

Blueberry Germplasm Screening at Several Soil pH Regimes. II. Plant Nutrient Composition

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Abstract. Seedlings from crosses among *Vaccinium corymbosum* L., *V. angustifolium* Ait, and *V. corymbosum/V. angustifolium* hybrid-derivative parents, and micropropagated 'Northblue', 'Northsky', and 'Northcountry' plants, were grown for 2 years at Becker, Minn., in low (5.0) and high (6.5) soil pH regimes. Nutrient composition expressed as a concentration and total content was determined for P, K, Ca, Mg, Fe, Mn, Zn, Cu, and B in the aboveground portion of the plant. Except for Fe, the pH regime effects on aboveground plant nutrient concentration and total content were much larger than population or population × pH regime interaction effects. Population × pH regime interactions were detected for all nutrients expressed as a concentration, except for P. Generalizations about plant performance and nutrient concentration of the plant could only be made in the context of a given pH regime. At low pH, P and Mn tissue concentrations increased and Ca, Mg, and B concentrations decreased as the percentage of lowbush ancestry increased. At high pH, K, Cu, and B concentrations decreased as the percentage of lowbush ancestry increased. Overall plant performance on the higher pH soils appeared to be positively correlated to aboveground tissue concentrations of Mn, K, and Cu. When expressed as total content, population × pH regime effects were only significant for tissue Mn. Differences in total nutrient content attributed to soil pH were primarily related to differences in plant dry weight.

Blueberry plants require an acidic soil high in organic matter, with relatively low nutrient inputs in commercial production (Galletta, 1975; Korcak et al., 1982). Acidifying soil amendments, which can be expensive and provide only short-term solutions to higher pH soils, are used to modify the soil for successful blueberry growth. Recently, studies have been conducted to better understand the variables involved in developing blueberry plants adapted to a wider range of physical and chemical soil properties (Finn et al., 1993; Korcak, 1989; Korcak et al., 1982; Rosen and Luby, 1987). *Vaccinium angustifolium* has been suggested as being more tolerant of upland soils (which usually have higher pH) than *V. corymbosum*, as well as being a source of adaptation to northern climates (Galletta, 1975; Korcak, 1986a; 1989; Korcak et al., 1982; Rosen and Luby, 1987).

Several researchers have studied factors affecting the nutrient status of *V. angustifolium*, *V. corymbosum*, and hybrids of these species. Most research has focused on leaf nutrient concentration under ideal nutrient conditions (Korcak, 1986b; Korcak et al., 1982; Rosen and Luby, 1987), at various pH levels in containers (Cain, 1954; Hall et al., 1964; Townsend, 1969; 1971), or on various soil types (Chandler et al., 1985; Hall et al., 1964; Haynes and Swift, 1986; Korcak, 1986b, Korcak et al., 1982; Reich et al., 1982). We found no field studies that have examined nutrient concentration and total nutrient content under various soil pH regimes.

The foliar nutrient composition of highbush, lowbush, and species-hybrid derivatives has been shown to differ (Ballinger, 1966; Chandler et al., 1984; Korcak, 1986b; 1988; 1989; Korcak

et al., 1982; Rosen and Luby, 1987). Hall et al. (1964) reported that the foliar Mn concentration in *V. angustifolium*, at optimal pH levels, was up to 10 times the level that Eck (1988) reported as being excessive in *V. corymbosum*. Based on this striking difference and the hypothesis that *V. angustifolium* might be more tolerant of higher pH, researchers have attempted to identify potential relationships between nutrient composition and pH tolerance. Hall et al. (1964) found in *V. angustifolium* that Ca, Mg, and Fe concentrations increased or were unchanged, and P, K, and Mn concentrations and plant dry weight decreased as pH level increased. However, all total nutrient content levels, a function of plant dry weight, were lower at higher pH. Recently, Gupton and Spiers (1992) reported that heritability estimates for *V. ashei* crosses were high for tissue concentrations of Mn, Zn, Ca, Mg, and K. Genetic correlations between elemental concentrations and visual ratings also were observed.

Rosen and Luby (1987) reported variations in foliar elemental composition in *V. angustifolium*, *V. corymbosum*, and *V. Corymbosum/V. angustifolium* hybrid derivatives and progenies derived from them. These authors identified parents whose progenies tended to accumulate higher or lower concentrations of various nutrients and determined that the leaf concentration of various nutrients could be related to the percent lowbush ancestry of a progeny or parent. These conclusions, along with those of Korcak et al. (1982) and Brown and Draper (1980), who examined largely highbush progenies, suggested that nutrient concentration and total content can vary among *Vaccinium* spp. and may provide an additional selection criterion for identifying genotypes tolerant of higher pH.

In a companion paper, we reported that blueberry seedlings produced from crosses among *V. corymbosum*, *V. angustifolium*, and *V. corymbosum/V. angustifolium* hybrid derivative parents varied in growth and development when grown for two seasons under three soil pH regimes (pH ≈5.0, 5.5, and 6.5) (Finn et al., 1993). The objectives of this study were to 1) characterize the influence of *V. angustifolium* ancestry and soil pH on the nutrient status of progenies, and 2) determine whether a relationship exists between nutrient status and performance on a higher pH soil.

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Table 1. Ancestry of blueberry cultivars and populations.

