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Nitrogen Form and Solution pH Influence Growth and Nutrition of Two *Vaccinium* Clones

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Abstract. **The effects of pH and N form on growth and nutrition of blueberry *(Vaccinium corymbosum* L. x *V. angustifolium* Ait. CV. Northblue) and cranberry *(V. macrocarpon* Ait. CV. Searles) were tested in separate greenhouse hydroponic experiments. A factorial treatment arrangement of two pH levels (4.5 and 6.5) and three N forms (NO_3-N, NH_4-N, and NH_4-N/NO_3-N) was used for each clone. Blueberry shoot growth and final dry weight were greatest at pH 4.5, regardless of N form. In contrast, cranberry fresh weight accumulation and final dry weight were higher with NH_4-N/NO_3-N or NH_4-N than with NO_3-N alone. Cranberry plants receiving NO_3-N alone accumulated low levels of tissue N and grew relatively poorly at both pH levels. Differences in N response by these two species may be due partially to the environments in which they were selected. Soil from the site where 'Northblue' blueberry was selected contained relatively high NO_3-N and low NH_4-N levels; soil from commercial 'Searles' cranberry bogs had relatively low NO_3-N and high NH_4-N levels. Both species accumulated relatively high levels of root Fe, regardless of pH or N form. Levels of Fe in the root were as much as 100 times higher than in the shoot. Based on X-ray microanalysis of cranberry roots, most of the Fe appeared to be precipitated on the root surface as iron phosphate. Concentrations of Mn in shoots and roots depended on N form and pH. In general, root Mn was highest at pH 6.5 and apparently was precipitated with Fe.**

Most Ericaceous plants are native to acidic soil environments where low vitrification rates cause NH_4-N to be the dominant N form available to plant roots (Rorison, 1986). Response of blueberry and cranberry to NO_3-N and NH_4-N nutrition has been variable. In some studies (Cain, 1952; Greidanus et al., 1972; Peterson et al., 1988; Townsend, 1967, 1969), NH_4-N was superior to NO_3-N in promoting growth, while in others there was no difference (Dirr, 1974; Hammett and Ballinger, 1972; Oertli, 1963). Failure to control pH and vitrification in the medium may partially contribute to variable results. Hammett and Ballinger (1972), for example, noted that highbush blueberries grew as well on NO_3-N as on NH_4-N when the pH was <6.2. Genotypic differences in NO_3-N use within the *Vaccinium* genus may also account for some of the variation. Cranberries appear to grow better with NH_4-N than NO_3-N and generally grow poorly when supplied with NO_3-N alone (Greidanus et al., 1972). However, beneficial effects of NO_3-N have also been demonstrated (Leschyson and Eaton, 1971), especially when solution pH is in the acid range (Addoms and Mounce, 1932).

Growth rates of most non-Ericaceous plants supplied with NH_4-N as the sole form of N are generally reduced compared to those provided with NO_3-N, unless pH is strictly maintained

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between 5.7-6.1 (Peet et al., 1985; Rufty et al., 1983). *Vaccinium* spp. appear to be tolerant of NH_4-N, even at pH levels between 4.0-5.0. Precise mechanisms for NH_4-N tolerance by *Vaccinium* are not known, but maybe related to a lower cation requirement or a greater ability to synthesize organic acids in the absence of NO_3-N compared to non-tolerant plants (Salsac et al., 1987).

The objective of the present experiments was to use hydroponic culture to characterize the effects of pH and N form on growth, nutrition, and root chemical properties of blueberry and cranberry. As the cranberry experiment was not conducted the same year as the blueberry experiment, the effects of yearly climatological differences may bias direct interspecific comparisons. Therefore, differences in direction of responses, not in degree of response or absolute numerical variation, will be presented and discussed.

Materials and Methods

The first experiment was conducted with 'Northblue', a halfhigh blueberry clone, propagated from tissue culture. Plantlets were transferred to 0.43-liter pots containing acid peat and then maintained in the greenhouse for≈2 months.

