Root morphology, yield and nitrogen uptake in two potato clonal selections of Russet Norkotah at different soil nitrogen levels

Mehdi Sharifi 1, Bernie. J. Zebarth 2, Mohammad A. Hajabbasi 1 and Mahmoud Kalbasi 1

1 Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, Iran, Phone: 0311-3913471 Email: sharifi@ag.iut.ac.ir, hajabbas@cc.iut.ac.ir, kalbasi@cc.iut.ac.ir; 2- Potato Research Centre, Agriculture and Agri-Food Canada, PO Box 20280, Fredericton, New Brunswick, Canada E3B 4Z. Phone: +1-506-4524828 Email: ZebarthB@agr.gc.ca

Abstract
The low vine vigor and high N requirement of Russet Norkotah may lead to higher risk of nitrate leaching compared to other cultivars. Recent clonal selections from Texas have produced strains that have larger and stronger vines, which may alter N requirements. The importance of clonal variation in N requirements and root morphological properties is not known. A field experiment was conducted during 2002 to evaluate yield, N uptake and root morphological characteristics of two Russet Norkotah clonal selections at different soil N levels. The standard clone (SRC) and Texas selection 112 (TX112) of Russet Norkotah were used. Whole plants were excavated and partitioned to different components. Root length (RL), root length density (RLD), root average diameter (RAD) and root dry weight (RDW) were measured. Tuber yield, dry weight and N concentration of different component and plant N content were determined. Soil inorganic N was measured at planting and at harvest. The two clones of Russet Norkotah had quite different partitioning of dry matter and N but there was little difference in their vine yield, total dry weight and plant N content. Vines dry weight, RDW, RL and RLD was higher in TX112 than SRC, whereas tuber nitrogen concentration was higher in SRC than TX112 clone. The nitrogen fertilization increased tuber yield, total dry weight, vine dry weight and tuber and vine N concentrations but significantly decreased the RL and RLD. The TX112 vine growth was more responsible to N application than SRC whereas the SRC root growth was more sensitive to N application than the TX112 clone. Although, Root length and RLD were significantly higher for TX112 clone compared to SRC but cultivar Russet Norkotah has a more limited root system compare to other potato cultivars. Soil nitrate concentration was not affected by N fertilization and clone after harvest. Under the conditions of this study, use of new clonal selections of cultivar Russet Norkotah did not have any yield or nitrate leaching advantages over the standard cultivar. Nitrogen fertilization increased mostly vegetative growth and risk of nitrate leaching to groundwater especially in early season.

Key Words: dry matter production, nitrogen accumulation, root characteristics, Solanum tuberosum L., tuber yield

Introduction
Potato (Solanum tuberosum L.) is the fourth most important world food crop, after rice, wheat, and maize which require high inputs of N and water for optimum production. Combination of superficial rooting system, high nitrogen fertilizer application rates and heavy rain or irrigation greatly increases the potential for nitrate leaching which consequently is more costly and may pose environmental pollution. While numerous studies have explored improved N management practices as a strategy for minimizing N loss, there is potential for exploiting the genetic variability among cultivars and mutant strains of asexually propagated crop species such as potato for improved N uptake. Significant variations in N use efficiency characteristics have been identified among potato cultivars, clonal selections, and ascensions of wild potato species (Errebhi et al., 1999; Zebarth et al., 2004; Zvomuya et al., 2002). This
suggests that there may be the potential to reduce the risk of nitrate leaching through selection of more efficient potato cultivars or clonal selections of cultivars.

Russet Norkotah was released as an early fresh market russet in 1987 (Johansen et al., 1988). It is popular because of its relatively high yield, high percentage of U.S. No. 1 tubers and excellent tuber type. This cultivar has low vine vigor, is susceptible to early die-down, and requires higher fertilizer N inputs than many other cultivars (Zvomuya et al., 2002). Residual soil nitrate measured in commercial potato fields was almost twice as high for Russet Norkotah compared to Russet Burbank and Shepody, suggesting an increased risk of nitrate leaching with Russet Norkotah production (Zebarth et al., 2003). This was attributed to higher N fertilization rates, (Zebarth et al., 2003) and lower N uptake efficiency (Zebarth et al., 2004) for Russet Norkotah compared to Russet Burbank and Shepody.

Recent clonal selections of Russet Norkotah have identified strains with higher yield potential and larger and stronger vines that may require lower fertilizer N inputs (Miller et al., 1999). Miller et al. (1995) demonstrated that clonal selection could result in the improvement of existing cultivars with modification of traits such as stronger vines, which can improve productivity under stressful conditions. New clonal selections of Russet Norkotah from Texas produced greater biomass than the standard clone of Russet Norkotah per kg of N applied when N rates were low and per kg of fertilizer N absorbed by the plant (Zvomuya et al., 2002). Their superior yield has been attributed to increased vine vigor and resistance to verticillium wilt (Miller et al., 1999).

