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Nitrogen Uptake, Leaf Nitrogen Concentration, and Growth of Saskatoons in Response to Soil Nitrogen Fertility

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ABSTRACT

Nutrient requirements of the saskatoon (*Amelanchier alnifolia*: Rosaceae), a relatively new horticultural crop on the Canadian prairies, are unknown. In this study, two-year old saskatoon plants of the cultivar 'Smoky' were grown in a greenhouse in pots under four different soil nitrogen (N) regimes (20, 40, 60, and 80 mg N L^{-1}). Half the plants were harvested after one growing season. After a five-month period of dormancy, the remaining plants were grown for a second growing season under the same soil N regimes. At harvest, plant growth, dry weight biomass, and leaf N concentration were measured, and soil N uptake was calculated. In both years, leaf N concentration and plant N uptake were strongly positively correlated (first year $r = 0.93$; second year $r = 0.95$) and increased linearly with an increase in soil N. Stem diameter and new shoot growth increased in both years of the study in response to additional N. The soil N treatments had no significant effect on plant biomass during the first growing season. In the second year, stem, root, total shoot and total plant biomass increased with increasing soil N.

Keywords: saskatoon, serviceberry, *Amelanchier alnifolia*, nitrogen, fertilization, nitrogen uptake, foliar nutrient concentration

INTRODUCTION

The saskatoon (*Amelanchier alnifolia* Nutt., Rosaceae) is a fruit-bearing shrub or small tree native to the North American prairies. Its fruit were widely used by aboriginal people and early settlers (Harris, 1970). In recent years, saskatoons have been grown in commercial orchards; the fruit are marketed fresh,

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frozen, or processed. Limited agronomic research has been performed on the saskatoon, and its nutrient requirements are unknown. Although a number of fertilization practices have been suggested, the merit of these practices has not been studied (St-Pierre, 1997). Nitrogen (N) is the most important nutrient in most fertility programs, as it is deficient in many soils and it influences many aspects of growth and yield. Additionally, knowledge of optimum leaf N concentrations is essential for developing and monitoring fertility regimes for perennial fruit trees or shrubs. In this study, growth, N uptake, and leaf N concentrations of young saskatoon plants grown in pots under various soil N regimes, and the relationship among these three parameters, were examined. Conducting this research in pots permitted some control over the variability often encountered in field trials, and facilitated the monitoring of plant nutrient uptake.

MATERIALS AND METHODS

This experiment was conducted in a greenhouse in the Department of Plant Sciences at the University of Saskatchewan, Saskatoon, SK. Two-year-old saskatoon plants of the cultivar 'Smoky' were potted in December 1998 in 3 L pots in a mixture of a clay top soil and perlite (1:1 by volume). Perlite was added to improve the drainage of the soil. Prior to potting, the soil mixture was analyzed on a dry-weight basis for both macro- and micronutrients at Enviro-Test Laboratories in Saskatoon, SK. The plants were grown in a greenhouse at 24°C day and 18°C night temperatures, respectively, with a 16 h day length. Four N treatments with six plants for each treatment within a block were arranged in a randomized complete block design with four blocks. Fertilizer treatments were established two weeks after potting and consisted of four levels of N: 20, 40, 60, and 80 mg N L^{-1} (the equivalent by volume of 30, 60, 90, and 120 kg ha^{-1}). Sufficient 20-20-20 (Plant Products 20-20-20 N-P_2O_5-K_2O plus micronutrients) fertilizer was added to all the pots to bring the N content up to 20 mg L^{-1}, and urea (46-0-0) was used to make up the additional N for the 40, 60, and 80 mg L^{-1} treatments. The 20-20-20 fertilizer was used to ensure that the pots contained sufficient amounts of macro- and micronutrients other than N. Extra phosphorus (P) fertilizer in the form of triple superphosphate (0-45-0) was added to each pot to bring the total soil P content up to 40 mg P L^{-1} (60 kg P ha^{-1}), a general rate recommended for orchard soils (St-Pierre, 1997). All fertilizer was dissolved in approximately 500 mL of water before being added to each pot. This was just enough water to saturate the pot with minimal or no leaching. Any leachate was caught by saucers placed under the pots and reabsorbed into the soil. Blossoms were removed at the beginning of the experiment from the few plants that flowered.