To initiate the solution culture phase of the experiment, plant roots were thoroughly rinsed in distilled water to remove adhering peat. Each plant was then transferred to a black plastic pot containing 7 liters of a nitrogen-deficient background nutrient solution of the following composition (in mM):, $CaSO_4 \cdot 2H_2O$, 1.0; $MgSO_4 \cdot 7H_2O$, 0.75; K_2SO_4, 0.5; $Ca(H_2PO_4)_2$, 0.13; (in μM), FeNaEDTA, 80; H_3BO_3, 46; $MnCl_2 \cdot 4H_2O$, 9; $ZnSO_4 \cdot 7H_2O$, 0.8; $CuSO_4 \cdot 5H_2O$, 0.3; $H_2MoO_4 \cdot H_2O$, 0.1, adjusted to a pH of 4.5. Nitrogen was then adjusted in the background solution to 2 mM using NH_4NO_3 as the N form. Plants were maintained in this solution for 6 weeks to allow initiation of new roots. Solutions were continuously aerated. Greenhouse air temperatures were set for a 14-hr 28C day and a 10-hr 20C night.

Treatments were initiated by transferring plants to the background nutrient solution containing NH_4-N alone, NH_4-N and NO_3-N, or NO_3-N alone in factorial combination with pH treatments of 4.5 and 6.5. A randomized complete block design was used with four replications. All N levels were adjusted to 2 mM using $(NH_4)SO_4$ in the NH_4-N-alone solution, NH_4NO_3 in the NH_4-N/NO_3-N solution and $Ca(NO_3)_2$ in the NO_3-N-alone solution. Calcium sulfate was omitted in the NO_3-N-alone background solution to keep initial Ca levels equal. Therefore, to vary N source, sulfate was also varied: 3.25 mM in the NH_4-N-alone solution, 2.25 mM in the NH_4-N/NO_3-N solution, and 1.25 mM in the NO_3-N solution. Solutions were changed every 14 days and pH was adjusted daily using $Ca(OH)_2$ or H_2SO_4. A nitrification inhibitor, 2-chloro-6-(trichloromethyl) pyridine (nitrapyrin), was added to all solutions at the rate of 4 μM, which successfully inhibited conversion of NH_4-N to NO_3-N. During the course of the experiment, NO_3-N and NH_4-N levels were determined using conductimetric procedures (Carlson, 1978; 1986) before changing solutions.

Treatments were initiated 8 Feb. 1985 and the experiment was terminated in 12 Oct. 1985. Shoot length was periodically measured during the experiment. At harvest, shoots were detached from roots. Roots were rinsed in deionized water for ≈10 sec and blotted dry on paper towels. Shoots and roots were dried at 60C for 3 days and dry weights were recorded. Dried shoots and roots were ground in a Wiley mill to pass through a 40-mesh screen. Dried samples were digested in concentrated H_2SO_4 and Kjeldahl N was determined using conductimetric procedures (Carlson, 1978). After ashing and resuspending in 2 N HCl, other elements were determined using an inductively coupled plasma spectrometer (Munter et al., 1984).

In a second experiment, with the cranberry clone 'Searles', stem cuttings were rooted directly in l-liter jars containing the same solution described above for rooting blueberry. Solutions were continuously aerated and adjusted to pH 4.5 daily. After roots were initiated (6 weeks), plants were transferred to black plastic pots containing 7 liters of nutrient solution. Treatments were the same as those described for the blueberry experiment. A randomized complete block design was used with four replications. As for blueberries, nitrapyrin was used to inhibit nitrification. Treatments were initiated 22 Apr. 1987 and the experiment was terminated 30 Sept. 1987. Fresh weight of each plant was recorded at monthly intervals.

Cranberry plants were harvested in a similar manner as described for the blueberries, except that subsamples(≈1 g) of fresh root tips were collected, frozen in liquid N_2, and stored at –70C for subsequent x-ray microprobe analysis.

For x-ray microanalysis, the frozen cranberry root samples were freeze-dried and mounted onto aluminum stubs covered with double-stick tape. Carbon paint was used to further secure the root samples onto the stub. Samples were then transferred to a vacuum evaporator and coated with nickel. All observations were made with a Phillips 500X SEM and an EDAX 71lF energy dispersive x-ray analysis unit. The incident 12-KeV electron beam was standardized for each stub by focusing onto an exposed Al margin and adjusted using the beam spot size control until 3000 counts per second of Al X-rays plus background were obtained. X-ray spectra were collected from crystal-like particles on the root surface as well as from epidermal cell surfaces. Counts per 80 sec were recorded as a relative measure of nutrient level.