Although, the physiological basis of genotypic variation in nitrogen use efficiency of potato is poorly understood but the difference in root morphological characteristics have been considered as one of the possible mechanism. Sattelmacher et al. (1989) attribute differing nitrogen uptake efficiency of two commercial potato cultivars to differences in root morphology.

The objective of this study was to determine the effect of N fertilization on plant dry matter, N accumulation and root morphological parameters of two clonal selections of Russet Norkotah.

Materials and Methods

The study site was at Potato Research Centre, Agriculture and Agri-Food Canada, Fredericton, New Brunswick, Canada (45° 55' N; 66° 37' W). Soil was a coarse-textured developed on till deposits, and classified as Haplorthods with unfertilized barley (Hordeum vulgare L.) as preceding crop. Soil (0-15 cm) had 505 g kg⁻¹ sand, 346 g kg⁻¹ silt, and 149 g kg⁻¹ clay (hydrometer method); pH of 6.2 (1:1 water), and organic carbon content of 20.7 g kg⁻¹ (combustion method). Soil inorganic N was measured at planting and at harvest as a possible indicator of N uptake efficiency. Soil samples (0-30 cm) were taken and frozen for subsequent analysis. Soils were passed through a 4.75-mm sieve to remove coarse mineral fragments, extracted with 1.7 M KCl, and the extract analyzed colorimetrically for NO₃⁻ and NH₄⁺ concentrations using a Technicon TRAACS 800 auto-analyzer (Zebarth and Milburn, 2003).

A factorial arrangement of treatments in a randomized complete block design with four replications was used with two fertilizer N rates (0 and 150 kg N ha⁻¹) and two clonal selections of potato cultivar Russet Norkotah. The two clonal selections were the original Russet Norkotah (Johansen et al., 1988) and Texas 112 (Miller et al., 1999). Each plot contained six rows 10 m in length, with two outer rows acting as guards. Hand-cut 57 g (± 7 g) seed was hand-planted on May 24 (2002) at 0.30 m within-row spacing in rows 0.91 m apart. Nitrogen fertilizer was applied as ammonium nitrate (NH₄NO₃), banded at planting approximately 7.5 cm to each side, and 5 cm below the seed pieces. All plots received 150 kg
P₂O₅ and K₂O ha⁻¹ banded similar to N at planting time. Standard commercial practices were used for tillage and, weed, insect, and disease control.

One representative plant was taken from each plot on August 26, 2002 (96 DAP). Whole plants were excavated and partitioned into roots, stolons, tubers, vines and fruit. The plant components were dried at 55 °C and weighed. Nitrogen concentration in each component was determined by combustion using a Leco CNS-1000. Tuber yield, tuber dry weight, vine dry weight, total dry weight (TDW) and total plant N content (PN) were calculated as described by Zebarth and Milburn (2003).

Before drying, roots were washed using a hydropneumatic elutriation root washer (sieve size = 0.47 mm) (Smucker et al., 1982). Roots photos were taken using an Epson PhotoPC 750z digital camera and were analysis by WinRHIZO Version 2002C PRO software (Arsenault et al., 1995). Root length and average diameter were calculated.

Data were subjected to analysis of variance (ANOVA) using the General Linear Model of SAS (SAS Institute Inc., Cary, NC, Version 8). Treatments interaction means were compared using Fisher’s Protected Least Significant Difference (LSD) test. A logarithmic transformation of soil nitrate concentration was performed prior to statistical analyses.

Results and Discussion

Yield and Dry Matter Production

Although, vine and root dry weight were significantly higher for the TX112 clone compare to SRC but clones did not significantly differ in tuber yield and TDW (Table 1 and 2). The SRC partitioned 12% more dry matter to tubers than did TX112 clone, whereas TX112 clone partitioned 11% more dry matter to vines than did SRC. Zvomuya et al. (2002) reported that the genotype main effect was not significant for any of the yield parameters but harvest index (HI) was 7% greater for SRC than for TX selections, reflecting the larger vine growth that characterizes the selections.

Nitrogen fertilization increased tuber yield, vine dry weight and total dry weight by 42, 139 and 42%, respectively, but did not affect other parameters (Table 1). This suggests that N application resulted in an increase in the proportion of TDW that was partitioned to the vines. Millard et al. (1989) reported similar result for N fertilization effect on TDW and tuber dry weight in Maris Piper potato. The difference in effect of N fertilization on tuber dry weight and tuber yield confirms reducing of tuber specific gravity with N application. There was a significant clone by N rate interaction on vine dry weight which N fertilization resulted in higher increase of vine dry weight for the TX112 clone than SRC (Fig. 1). The vine dry weight, therefore, was significantly higher for TX112 clone than for SRC only in fertilized treatments.