Half of the plants were harvested in March 1999 to measure growth and biomass after 15.7 weeks of growth. The remaining plants were placed in a growth chamber for one month to acclimate them into dormancy, after which they were kept in a cooler for five months at 2°C to simulate an overwintering period. These plants were removed from the cooler in October 1999 and placed in the greenhouse to continue the study for another growing season. Fertilizer was applied to the pots two weeks later, in the manner previously described. The N fertilizer required to bring the soil N content back up to the original treatment levels was calculated according to a soil test done at the end of the previous growing season from the harvested pots. These remaining plants were harvested in December 1999 after 12 weeks of growth.

In both years, plant height and basal stem diameter measured 1 cm above the soil surface were recorded at the time of fertilization and at the time of harvest. The number of suckers and the length of the current season's growth of all shoots (referred to as new-shoot growth) were also measured at harvest. The plant's leaves, roots, stems, and suckers were harvested, dried at 60°C, and weighed. Soil nitrate levels and leaf N concentration at each harvest were analyzed on a dry-weight basis at Enviro-Test Laboratories (Saskatoon, SK). Plant uptake of N for each treatment was calculated as the difference in soil N content between the beginning and the end of each growing season. Although loss of soil N due to denitrification and volatilization also could have occurred, they were considered to be minimal compared with plant uptake. Data were analyzed by analysis of variance and contrasts using the GLM Procedure of SAS (SAS Institute, Cary, NC). Pearson correlations were performed using SYSTAT version 8.0 (SPSS, Chicago, IL). The data were checked for normality prior to statistical analyses. A log transformation was used when necessary to create linearity prior to correlation analysis.

RESULTS

First Season Results

Leaf N concentration and plant N uptake increased linearly with increasing soil N treatment levels (Figure 1). At the end of the first growing season, N uptake by the plants was strongly correlated with leaf N concentration ($r = 0.93$, $P < 0.001$). The increase in stem diameter increased linearly with increasing soil N levels, as indicated by the significant linear contrast (Table 1). However, this linear increase in stem diameter appeared to reach a plateau at the 60 mg N L^{-1} rate. Plant N uptake was also positively correlated with the increase in stem diameter ($r = 0.647$; $P = 0.007$). The length of new-shoot growth of plants grown at the three highest levels of N was greater than that at the lowest rate. However, no further increase in shoot growth occurred at rates higher than 40 mg N L^{-1}. Plants grown at the highest rate of N produced significantly more suckers. No differences in any of the plant biomass parameters were observed in response to the N treatments in year one (Table 2).

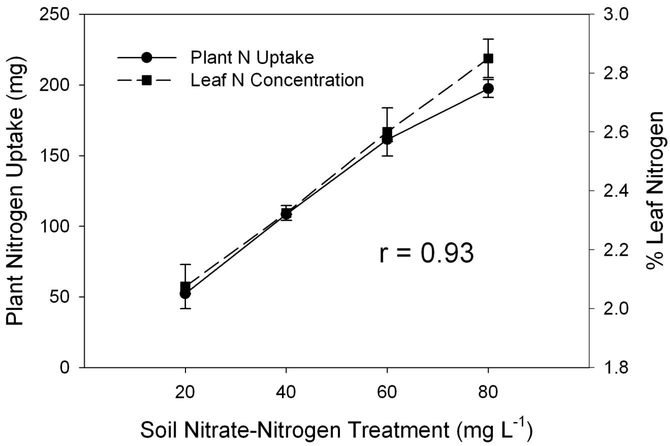

Figure 1. Total nitrogen uptake and leaf nitrogen concentration of potted saskatoon plants during their first season of growth at four different soil nitrogen levels. Vertical bars indicate standard error of the mean.

Second Season Results

Leaf N levels and plant N uptake increased linearly in response to the soil N treatments in the second year of the trial (Figure 2). Nitrogen uptake by the plant was strongly positively correlated with leaf N concentration ($r = 0.95$, $P < 0.001$). Growth differed significantly in response to N treatments during the second growing season. The length of the new stem growth,

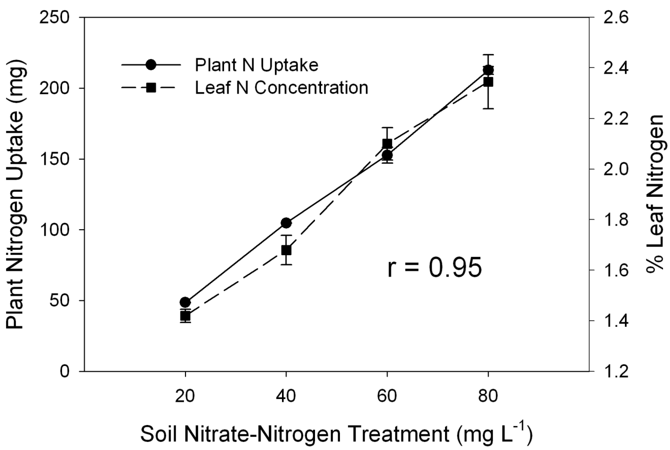

Figure 2. Total nitrogen uptake and leaf nitrogen concentration of potted saskatoon plants during their second season of growth at four different soil nitrogen levels. Vertical bars indicate standard error of the mean.