Soil samples (0- to 15-cm and 15- to 30-cm depths) were collected from the site where the original 'Northblue' blueberry plant was selected in Becker, Minn., and from several 'Searles' cranberry plantings near Wisconsin Rapids, Wis. Samples from both locations were collected the first week in May and the first week in June. The soil collected at Becker was a Hubbard loamy sand (Udorthenic Haploborolls) and that collected at Wisconsin Rapids was a Markey muckey peat (Terric Borosaprists) overlaid with a Newson sand (Humaqueptic Psammaquents). Samples were kept moist and cool (4C) before analysis. Nitrate-N and NH_4-N were determined in 1 soil :5 2-N KCl (w/v) extracts using conductimetric procedures (Carlson, 1978, 1986). Percent moisture in the samples was determined and results expressed on a dry-weight basis.

Results

Blueberry and cranberry growth. Blueberry growth was affected more by pH of the nutrient solution than by N form (Table 1). By 210 days after treatment initiation, shoots were about three times longer in plants growing in solutions adjusted to pH 4.5 than to 6.5. In the pH 6.5 treatment, plants appeared stunted, although the leaves generally were green with no signs of chlorosis. Roots in the high pH medium were dark and stunted regardless of N form. In the low-pH medium, roots were white with NH_4-N, gray-brown with NO_3-N, and intermediate with the mixture. Nitrogen form did not have a significant effect on shoot and root dry weight, although growth was numerically highest with the combination of N forms. 'Northblue' blueber-

Table 1. Solution pH and N form effects on 'Northblue' blueberry shoot length and final shoot and root dry wt.

	Days after treatment initiation				
				246	
	0	105	210	Dry wt (g)	
Variable	Shoot length (cm)			Shoot	Root
N form					
NH_4	38.3	63.9	127.3	19.61	4.71
NH_4/NO_3	39.4	83.3	193.0	28.63	9.42
NO_3	34.4	73.3	163.1	24.54	6.39
Significance	NS	NS	NS	NS	NS
pH					
4.5	37.1	88.8	237.4	37.21	11.71
6.5	37.1	58.2	84.9	11.30	1.98
Significance	NS	*	*	**	**

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively. The interaction was nonsignificant in all cases.

ries appear to be able to use either NO_3-N or NH_4-N and grow best when the pH of the medium is in the acid range.

In contrast to blueberry, cranberry growth was affected more by N form than by pH (Table 2). Fresh and dry weight yields were significantly depressed when NO_3-N was the sole form of N. However, fresh weight and final dry weight were greatest when NO_3-N plus NH_4-N was provided at either pH. Root color was affected by N form and pH. Ammonium-N grown plants had light gray roots at pH 4.5 and were much darker at 6.5. Nitrate-N grown plants had brown-gray roots at 4.5 and black stunted roots at 6.5. At each respective pH, NH_4-N plus NO_3-N-grown plants had roots that were slightly darker than roots of plants grown in NH_4-N alone. Root dry weight was lower at pH 6.5 than at 4.5, although shoot dry weight was apparently unaffected by pH.

Nutrient concentrations in shoots. Nutrient levels in blueberry and cranberry shoots are presented in Tables 3 and 4. Nitrogen concentrations in both blueberry and cranberry were significantly lower in the NO_3-N treatments than in the NH_4-N treatments. Since stems and leaves were combined for nutrient analysis, relatively low N concentrations were observed in all treatments. For both species, Ca and Mg concentrations were highest for the NO_3-N treatment, while pH had a variable effect. Nitrogen form had no effect on K levels; however, shoot K was greater at pH 4.5 than at 6.5. Phosphorus levels were highest in cranberry shoots when plants were provided with NH_4-N. Levels of P in blueberry shoots were not significantly affected by N form. Shoot Fe levels were not affected by pH or N source in blueberry, but lower Fe in cranberry shoots was associated with higher solution pH. Zinc, Cu, and B concentrations in blueberry shoots were not affected by pH or N source. Cranberry in high pH and NO_3-N treatments had the lowest shoot concentrations of B and Zn. Significant pH × N from interactions occurred with both species for Mn levels (Table 5). In general, shoot Mn was higher at low pH than at high pH. For cranberries, Mn was higher with NO_3-N than with NH_4-N. For blueberries, there was no distinct Mn effect associated with N form.

