thus tuber marketability.

Key words
Nitrogen fertilizers, brown spot, hollow heart, controlled-release nitrogen, potato quality.

Introduction
Potato (*Solanum tuberosum* L.) has a high nitrogen (N) requirement, which can ultimately affect potato tuber yield and quality (Cambouris *et al.* 2016). Potato tuber quality is a broad term encompassing features such as texture, color of raw and processed products, external and internal physiological disorders, specific gravity, general appearance and nutritive value (Sowokinos 2007). Indeed, internal and external physiological disorders can reduce the marketability of potato tubers. Sowokinos (2007) stated that these defects may be due to both biotic (e.g., bacteria, fungi, viruses, phytoplasms and nematodes) and abiotic stress (e.g., soil fertility, soil type, agronomic practices and environmental conditions).

Important external defects include misshapen tubers, rhizoctonia and common scab. Rhizoctonia is identified by the presence of hard, black or dark brown masses on the surface of the tubers (Christ 1998). Common scab is a bacterial infection of potato caused by *Streptomyces scabies* and other *Streptomyces* species, which induce necrotic lesions (Christ 1998). The effect of N fertilizer rate on misshapen tubers is inconsistent. Sparrow and Chapman (2003) reported an inconsistent effect of N rate on yield of misshapen tuberswith often no practical importance, while Rens *et al*. (2015) found no effect. Nonetheless, soil moisture availability plays a key role in affecting the yield of misshapen tubers (Sparks 1958). It was also reported that split N application may increase the yield of misshapen tubers by enhancing second growth on tubers (Roberts *et al.* 1982). Internal physiological disorders such as hollow heart and brown heart are some of the more important internal defects of potatoes grown in Canada. Hollow heart usually results from too rapid or irregular growth due to over-fertilization, and often occurs during wet seasons in very fertile or heavily irrigated soils (Bussan 2007; Christ 1998). Brown spot, on the other hand, is mostly due to a lack of adequate soil moisture, moisture fluctuations and high temperatures, particularly at latter stages of growth. These defects can only be identified after slicing the potato tubers, since affected tubers and foliage show no external symptoms (Silva *et al.* 1991). Some studies indicate that high N fertilizer rates and increased N availability were associated with increased hollow heart and brown spot (McCann and Stark 1989; McPharlin and Lancaster 2010). However, the effect of N fertilizer rate may be partly related to the timing of N fertilizer application and soil moisture (Abbas and Ranjan 2015; McCann and Stark 1989; Silva *et al.* 1991), and may vary according to site conditions (McPharlin and Lancaster 2010). Porter and Sisson (1991) found no effect of N fertilizer rates on hollow heart in large Russet Burbank tubers, however the incidence of hollow heart in large Shepody tubers was reduced at rates above 90 kg N ha^{-1}. Other studies found no effect of N rate on hollow heart or internal brown spot (Silva *et al.* 1991; Sparrow and Chapman 2003).

Most studies focused on N fertilizer rate and other abiotic and biotic stresses. The interaction between N fertilizer source and rate on external and internal defects in potatoes has rarely been investigated. We examined the impact of N fertilizer source and rate on external and internal defects of potato tubers across five growing seasons under irrigated conditions on sandy soils in Quebec, Canada.

Methods

Site description

The field experiment was conducted over five growing seasons (2008–2012) on a sandy-loam soil in Ste-Catherine-de-la-Jacques-Cartier (46°51′N, 71°37′W), near Quebec City, Canada. In order to follow the irrigation pivot system and to respect the potato rotation, two fields were used. The first field was a Morin soil series and was used in 2008, 2010 and 2012 and the second field was a Pont-Rouge soil series and was used in 2009 and 2011. Both soil series are very similar and were classified as Orthic Podzols. Each year, the cultivar Russet Burbank was used. The preceding crops were corn (*Zea mays* L.) in 2008 and 2012, spring wheat (*Triticum aestivum* L.) in 2009 and 2010 and oats (*Avina sativa* L.) in 2011. Soil properties and climatic conditions at the site during the experiment were previously reported (Cambouris *et al.* 2016).