Table 1
Effect of soil nitrogen (N) levels on growth of potted saskatoon plants

	N treatment (mg L^{-1})	Increase in stem diameter per plant (mm)	Length of new shoot growth per plant (cm)	Number of new suckers per plant
Year 1	20	1.52	20.9	0.33
	40	2.05	30.3	0.25
	60	2.13	26.2	0.08
	80	2.03	26.2	0.58
	S.E.[z]	0.115	1.45	0.082
	Significant contrasts[y]	L*, Q*, 1 *vs* 2 – 4** 1 – 2 *vs* 3 – 4*	Q*, 1 *vs* 2 – 4**	Q**, 1 – 3 *vs* 4**
Year 2	20	1.11	105.6	0.08
	40	1.13	114.5	0.00
	60	1.75	109.3	0.08
	80	1.60	133.3	0.08
	S.E.	0.206	7.21	0.08
	Significant contrasts	L*, 1 – 2 *vs* 3 – 4*	L*, 1 – 3 *vs* 4*	NS
Cumulative over two years	20	2.50	125.1	0.42
	40	3.13	145.9	0.50
	60	3.72	135.1	0.25
	80	3.62	154.7	0.50
	S.E.	0.199	5.90	0.286
	Significant contrasts	L**, 1 *vs* 2 – 4**, 1 – 2 *vs* 3 – 4**	L*, 1 *vs* 2 – 4*, 1–3 *vs* 4*	NS

[z]Standard error of the mean.

[y]L = linear contrast; Q = quadratic contrast; other contrasts are trend analyses with the number indicating the treatment (1 = 20, 2 = 40, 3 = 60, 4 = 80) i.e. 1 vs 2–4 = treatment 1 (20 mg N L^{-1}) versus treatments 2–4 (40–80 mg N L^{-1}). Level of significance indicated by * such that * < 0.05,** <0.01,*** <0.001; NS = not significant.

Means are calculated for six plants in year 1, and for three plants in year 2, and both years together.

the increase in stem diameter, and the dry weights of the roots, older stems, total stems, total shoots, and the total plant all increased in a linear fashion in response to N treatments (Tables 1 and 2). The dry weight of the new stem growth was significantly lower at the 20 mg N L^{-1} rate than at the three higher rates. Stem diameter and new shoot growth over the two years of the experiment increased linearly in response to an increase in soil N. Once again, however, this linear increase in stem diameter appeared to reach a plateau at the 60 mg N L^{-1} rate during the second season of the trial and for both years combined. Leaf N concentration and plant N uptake were positively correlated with root dry weight (leaf: r = 0.55, P = 0.027; N uptake: r = 0.59, P = 0.017); sucker

Table 2
Effect of soil nitrogen (N) levels on plant dry weight of biomass components of saskatoons grown in pots

	N treatment ($mg\ L^{-1}$)	Leaves (g)	New stem (g)	Older stem (g)	Total stem (g)	Suckers (g)	Total shoot (g)	Roots (g)	Total plant (g)
Year 1	20	2.69	0.74	5.42	6.16	0.11	45.0	7.86	16.8
	40	3.34	1.16	6.31	7.47	0.00	54.8	9.15	20.0
	60	2.89	0.98	5.95	6.92	0.00	50.2	7.97	17.8
	80	3.10	0.97	5.48	6.45	0.20	48.0	7.85	17.6
	S.E.^{z}	0.294	0.463	0.371	0.450	0.078	3.10	0.481	0.91
	Significant contrasts^y	NS	NS	NS	NS	NS	NS	NS	NS
Year 2	20	7.32	2.92	9.5	12.4	0.22	59.9	9.8	29.8
	40	8.33	3.87	12.0	15.9	0.46	74.0	10.7	35.3
	60	7.98	3.52	11.8	15.3	1.08	73.1	10.8	35.1
	80	8.72	3.81	12.4	16.2	1.65	79.8	12.3	38.9
	S.E.	0.398	0.248	0.43	0.59	0.539	2.38	0.51	0.91
	Significant contrasts	NS	$1\ vs\ 2-4^{*}$	L^{*} $1\ vs\ 2-4^{*}$	L^{*} $1\ vs\ 2-4^{***}$ $1-2\ vs\ 3-4^{*}$ $1-3\ vs\ 4^{*}$	NS	L^{***} $1\ vs\ 2-4^{***}$ $1-2\ vs\ 3-4^{**}$ $1-3\ vs\ 4^{**}$	L^{**} $1\ vs\ 2-4^{*}$ $1-2\ vs\ 3-4^{*}$ $1-3\ vs\ 4^{*}$	L^{***} $1\ vs\ 2-4^{***}$ $1-2\ vs\ 3-4^{***}$ $1-3\ vs\ 4^{***}$