Nutrient concentrations in roots. Concentrations of N in blueberry and cranberry roots were lower in the NO_3-N treatment than treatments that included NH_4-N (Tables 6 and 7). Solution pH had no effect on root N concentrations. Levels of K in blueberry roots increased with lower pH, while, in cranberry, root K levels were highest with the NO_3-N/NH_4-N treatment, regardless of pH. Root Ca concentrations increased with pH and were highest with NO_3-N. In blueberries, root Mg levels were highest with NO_3-N. In contrast, root Mg in cranberries increased with increasing pH, but N form had no effect. Increasing solution pH had a strong effect on increasing root Mn levels in both species. Root Mn tended to increase with nitrate, although, for blueberry, increases were greater at pH 6.5 than at pH 4.5, which accounted for the significant N form × pH interaction (Table 5). Root Fe levels were ≈100 to 200 times higher than shoot Fe levels. In blueberry, highest Fe levels were associated with NH_4-N, regardless of pH, while, in cranberry, root Fe was highest at pH 4.5, regardless of N form.

Ammonium and nitrate uptake. Solution NO_3-N and NH_4-N concentrations were determined every 2 weeks before a solution change. In general, blueberry plants depleted all NO_3-N and NH_4-N from low-pH solutions within the 2 weeks. Because of slower growth in the high-pH treatments, most of the NO_3-N and NH_4-N remained in solution after the same 2 weeks. In contrast, cranberries depleted NH_4-N to the same extent from both high- and low-pH solutions; however, depletion of nitrate

Table 2. Solution pH and N form effects on 'Searless' cranberry fresh weight accumulation and final shoot and root dry wt.

	Days after treatment initiation							
							161	
	0	28	69	97	126	155	Dry wt (g)	
Variable	Fresh wt (g)						Shoot	Root
N form								
NH_4	1.4	4.6	16.5	29.1	47.3	51.7	16.08	1.10
NH_4/NO_3	1.2	3.9	14.5	27.8	54.7	69.7	22.04	1.54
NO_3	1.0	2.8	10.0	17.1	27.1	31.2	8.94	1.35
Significance	NS	NS	NS	*	**	**	**	*
LSD (0.05)	---	---	---	10.6	14.1	12.7	4.4	0.3
pH								
4.5	1.3	4.2	14.5	27.9	45.8	54.5	16.45	1.50
6.5	1.2	3.4	10.3	21.4	40.2	47.1	14.92	1.15
Significance	NS	NS	NS	NS	NS	NS	NS	*

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively. The interaction was nonsignificant in all cases.

Table 3. Solution pH and N form effects on elemental composition of 'Northblue' blueberry shoots.

	Elemental composition (dry-wt basis)										
	N	P	K	Ca	Mg	Fe	Al	Mn	Zn	Cu	B
Variable	($g \cdot kg^{-1}$)					($mg \cdot kg^{-1}$)					
N form											
NH_4	13.7	1.70	3.33	2.45	0.99	125	29	373	37	4	38
NH_4/NO_3	11.0	1.54	3.39	2.89	1.01	100	26	278	37	5	45
NO_3	10.4	1.51	3.92	4.31	1.56	68	32	186	32	4	50
Significance	**	NS	NS	**	**	NS	NS	NS	NS	NS	NS
LSD (0.05)	1.5	---	---	0.67	0.23	---	---	---	---	---	---
pH											
4.5	11.4	1.51	3.99	3.39	1.16	77	30	404	34	4	47
6.5	12.0	1.65	3.09	3.05	1.22	118	28	220	37	4	41
Significance	NS	NS	*	NS	NS	NS	NS	**	NS	NS	NS
pH × N form											
Significance	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Table 4. Solution pH and N form effects on elemental composition of 'Searles' cranberry shoots.