Experimental design and treatments

Details of the experiment and treatments were previously reported by Cambouris *et al*. (2016). Briefly, 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 PCU product was Environmentally Smart Nitrogen (44–0–0) developed by Agrium Inc. (Agrium Advanced Technologies, Calgary, AB, Canada, www.agriumat.com). Each experimental unit consisted of six rows measuring 8 m in length, with a row spacing of 0.91 m and within-row spacing of 0.43 m (total area of 43.7 m^2). The potato crop was planted on 14 May 2008, 19 May 2009, 10 May 2010, 25 May 2011, and 14 May 2012. Phosphorus and potassium were applied based on local recommendations. At planting, 100 kg P_2O_5 ha^{-1} was banded as triple superphosphate. Potassium was applied at 230 kg K_2O ha^{-1} in two applications: pre-plant broadcast of 170 kg K_2O ha^{-1} as potassium chloride, and 60 kg K_2O ha^{-1} banded at planting in a 50%-50% mixture of potassium chloride and Sulmomag (22% K_2O, 11% Mg and 22% S).The N treatments at planting were applied 0.05 m below the seed. The PCU was applied 100% at planting and the AN and AS were applied 40% at planting and 60% at hilling, based on the locally recommended practice. The second application (at hilling) of AS and AN were performed 42, 51, 43, 41, and 38 days after planting (DAP) in 2008, 2009, 2010, 2011 and 2012, respectively. The targeted DAP for second N application was 40 and therefore differences were due to environmental conditions.

Soil and plant sampling and analyses

The potato vines were desiccated using diquat as desiccant on 14 Sept. 2008, 15 Sept. 2009, 10 Sept. 2010, 11 Sept. 2011, and 9 Sept. 2012. Tubers were then harvested on 135, 127, 133, 124, and 133 DAP in 2008, 2009, 2010, 2011 and 2012, respectively, to determine total and marketable yields. A representative subsample of 50 washed marketable tubers were visually classified into five classes to determine the external defects, i.e., the presence of scab and rhizoctonia and the intensity of the symptoms. In addition, a representative subsample of 25 washed marketable tubers were longitudinally cut to determine the presence or absence of internal defects such as hollow heart and brown spot.

Statistical analysis

Analysis of variance across years was performed using PROC MIXED of SAS (SAS Institute 2013) on the effect of N fertilizer treatments on the external and internal defects. The fertilizer treatments had a factorial structure, with three N sources and four N rates, augmented by one unfertilized control. Hence, contrasts were derived from this factor to investigate the main effect of N sources and rates, as well as the interaction between both factors. The N fertilizer treatments were treated as fixed effects, with year and block (year) as random effects. Only the 2009 data was used for brown heart since most of the values for the other years were zero. All data were tested for homogeneity and normality, and all effects were declared statistically significant at $P < 0.05$.