^{z}Standard error of the mean.

^{y}L = linear contrast; Q = quadratic contrast; other contrasts are trend analyses with the number indicating the treatment (1 = 20, 2 = 40, 3 = 60, 4 = 80) i.e. 1 vs. 2–4 = treatment 1 (20 mg N L^{-1}) versus treatments 2–4 (40–80 mg N L^{-1}). Level of significance indicated by *such that $^* < 0.05$, $^{**} < 0.01$, $^{***} < 0.001$; NS = not significant.

Means are based on three plants.

dry weight (leaf: r = 0.52, P = 0.038; N uptake: r = 0.52, P = 0.041); total plant dry weight (leaf: r = 0.52, P = 0.041; N uptake: r = 0.63, P = 0.009); and the increase in stem diameter over the two years (leaf: r = 0.52, P = 0.038; N uptake: r = 0.63, P = 0.009). Plant N uptake was also positively correlated with the dry weight of the new stem growth (r = 0.56, P = 0.023), and with total shoot dry weight (r = 0.63, P = 0.010).

DISCUSSION

Initially, the greatest response of saskatoon plants grown at increasing levels of soil N was an increase in leaf N concentration, stem diameter, and the amount of new shoot growth. As the plant demand for N increased in the second growing season, the effect of the N treatments became evident in the plant biomass as well. In general, the saskatoon plants grown at higher levels of soil N resulted in plants with a higher leaf N concentration, larger stems of a greater diameter and dry weight, a greater shoot growth in terms of length and biomass, and larger root systems. Leaf biomass alone was not influenced by the soil N treatments in this study.

An increase in leaf nitrogen concentration in response to increases in soil nitrogen has been frequently reported in the past in both pot and field studies of apple (*Malus domestica*) (Marks and Clarke, 1995; Noè et al., 1995), pear (*Pyrus spp.*) (Gilliam et al., 1984; Raese, 1997), citrus (*Citrus spp.*) (Maust and Williamson, 1994), and cherry (*Prunus avium*) (Fallahi et al., 1993). Stem diameter was reported to increase in response to increasing nitrogen fertilization in container-grown pear (*Pyrus calleryana*) (Gilliam et al., 1984) and cypress (*Cupressus arizonica*) (Stubbs et al., 1997). Shoot growth was enhanced in response to added nitrogen in the second year of this study but not the first. Variable responses of shoot growth to increasing rates of nitrogen have been reported. Raese (1997) found greater shoot growth in a pear (*Pyrus communis*) orchard fertilized with a higher rate of nitrogen. Shoot growth increased in apples (*M. domestica*) at two of four field sites following nitrogen fertilization (Marks and Clarke, 1995). Shoot extension growth of apples (*M. domestica*) grown in pots increased in response to increasing levels of nitrogen fertilizer in only one of the two years of the study (Karkara et al., 1986). However, shoot length did not respond to various rates of nitrogen application in container-grown crabapple (*Malus x zumi* cv. Calocarpa) and maple (*Acer x freemanii* cv. Jeffersred) (Rose et al., 1999). Shoot growth and shoot dry weight of container-grown citrus (*Citrus spp.*) (Maust and Williamson, 1994), and shoot dry weight of container-grown apples (*Malus spp.*) (Neilsen et al., 1995) were found to increase with increasing rates of nitrogen fertilizer up to a certain concentration after which the growth response plateaued.

In this study, root dry weight increased during the second year of growth in response to increasing N levels. Previous research indicates that the response of root growth to N fertilization can vary. Root growth of pot-grown plants of other species has been reported to increase (Maust and Williamson, 1994; Stubbs et al., 1997), decrease (Griffin et al., 1999), or not respond (Gagnon et al., 1995; Ruter, 1998) to increasing rates of N. In this study, an increase in root growth may be attributed to an overall increase in plant growth and vigor.