	Elemental composition (dry-wt basis)										
	N	P	K	Ca	Mg	Fe	Al	Mn	Zn	Cu	B
Variable	($g \cdot kg^{-1}$)					($mg \cdot kg^{-1}$)					
N form											
NH_4	15.0	2.02	6.65	3.96	1.43	76	32	132	22	4	80
NH_4/NO_3	14.1	1.80	6.84	4.31	1.19	71	30	170	22	4	77
NO_3	6.4	1.07	6.37	5.34	1.36	75	28	338	19	4	65
Significance	**	**	NS	**	**	NS	NS	**	*	NS	**
LSD (0.05)	2.0	0.31	---	0.32	0.13	---	---	39	2	---	7
pH											
4.5	12.1	1.69	6.99	4.26	1.26	86	32	234	23	5	78
6.5	1.16	1.57	6.24	4.82	1.40	61	27	192	19	4	70
Significance	NS	NS	*	**	NS	**	NS	*	**	NS	*
pH × N form											
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	**

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Table 5. Manganese concentrations in 'Northblue' blueberry and 'Searles' cranberry roots and shoots as affected by pH and N form interaction.

		Blueberry		Cranberry	
pH	N form	Roots	Shoots	Roots	Shoots
4.5	NH_4	303	561	151	163
	NH_4/NO_3	544	302	138	158
	NO_3	311	348	469	382
6.5	NH_4	1116	184	3523	101
	NH_4/NO_3	1042	253	2678	183
	NO_3	3620	223	3304	294
pH × N form Significance		**	**	NS	*

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

from solution was slow, regardless of pH. Within the 2 weeks between solution changes, neither NH_4-N nor NO_3-N was completely depleted from solution. In short-term depletion experiments with cranberry plants, NH_4-N uptake rates were 30 to 100 times higher than corresponding NO_3-N uptake rates (data not presented).

Changes in solution pH. Although a relatively large volume of solution (7 liters) was used per plant, solution pH did not remain stable for more than 24 hr. Both species grown in solutions with NH_4-N or NH_4-N plus NO_3-N initially decreased solution pH by 0.5 to 1.0 pH unit. In contrast, blueberries grown in solutions with NO_3-N alone at pH 4.5 generally increased solution pH by 0.5 to 1.0 pH unit. Blueberries grown in solutions with NO_3-N alone at pH 6.5 increased pH only slightly (<0.2 pH unit). Cranberries supplied with NO_3-N caused little change in solution pH. The lack of pH change in the NO_3-N only treatments with cranberry corresponds with low rates of NO_3-N uptake.

Discussion

The lack of response by blueberry to N form in the present study agrees with results reported by Oertli (1963) and Hammett and Ballinger (1972), but contradicts other studies (Cain, 1952; Peterson et al., 1988; Townsend, 1967, 1969) where NH_4-N was superior to NO_3-N in promoting growth. Cranberry growth rate was lower when NO_3-N was the sole form of N compared to when NH_4-N or NH_4-N plus NO_3-N was supplied. Greidanus et al. (1972) reported that NO_3-N was detrimental to cranberry growth and suggested that any growth in the NO_3-N solutions was due to to NO_3-N reduction by microorganisms before use by the cranberry. In the present experiments, NO_3-N did not inhibit growth as long as NH_4-N was also supplied. Moreover, cranberry plants supplied with both NO_3-N and NH_4-N accumulated more total shoot N (331 mg) than plants supplied with NH_4-N alone (241 mg) or NO_3-N alone (57 mg).

Nitrogen concentrations in cranberry shoots and roots were much lower in the NO_3-N treatments than in the NH_4-N treatments. Stieber and Peterson (1987) have reported that, when cranberry vines are starved of N, active growth still occurred as a result of endogenous recycling of N when N concentrations in vines were as low as 5.5 $g \cdot kg^{-1}$. In this experiment, treatments were initiated when total plant fresh mass was ≈ 1 g and the final total fresh mass was > 30 g. Because of this large increase in plant mass, more than endogenous N would be required to maintain growth for the 160-day duration of the experiment. The possibility does exist that microorganisms in solution played a role in NO_3-N reduction before use by the cranberry. Although this issue cannot be resolved in the present experiments, low NO_3-N uptake rates and low N accumulation in shoots provided only with NO_3-N suggest that cranberry has a limited capacity for NO_3-N uptake and metabolism. In blueberry, N concentrations in NO_3-N-grown plants were lower than NH_4-N-grown plants, but not as depressed as in cranberry. A combination of NH_4-N and NO_3-N appeared to be equal to or better than either form alone for blueberry and cranberry growth. This growth response suggests that N may be used more efficiently by these species if both NH_4-N and NO_3-N are provided. These results clearly indicate that NO_3-N per se is not toxic to either species.