Results from this study contradict earlier reports of consistently higher tuber yields with Texas Norkotah strains compared to standard Russet Norkotah (Miller et al., 1999). This discrepancy may be due to different environmental conditions of the previous study sites compared to the present study. The Texas strains were developed for improved performance under the stressful conditions of Texas (Zvomuya et al., 2002). The lack of a significant yield response in this study may reflect the lack of significant disease pressure or moisture stress, as well as the generally shorter growing season in Atlantic Canada compared to other growing regions. It may also relate to later maturity of Texas selections (Zvomuya et al., 2002). The difference in vine dry weight between the clones corresponds to superior vine growth associated with Texas selection compared with standard cultivars.

Nitrogen Concentration of Vines, Roots and Tubers at Harvest
Genotype main effects were significant for tubers N concentration but roots and vines N concentrations were not affected by clone (Table 2). N fertilization significantly affected vine and tuber N concentration. There were significant clone x N rate interaction for tubers N concentration. Nitrogen fertilization resulted in higher increase of tuber N concentration for SRC than TX112 clone at harvest (Fig. 2). The tubers N concentration, therefore, was significantly higher for SRC than for TX112 clone only in fertilized treatments. This may be related to translocation of N from the canopy to tubers occurred earlier in SRC than TX112 clone due to its earlier maturity. It is consistent with lower value (but not significant) of vine N concentration in TX112 clone than SRC. Zvomuya et al. (2002) reported that vine, tuber and total N uptake increased linearly as N rate increased from 28 to 336 kg ha\(^{-1}\).

**Nitrogen Uptake**

Nitrogen uptake like dry matter production was not affected by genotype but N fertilization increased N uptake by 160%. Zebarth et al. (2004) showed that N accumulation increased linearly with increasing crop N supply.

**Root Morphology**

Root length and RLD were significantly higher for TX112 clone compared to SRC; however, RAD was not affected by clone. Nitrogen fertilization significantly decreased RL and RLD but did not affect RAD. There was a significant clone by N rate interactions on RLD (Table 2). Rate of decrease in RLD with N fertilization was higher for the SRC compared with the TX112 clone. The SRC had significantly lower RLD in fertilized compared to non-fertilized treatments (Fig. 3).

Mean values of RL and RLD were about 0.60 km plant\(^{-1}\) (2.2 km m\(^{-2}\)) and 0.60 cm cm\(^{-3}\) respectively (Table 1). These values are small in comparison to previously published values for potato (Vos and Groenwold, 1986; Lesckynski and Tanner, 1976; Stalham and Allen, 2001). RL and RLD differences among various experiments could be attributed in part to genotypic differences and response of these genotypes to various treatments. Russet Norkotah cultivar is an early maturing, determinate variety, and thus has a relatively limited root system compared with other potato cultivars. Root average diameter was about 0.34 mm, which is greater than those previously reported for other potato cultivars. Lesczynski and Tanner (1976) stated that the major portion of Russet Burbank potato roots had diameters less than 0.2 mm. Vos and Groenwold (1986) found that 91% of root diameters were smaller than 0.44 mm.

**Soil Mineral Nitrogen Concentrations**

Soil inorganic N content (0-30 cm) at planting was 7 kg NH\(_4\)-N ha\(^{-1}\) and 14 kg NO\(_3\)-N ha\(^{-1}\). Soil nitrate and ammonium concentrations for 0-30 cm depth were not affected by clone or N fertilization at harvest (Table 2). The highest risk of nitrate leaching, therefore, is early in the growing season prior to rapid N uptake by crop, and outside of the growing season when soil residual nitrate and mineralized nitrogen may leach.

**Conclusions**

Results indicate that there are significant genotypic differences in root morphology among clonal selections of Russet Nokotah. The standard Russet Norkotah clone has a more limited root system in comparison to TX112 clone. Significance of the size of rooting system for yield or nitrogen uptake is much greater when experimental condition such as soil type, soil
humidity and soil fertility become growth limiting factors (El Bassam, 1981). Soil fertility and nitrogen mineralization in our experiment was perhaps still high, even for the non-fertilized treatments. In more adverse conditions (low nitrogen supply and moisture stress), TX112 clone with stronger root system may show some advantages over SRC.