Results

External defects

The total yield results were previously reported by Cambouris *et al*. (2016), where total tuber yields increased with N rate but was similar among the N sources. The yield of misshapen tubers was affected by N rate, and increased with increasing N rate up to 200 kg N ha^{-1} (Table 1). This was likely due high N availability at higher N rates. Sparrow and Chapman (2003) applied AN up to 250 kg N ha^{-1} at planting followed by several topdressing N rates at nine sites in Australia. They reported that N rate at planting increased the yield of misshapen tubers at only two sites, while topdressing reduced the yield of misshapen tubers at one of these two sites. Conversely, Rens *et al*. (2015) found no effect using liquid urea AN. To our knowledge, our study was the first to use different N sources and application methods. The PCU and AN resulted in a greater quantity of misshapen tubers than AS (Table 1), probably as a result of greater N availability and apparent N recovery from PCU and AN (Cambouris *et al.* 2016). The nitrification of AS was probably delayed under the cool climatic conditions (Shrestha *et al.* 2010). In addition, there was probably a reduction in soil pH in the AS plots, which likely reduced root growth and N uptake. Rhizoctonia was significantly influenced by N rate, and was absent to a greater extent when N was applied at 280 kg N ha^{-1} than at 60 to 200 kg N ha^{-1} (Table 1), due probably to a more rapid emergence of the potato plants at the higher N rate (Christ 1998). However, it was not entirely clear why rhizoctonia was similar between the control and the highest N rate. Common scab was affected by N rate, and was absent to a greater extent when N was applied at 0 to 120 kg N ha^{-1} than at 280 kg N ha^{-1} (Table 1). The absence of common scab was more pronounced for AN and AS than for PCU (Table 1). This was likely due to the ammonium forms of N, which may have lowered the soil pH (Christ 1998).

Internal defects

Nitrogen fertilizer rate had no effect on hollow heart (Table 1), which was in agreement with the findings of other studies (Porter and Sisson 1991; Silva *et al.* 1991; Sparrow and Chapman 2003). Hollow heart was absent to a greater extent for AS than AN and PCU (Table 1). In contrast, brown spot was influenced by N rate, but this depended on the N source (Table 1). For AS and AN, a greater proportion of tubers showed signs of brown spot when N was applied at more than 120 kg N ha^{-1} than at 0 to 60 kg N ha^{-1} (not shown). For PCU, there was a greater incidence of brown spot at 200 kg N ha^{-1} than any other N rates (not shown). This suggests that high N rates may increase the incidence of brown spot (McCann and Stark 1989; McPharlin and Lancaster 2010). Although not significant, there was a trend towards higher brown spot for PCU than AS and AN (Table 1).

Table 1. Nitrogen fertilizer treatment effects on external and internal defects of Russet Burbank potato tubers.

	Misshapen tubers	Absence of rhizoctonia	Absence of common scab	Absence of hollow heart	Absence of brown spot
	Mg ha^{-1}	%			
		P value			
Treatment	< 0.0001	0.046	< 0.0001	ns[†]	0.0006
Contrast					
N rate (R)	< 0.0001	0.006	0.032	ns	0.0003
N Source (S)	0.009	ns	< 0.0001	0.035	ns
R x S	ns	ns	ns	ns	0.032
		Mean			
kg N ha^{-1}					
0	1.1d[‡]	44.9ab	99.2a	92.1	99.0a
60	2.2c	39.3b	98.9a	91.9	95.3a
120	3.6b	38.5b	98.6a	90.4	91.3ab
200	4.3a	42.6b	98.5ab	90.6	82.7c
280	4.3a	49.6a	97.4b	91.5	88.7b
N source					
AN	3.72a	40.1	98.9a	90.7b	90.0
AS	3.09b	45.3	98.9a	92.2a	91.7
PCU	4.01a	42.1	97.2b	90.4b	86.7

† ns, not significant ($P > 0.05$).

‡ Means followed by the same letter are not significantly different at ($P > 0.05$).

Conclusion

This study investigated the interaction between N fertilizer rate and source on external and internal physiological disorders of potato tubers. Generally, the yield of misshapen tubers was greater and there was a lower incidence of rhizoctonia at higher N rates. Conversely, common scab and brown spot were more prevalent at higher N rates. The yield of misshapen tubers and the presence of hollow heart were greater for AN and PCU than AS. There was also a greater occurrence of common scab for PCU as compared to AN and AS. Our results suggest that while PCU may give similar potato tuber yields to AN and AS, there may be a higher tendency for common scab when PCU is applied as compared to AN and AS. Overall, this study showed that N fertilizer rate and source are important factors that can influence the occurrence of external and internal physiological disorders of potato tubers, and thus tuber marketability.

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