Responses to N form by these two *Vaccinium* clones may partially result from the conditions under which they were selected, a hypothesis suggested for cranberry by Greidanus et al. (1972). 'Northblue' blueberry resulted from crosses between *V. angustifolium* and *V. corymbosum* germplasm originally propagated and selected in a well-drained, sandy, acid soil in central Minnesota (Luby et al., 1986). 'Searles' cranberry is a selection made in 1903 from native vines growing in acid bogs (Stang

Table 6. Solution pH and N form effects on elemental composition of 'Northblue' blueberry roots.

	Elemental composition (dry-wt basis)										
	N	P	K	Ca	Mg	Fe	Al	Mn	Zn	Cu	B
Variable	($g \cdot kg^{-1}$)						($mg \cdot kg^{-1}$)				
N form											
NH_4	22.1	6.96	3.43	3.62	1.07	13.06	184	709	56	40	10
NH_4/NO_3	21.6	6.02	3.65	5.10	1.53	8.37	159	793	55	39	12
NO_3	16.9	6.66	4.13	5.99	1.96	6.69	173	1968	55	20	13
Significance	*	NS	NS	*	**	*	NS	**	NS	*	NS
LSD (0.05)	4.2	---	---	1.69	0.34	4.93	---	581	---	10	---
pH											
4.5	20.2	6.34	4.30	3.74	1.50	9.50	159	386	52	36	10
6.5	20.2	6.75	3.17	6.06	1.53	9.26	185	1926	57	30	14
Significance	NS	NS	NS	**	NS	NS	NS	**	NS	NS	*
pH × N form											
Significance	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Table 7. Solution pH and N form effects on elemental composition of 'Searles' cranberry roots.

	Elemental composition (dry-wt basis)										
	N	P	K	Ca	Mg	Fe	Al	Mn	Zn	Cu	B
Variable	($g \cdot kg^{-1}$)						($mg \cdot kg^{-1}$)				
N form											
NH_4	21.5	12.9	5.29	6.38	1.83	13.0	346	1837	55	22	53
NH_4/NO_3	23.4	10.1	6.70	4.65	1.74	8.8	262	1408	49	16	24
NO_3	11.2	13.1	4.67	7.65	1.76	13.3	211	1887	62	17	48
Significance	**	NS	*	*	NS	NS	*	NS	*	NS	NS
LSD (0.05)	4.5	---	1.43	2.07	---	---	114	---	9	---	---
pH											
4.5	18.0	12.6	5.37	2.20	1.30	15.0	259	253	42	15	47
6.5	19.3	11.5	5.74	10.25	2.25	8.4	289	3169	68	21	37
Significance	NS	NS	NS	**	**	**	NS	**	**	*	NS
pH × N form											
Significance	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS

NS,*,**Nonsignificant or significant at $P = 0.05$, or 0.01, respectively.

and Dana, 1984). Soil NO_3-N levels were high and NH_4-N levels were low in the original blueberry site, while, in the cranberry bogs sampled, soil NH_4-N levels were high and NO_3-N levels were low (Table 8). The implication is that 'Northblue' blueberry, because of imposed selection pressures of high NO_3-N in the root zone, has mechanisms to take up and use NO_3-N. In contrast, 'Searles' cranberry, a selection from the wild where NH_4-N apparently is the dominant N form, has a limited capacity to efficiently take up and/or use NO_3-N.

Table 8. Comparison of pH and extractable NO_3-N and NH_4-N in a blueberry and cranberry soil at two depths.[z]

Depth (cm)	Blueberry soil N form ($mg \cdot kg^{-1}$)		Cranberry soil N form ($mg \cdot kg^{-1}$)	
	NO_3-N[y]	NH_4-N	NO_3-N	NH_4-N
0–15	4.0 ± 2.6	0.6 ± 0.3	0.4 ± 0.2	1.6 ± 0.6
15–30	2.8 ± 1.5	0.4 ± 0.2	0.4 ± 0.3	4.4 ± 2.3

[z]Means of three replications ± SD at two sampling dates.
[y]NO_3-N and NH_4-N extracted with 2 N KCl (1 soil : 5 extractant).

