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

Carl J. Rosen¹, Deborah L. Allan¹, and James J. Luby²
University of Minnesota, St. Paul, MN 55108

Additional index words. blueberry, cranberry, ammonium, nitrate, X-ray microanalysis, soil nitrogen

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 (NO₃-N, NH₄-N, and NH₄-N/NO₃-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 NH₄-N/NO₃-N or NH₄-N than with NO₃-N alone. Cranberry plants receiving NO₃-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 NO₃-N and low NH₄-N levels; soil from commercial ‘Searles’ cranberry bogs had relatively low NO₃-N and high NH₄-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 NH₄-N to be the dominant N form available to plant roots (Rorison, 1986). Response of blueberry and cranberry to NO₃-N and NH₄-N nutrition has been variable. In some studies (Cain, 1952; Greidanus et al., 1972; Peterson et al., 1988; Townsend, 1967, 1969), NH₄-N was superior to NO₃-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 NO₃-N as on NH₄-N when the pH was <6.2. Genotypic differences in NO₃-N use within the Vaccinium genus may also account for some of the variation. Cranberries appear to grow better with NH₄-N than NO₃-N and generally grow poorly when supplied with NO₃-N alone (Greidanus et al., 1972). However, beneficial effects of NO₃-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 NH₄-N as the sole form of N are generally reduced compared to those provided with NO₃-N, unless pH is strictly maintained...
between 5.7-6.1 (Peet et al., 1985; Rufty et al., 1983). *Vaccinium* spp. appear to be tolerant of NH$_3$-N, even at pH levels between 4.0-5.0. Precise mechanisms for NH$_3$-N tolerance by *Vaccinium* are not known, but may be 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 half-high 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$_4$·2H$_2$O, 1.0; MgSO$_4$·7H$_2$O, 0.75; K$_2$SO$_4$, 0.5; Ca(H$_2$PO$_4$)$_2$, 0.13; (in µM), FeNaEDTA, 80; H$_3$BO$_3$, 46; MnCl$_2$·4H$_2$O, 9; ZnSO$_4$·7H$_2$O, 0.8; CuSO$_4$·5H$_2$O, 0.3; H$_2$MoO$_4$·H$_2$O, 0.1, adjusted to a pH of 4.5. Nitrogen was then adjusted in the background solution to 2 mM using NH$_4$NO$_3$ 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 28°C day and a 10-hr 20°C night.

Treatments were initiated by transferring plants to the background nutrient solution containing NH$_4$-N alone, NH$_3$-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$_4$)$_2$SO$_4$ in the NH$_4$-N-alone solution, NH$_4$NO$_3$ in the NH$_3$-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$_3$-N-alone solution, 2.25 mM in the NH$_3$-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$_2$SO$_4$. 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$_3$-N to NO$_3$-N. During the course of the experiment, NO$_3$-N and NH$_3$-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 60°C 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$_2$SO$_4$, 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 1-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 nitritification. 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 −70°C 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 711F 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 (Udorthic Halapollolls) and that collected at Wisconsin Rapids was a Markey mucky peat (Terric Borosaprists) overlaid with a Newson sand (Humaqueptic Psammareptus). Samples were kept moist and cool (4°C) before analysis. Nitrate-N and NH$_3$-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$_3$-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-
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 blueberries, 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
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 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·kg$^{-1}$. In this experiment, treatments were initiated when total plant fresh mass was $\geq$ 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 3. Solution pH and N form effects on elemental composition of 'Northblue' blueberry shoots.**

| Variable  | N (g·kg$^{-1}$) | P | K | Ca | Mg | Fe | Al | Mn | Zn | Cu | B |
|-----------|----------------|---|---|----|----|----|----|----|----|----|---|
| 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** | **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 |
| pH 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 | 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.**

| Variable  | N (g·kg$^{-1}$) | P | K | Ca | Mg | Fe | Al | Mn | Zn | Cu | B |
|-----------|----------------|---|---|----|----|----|----|----|----|----|---|
| 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** | **NS** | **NS** | **NS** | **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 |
| pH 6.5    | 1.16           | 1.57 | 6.24 | 4.82 | 1.40 | 61  | 27 | 192 | 19 | 4 | 70 |
| **Significance** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| pH × N form | NS | NS | NS | 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.**

| pH | N form | Blueberry | Cranberry |
|----|--------|-----------|-----------|
|    | 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       |
| **Significance** | **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.