By comparison of root parameter values obtained in this study with published results, we may conclude that cultivar Russet Norkotah has a more limited root system which may pose higher risk of nitrate leaching as compared with other potato cultivars (Zebarth et al., 2003). Two clones of Russet Norkotah had quite different partitioning of dry matter and nitrogen but there was little difference in their total dry weight and total plant N content. Under the condition of this study, use of new clonal selections of cultivar Russet Norkotah did not have any yield or nitrate leaching advantages over standard cultivars. Nitrogen fertilization increased mostly vegetative growth, total plant N content and risk of nitrate leaching to groundwater especially in early season. Nitrogen fertilization also increased tuber yield in standard Russet Norkotah although its tuber gravity was decreased.

References


**Figure 1.** The effect of N fertilization on vine dry weight of standard Russet Norkotah clone (SRC) and Texas112 clone of Russet Norkotah (TX112). Same lower case letters indicate non-significant difference at the 5% level of probability.

**Figure 2.** The effect of N fertilization on tuber N concentrations of standard Russet Norkotah clone (SRC) and Texas112 clone of Russet Norkotah (TX112). Same lower case letters indicate non-significant difference at the 5% level of probability.

**Figure 3.** The effect of N fertilization on root length density (RLD) of standard Russet Norkotah clone (SRC) and Texas112 clone of Russet Norkotah (TX112). Same lower case letters indicate non-significant difference at the 5% level of probability.
Table 1. Root length (RL), root length density (RLD), root average diameter (RAD), plant partitions and total dry weight, plant partitions N concentration, tuber yield, plant N content (PN), soil nitrate concentration at harvest (NO$_3^-$) and soil ammonium concentration at harvest (NH$_4^+$) for standard (SRC) and Texas 112 (TX112) clones of cultivar Russet Norkotah at two nitrogen level (0 and 150 kg N ha$^{-1}$). Values are means of 4 replications.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Treatments</th>
<th>Dry weight (g plant$^{-1}$)</th>
<th>Nitrogen concentration (%)</th>
<th>Tuber yield (g plant$^{-1}$)</th>
<th>PN (µg g$^{-1}$)</th>
<th>NO$_3^-$ (µg g$^{-1}$)</th>
<th>NH$_4^+$ (µg g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Roots</td>
<td>Tubers</td>
<td>Vines</td>
<td>Total</td>
<td>Roots</td>
<td>Tubers</td>
</tr>
<tr>
<td>Clone</td>
<td>SRC</td>
<td>0.60</td>
<td>0.60</td>
<td>0.34</td>
<td>7.40</td>
<td>272.15</td>
<td>54.67</td>
</tr>
<tr>
<td></td>
<td>TX112</td>
<td>0.65</td>
<td>0.65</td>
<td>0.34</td>
<td>12.02</td>
<td>222.78</td>
<td>87.93</td>
</tr>
<tr>
<td>N rate</td>
<td>0 (kg N ha$^{-1}$)</td>
<td>0.68</td>
<td>0.66</td>
<td>0.34</td>
<td>9.14</td>
<td>220.37</td>
<td>42.11</td>
</tr>
<tr>
<td></td>
<td>150 (kg N ha$^{-1}$)</td>
<td>0.58</td>
<td>0.59</td>
<td>0.34</td>
<td>10.28</td>
<td>274.56</td>
<td>100.49</td>
</tr>
</tbody>
</table>

Table 2. Statistical analyses for root length (RL), root length density (RLD), root average diameter (RAD), plant partitions and total dry weight, plant partitions N concentration, tuber yield, plant N content (PN), soil nitrate concentration at harvest (NO$_3^-$) and soil ammonium concentration at harvest (NH$_4^+$) results presented in Table 1.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>RL (km)</th>
<th>RLD (cm cm$^{-3}$)</th>
<th>RAD (mm)</th>
<th>Dry weight (g plant$^{-1}$)</th>
<th>Nitrogen concentration (%)</th>
<th>Tuber yield (g plant$^{-1}$)</th>
<th>PN (µg g$^{-1}$)</th>
<th>NO$_3^-$ (µg g$^{-1}$)</th>
<th>NH$_4^+$ (µg g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Roots</td>
<td>Tubers</td>
<td>Vines</td>
<td>Total</td>
<td>Roots</td>
<td>Tubers</td>
<td>Vines</td>
<td>Total</td>
</tr>
<tr>
<td>Block</td>
<td>**</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Clone (C)</td>
<td>*</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>ns</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>N rate (N)</td>
<td>***</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>***</td>
<td>**</td>
<td>ns</td>
</tr>
<tr>
<td>C x N</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
</tr>
<tr>
<td>CV (%)</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>25</td>
<td>22</td>
<td>19</td>
<td>20</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

*, **, *** Significant at the 0.05, 0.01 and 0.001 levels of probability, respectively.
ns = Not significant at the 0.05 level of probability.