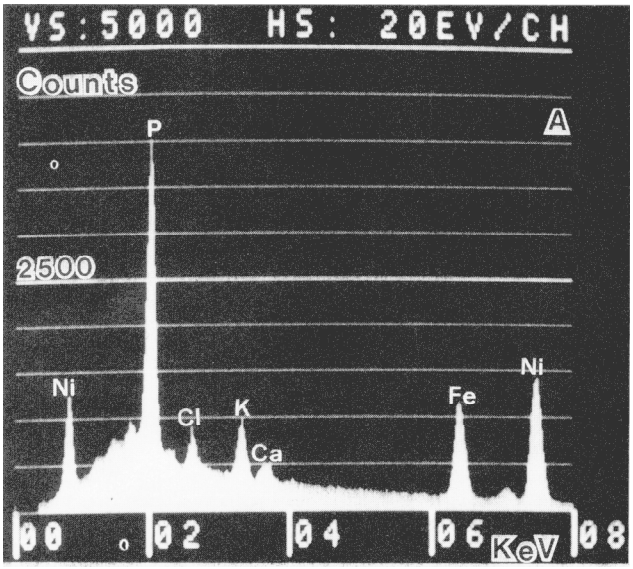
Growth responses of these clones to pH are less clear. Blueberry growth was severely inhibited at pH 6.5, whereas cranberry showed only a slightly lower root growth due to high pH. Townsend (1969) also found blueberry growth to be poor at higher solution pH levels compared to lower levels. For cranberry, previous studies have shown that increasing solution pH up to 6 increases shoot growth and that further increases in pH decreased shoot growth (Medappa and Dana, 1970). Both of these clones grow natively in acidic soil environments; however, based on solution culture experiments, 'Searles' cranberry seems to have a greater capacity to grow at a higher pH than 'Northblue' blueberry.

Effects of pH and N form on root color in Ericaceous plants have been reported in previous studies (Peterson et al., 1988; Townsend, 1967, 1969, 1971). Observations of Mn accumulation in roots with high solution pH and NO_3-N have led to the hypothesis that root darkening may result from precipitation of hydrated manganese oxide (Peterson et al., 1988; Townsend, 1971). In agreement with these previous reports, NO_3-N and high pH resulted in a darkening of blueberry and cranberry

roots. Furthermore, high root Mn was associated with-high solution pH, and, to a lesser extent, NO_3-N (Table 5), suggesting that root-zone pH and Mn precipitation play a role in root color.

Root concentrations of Fe were also extremely high in both clones. In contrast, shoot concentrations were as much as 100 times lower. In previous studies with blueberries (Townsend, 1967, 1969), root concentrations of Fe were found to be 20 to 30 times higher than shoot concentrations. With cranberries, Fe was selectively excluded from shoot tissues when present at high external concentrations (Medappa and Dana, 1970). Therefore, the high root Fe concentrations detected in the present experiment most likely were due to precipitation of iron salts on the root surface.

Using X-ray microanalysis, small crystal-like particles were observed on surfaces of cranberry roots from all treatments. X-ray spectra from roots grown in the NH_4-N/NO_3-N treatment at pH 4.5 and 6.5 are shown in Figs. 1 and 2. At the low pH, spectra from the particles had elevated levels of Fe and P compared to spectra from root epidermal cells devoid of particles