The extent of the growth response to N fertilization is dependent, at least in part, upon whether initial N levels are already present in sufficient quantities. The work of Maust and Williamson (1994) and Griffin et al. (1999) has clearly shown that growth and tissue N concentration increases (or decreases) in response to increasing N rates up to a certain concentration, after which the response plateaus. Leaf N concentration was found to plateau at much higher N fertilizer concentrations than growth in container-grown citrus (Maust and Williamson, 1994). Similarly, in this study, most of the growth response of the saskatoons often occurred between the first and second increment of soil N, while leaf N concentration continued to increase up to the highest level of N applied.

Overall, N fertility had less of an effect on saskatoon growth in this study during the first season than in the second. During the second season, a pot-induced fertilizer deficiency may have been created, as the plants were still contained in the same size pots at the same levels of soil N as in the first year, but the plant N demand increased as the plants grew in size. In the field, the roots of the same size plants would have spread out over a much greater volume of soil, permitting access to more N even if N concentration in the soil was equivalent to that in the pots. The nitrogen deficiency in the second season was readily apparent in the much lower leaf N levels. At the end of the first growing season, leaf N ranged from 2.08%–2.85%. Plants grown at the highest rate of N had a leaf N concentration which was above the normal range (1.8%–2.6% N, unpublished data) for saskatoons at this stage of growth, which would correspond to the end of August in field-sampled plants. However, by the end of the second season of growth, leaf N concentration ranged from 1.42%–2.35%. Only the two highest N treatments produced plants with adequate leaf N concentrations (2.10% and 2.35% N, respectively) at this stage of growth, which corresponds to the end of July and beginning of August in the field (normal range at this time is 2.1%–2.9% N, unpublished data).

The growth response and leaf N concentration data suggest that 40 mg N L^{-1} was likely sufficient for optimum growth during the first growing season. At this level of soil N, leaf N concentration was 2.33%, which was found to be average for this stage of growth (mean leaf N concentration at the end of August in the field = 2.3%, unpublished data). Plants grown with 40 mg N L^{-1} took up 108 mg of N in total, or 5.42 mg N g^{-1} dry weight during the first season. During the second growing season, the 80 mg L^{-1} rate was necessary for optimal growth. Leaf N concentration was 2.35% at this rate, which is just below average for this stage of growth (mean leaf N concentration at the end of July/beginning of August in the field = 2.5%, unpublished data). Plants grown with 80 mg N L^{-1} during the second season took up 213 mg of N in total, or 5.46 mg N g^{-1} plant dry weight. As the plants doubled in dry weight by the end of the second growing season, N uptake from the soil also doubled over that of the first season, while the N requirements of the plant on a dry-weight basis remained constant.

CONCLUSIONS

The growth response to additional N of plants with leaf N concentrations of 2.1% or less during the second season of this study suggests that the vegetative growth of young, non-fruiting saskatoon plants of the cultivar 'Smoky' may be increased with the application of additional N fertilizer if leaf N concentration at the end of July to early August is 2.1% or less. The results of this study also indicate that a leaf N concentration of 2.3% in late July to early August appears to be closer to optimum for non-fruiting saskatoons of this cultivar. This research has provided no information on the response of fruit yield or quality at this concentration of leaf N, nor on the N uptake required for mature, fruiting plants. These findings have shown that plants of approximately 40 cm and 50 cm in height (the average heights of the plants at the beginning of the first and second growing seasons, respectively) in the spring will likely require at least 108 mg and 213 mg of N, respectively, for optimum growth throughout the season. However, these values are an underestimate of the plant N uptake, as the nitrogen released by mineralization throughout the growing season was not accounted for. Additionally, the N requirement may vary according to plant performance in the field as affected by plant vigor, soil type and conditions, and climate. The actual amount of N fertilizer required in the field will also depend on the N fertilizer use efficiency. When N fertilizer is applied to the soil, losses normally occur due to leaching, denitrification, and volatilization. In addition, not all N applied to the soil zone around the plant will necessarily reach the roots. Thus, under field conditions more N will need to be applied to the soil than only what is required for plant growth.

Further studies of potted saskatoon plants grown at a wider range of soil N rates would be useful in discerning the critical minimum and maximum leaf N concentrations required for optimum growth. Research in larger-sized pots would allow for a more natural root spread that would more closely resemble a field situation and facilitate, to an extent, the transference of the findings to the field. Ultimately, comparative pot and field studies would be essential in determining the nutrient requirements for saskatoons. Future research conducted on fruiting plants will also be necessary to assess the effects of N fertility on fruit yield and quality.

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