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, 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, NO₃-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 NH₄-N/NO₃-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 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 NO₃-N use may account for the varied responses reported in the literature.
Addoms, R.M. and F.C. Mounce. 1932. Further notes on the nutrient requirements and the histology of the cranberry, with special reference to the sources of nitrogen. Plant Physiol. 7:643-656.

Cain, J.C. 1952. A comparison of ammonium and nitrate nitrogen for blueberries. Proc. Amer. Soc. Hort. Sci. 59:161-166.

Carlson, R.M. 1978. Automatic separation and conductimetric determination of ammonia and dissolved carbon dioxide. Anal. Chem. 50:1528-1532.

Carlson, R.M. 1986. Continuous flow reduction of nitrate to ammonia with granular zinc. Anal. Chem. 58:1590-1591.

Chancy, R.L. and P.F. Bell. 1987. Complexity of iron nutrition: lessons for plant-soil interaction research. J. Plant Nutr, 10:963-994.

Dirr, M.A. 1974. Nitrogen form and growth and nitrate reductase activity of the cranberry. HortScience 9:347-348.

Greidanus, T., L.A. Peterson, L.E. Schrader, and M.N. Dana. 1972. Essentiality of ammonium for cranberry nutrition. J. Amer. Soc. Hort. Sci. 97:272-277.

Hammett, L.K. and W.E. Ballinger. 1972. A nutrient solution-sand culture system for studying the influence of N form on highbush blueberries. HortScience 7:498-500.

Leschyson, M.A. and G.W. Eaton. 1971. Effects of urea and nitrate nitrogen on growth and composition of cranberry vines. J. Amer. Soc. Hort. Sci. 96:597-599.

Luby, J.J., D.K. Wildung, C. Stushnoff, S.T. Munson, P.E. Read, and E.E. Hoover. 1986. ‘Northblue’, ‘Northsky’, and ‘Northcountry’ blueberries. HortScience 21:1240-1242.

Medappa, K.C. and M.N. Dana. 1970. The influence of pH, Ca, P and Fe on the growth and composition of the cranberry plant. Soil Sci. 109:250-253.

Munter, R.C., T.C. Halverson, and R.D. Anderson. 1984. Quality assurance for plant tissue analysis by ICP-AES. Commun. Soil Sci. Plant Anal. 15:1285-1322.

Oertli, J.J. 1963. Effect of form of nitrogen and pH on growth of blueberry plants. Agron. J. 55:305-307.

Peet, M.M., C.D. Raper, L.C. Tolley, and W.D. Robarge. 1985. Tomato responses to ammonium and nitrate nutrition under controlled root-zone pH. J. Plant Nutr. 8:787–798.

Peterson, L.A., E.J. Stang and M.N. Dana. 1988. Blueberry response to NH$_4$-N and NO$_3$-N. J. Amer. Soc. Hort. Sci. 113:9-12.

Rorison, I.H. 1986. The response of plants to acid soils. Experientia 42:357-362.

Rufty, T.W., C.D. Raper and W.A. Jackson. 1983. Growth and nitrogen assimilation of soybeans in response to ammonium and nitrate nutrition. Bot. Gaz. 144:466-470.

Salsac, L., S. Chaillou, J. Morot-Gaudry, C. Lesaint, and E. Jolivet. 1987. Nitrate and ammonium nutrition in plants. Plant Physiol. Biochem. 25:805-812.

Stang, E.J. and M.N. Dana. 1984. Wisconsin cranberry production. HortScience 19:478.

Stieber, T. and L.A. Peterson. 1987. Contribution of endogenous nitrogen toward continuing growth in a cranberry vine. HortScience 22:463-464.

Townsend, L.R. 1967. Effect of ammonium nitrogen and nitrate nitrogen, separately and in combination, on the growth of the highbush blueberry. Can. J. Plant Sci. 47:555-562.

Townsend, L.R. 1969. Influence of form of nitrogen and pH on growth and nutrient levels in the leaves and roots of the lowbush blueberry. Can. J. Plant Sci. 49:333-338.

Townsend, L.R. 1971. Effect of acidity on growth and nutrient composition of the highbush blueberry. Can. J. Plant Sci. 51:385-390.