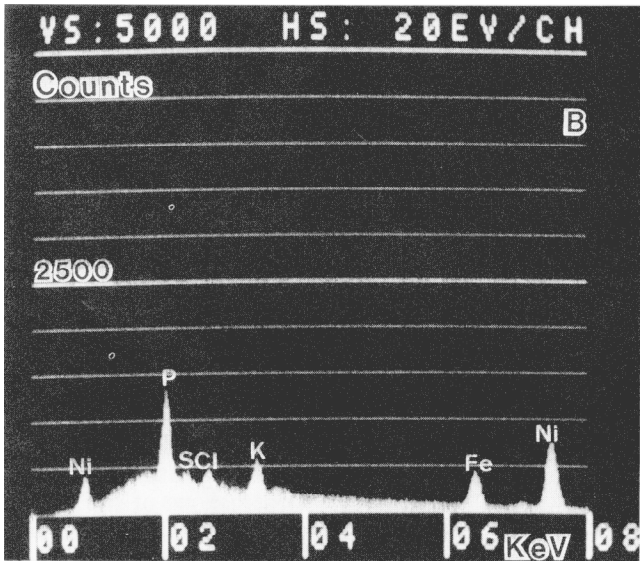
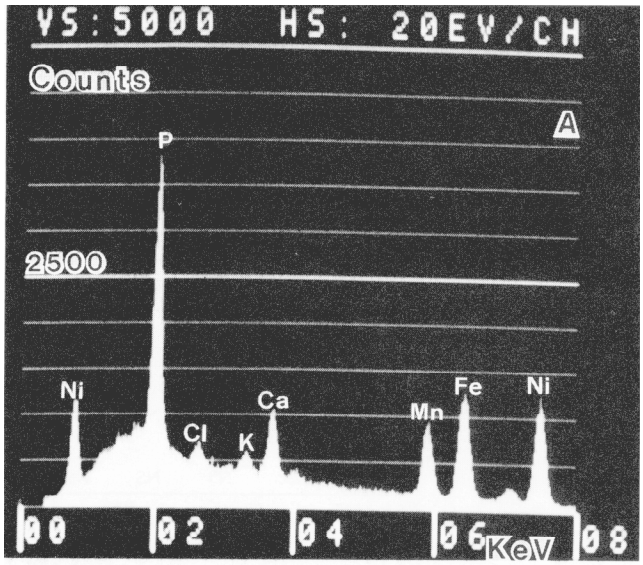


Fig. 1. X-ray microanalysis spectra of 'Searles' cranberry roots from pH 4.5, NH_4-N/NO_3-N treatment indicating relative nutrient levels. **(A)** Spectrum of crystal-like particle on root surface. **(B)** Spectrum of epidermal cell surface.



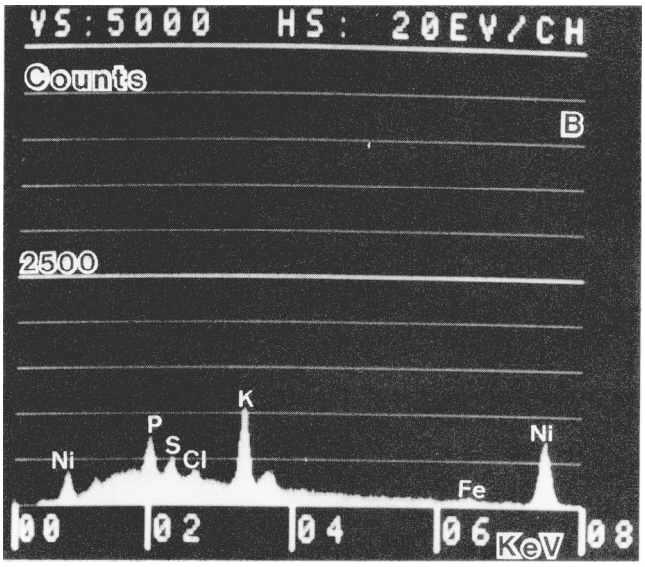


Fig. 2. X-ray microanalysis spectra of 'Searles' cranberry roots from pH 6.5, NH_4-N/NO_3-N treatment indicating relative nutrient levels. **(A)** Spectrum of crystal-like particle on root surface. **(B)** Spectrum of epidermal cell surface.

(Fig. 1 A and B). Manganese levels were generally below detection limits of the x-ray analyzer in roots grown at low pH. Similar results were observed at the high pH, except that Mn was also present in the particles (Fig. 2 A and B). A large portion of the Mn associated with the roots at the high-pH treatment is apparently external to the epidermal cells. Use of EDTA as a chelate for Fe has been shown to increase precipitation Fe on the root surface (Chancy and Bell, 1987). Thus, the form of Fe supplied, and the duration (7 to 9 months) and dosage (80 μM) to which roots were exposed, may have contributed to the Fe phosphate or hydroxide precipitation.

In conclusion, this study has demonstrated that N form was an important factor in the growth of 'Searles' cranberry, but was less important in the growth of 'Northblue' blueberry. Differences in the N response of these cultivars may be related to the environments in which they were selected. Conceivably, the variation within each species for NO_3-N use may account for the varied responses reported in the literature.

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