Cultivar/population (ancestry) ²	Lowbush (%)
Northsky (B-6 × R2P4)	25
Northcountry (B-6 × R2P4)	25
Northblue (B-10 × US-3)	25
8634 (MN-61 × Spartan)	25
8641 (GR-1 × Spartan)	25
8619 (MN-61 × Northblue)	33
8645 (Northblue × GR-1)	33
8603 (Spartan × GRVa.)	50
8616 (N70249 × Spartan)	50
8628 (N70249 × B-16)	50
8617 (N70249 × Northblue)	62
8602 (MN-61 × GRVa.)	75
8605 (GR-1 × GRVa.)	75
85306 [(N70249 × B-22)OP ³]	75
85319 (GR4-32 OP ³)	100
85335 (GR11-36 OP ³)	100
85336 (GR12-28 OP ³)	100
86200 (N7068 × N7084)	100
86205 (N7068 × N70146)	100
86206 (N7068 × N70153)	100
86216 (N7094 × N7084)	100
86261 (N70119 × N7094)	100
86265 (N70119 × N70146)	100
86283 (N70153 × N7098)	100
86287 (N70153 × N70146)	100

²For further information on parents refer to Finn et al. (1993).

³OP = open pollinated in a collection of *V. angustifolium*.

Materials and Methods

The diverse group of *Vaccinium* germplasm evaluated in this study included 22 populations and three cultivars (Table 1). Blueberry seeds from the various populations were sown in Dec. 1986 on sphagnum peat under mist in the greenhouse. Seedlings and rooted microcuttings of the cultivars were transplanted into 150-cm³ peat pots filled with a sphagnum peat/Pro-mix media and grown until 1 June 1987, in the greenhouse. The seedlings were

moved to an outdoor lath house 2 weeks before planting for acclimation to field conditions. Seedlings ranged from 10 to 30 cm tall at planting on 23 June 1987. The cultivar plants were about the same size as the seedlings at planting.

The planting was located at the Sand Plain Research Farm in Becker, Minn., on a Hubbard loamy sand (sandy, mixed, Udorthentic Haploborolls) with 2% to 3% organic matter and pH 5.5 (1: 1, soil: water paste). Other initial soil chemical properties are provided by Finn et al. (1993). The site was divided into four blocks and, within each block, three pH regimes were randomly assigned to 9 × 15 m sections. Culture practices have been described previously (Finn, et al., 1993). Soil pH was monitored from pretreatment through planting, until the plants were harvested from the field. Low (pH ≈5.0) and high (pH ≈6.5) pH regimes were established in Oct. 1986. Ground dolomitic limestone equivalent to 10.9 t·ha⁻¹ and FeSO₄·7H₂O (20% Fe) equivalent to 5.4 t·ha⁻¹ were incorporated to establish the low and high pH regimes, respectively. An additional 7.1 t·ha⁻¹ of lime was incorporated into the high pH regime in May 1987. In contrast to experiments reported in the companion paper (Finn et al., 1993) where growth and development were compared under three pH regimes, nutritional status was characterized only at the low and high pH levels.

The entire aboveground portion from each plant (stems and leaves), harvested on 7 Sept. 1988, was rinsed in tap water, then in distilled water, and oven dried at 60C for at least 48 h. All plants (2–5) from each population within each pH regime block were combined and ground to pass a 1.0 mm sieve. Tissue samples (1 g) were dry ashed at 500C overnight, and the ash was dissolved in 10 ml 2N HCl. Tissue nutrient concentrations (milligrams nutrient per kilograms tissue dry weight) of P, K, Ca, Mg, Fe, Mn, Zn, B, and Cu were determined by inductively coupled plasma emission spectroscopy (Munter et al., 1984). Because of limited plant material in the high pH regime, N and S determinations were not made. Total nutrient content per plant (grams nutrient per plant) was computed as nutrient concentration (grams nutrient per grams tissue dry weight) multiplied by the average population dry weight (grams tissue dry weight per plant).

Soil samples from each plot (six cores per plot) were collected in the interval from 0 to 15 cm. After air drying, soil pH was determined in a soil: water (1:1) paste; soil P was determined using the Bray P1 extractant (Bray and Kurtz, 1945); soil Ca, Mg, and K

Table 2. Selected soil chemical properties for soils collected at termination of the experiment from high (6.5 ± 0.3) and low (5.0 ± 0.2) pH regimes.²

Regime	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	<i>(mg·kg⁻¹)</i>							
High	61 ± 19	65 ± 17	1279 ± 370	78 ± 8	21 ± 1	10 ± 3	0.6 ± 0.1	1.9 ± 0.5
Low	45 ± 4	60 ± 10	366 ± 85	52 ± 16	79 ± 11	39 ± 3	0.8 ± 0.1	1.9 ± 0.2

²Mean and SD of four replications.

Table 3. Mean square probability values (ANOVA F-tests) for treatment effects and interactions for log₁₀ dry weight, nutrient concentration, and log₁₀ total nutrient content.

Source	df	Dry wt	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	<i>Nutrient concn</i>										
pH regime	1	0.05	0.06	0.04	0.02	0.04	0.98	0.01	0.03	0.01	0.03
Population (pop.)	24	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
pH regime × pop.	24	0.34	0.24	0.02	0.01	0.06	0.09	0.01	0.01	0.01	0.01
	<i>Total content</i>										
pH regime	1		0.05	0.05	0.07	0.06	0.04	0.02	0.08	0.03	0.04
Pop.	24		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
pH regime × pop.	24		0.18	0.13	0.32	0.46	0.17	0.01	0.15	0.15	0.26

were determined in ammonium acetate extracts (Thomas, 1982); and Fe, Mn, Cu, and Zn were determined in DTPA (diethylenetriamine pentaacetic acid) extracts (Lindsay and Norvell, 1978).

Analyses of variance were computed for a randomized complete block with split plots, where pH regime served as main plots and populations as subplots (Finn et al., 1993). The variation between pH levels for dry weight and total nutrient content was large and, therefore, the logarithmically transformed (base 10) values were analyzed (Steel and Torrie, 1980). For simplicity, data are presented as the antilog of the transformed means.

Results and Discussion

At the end of the experiment, concentrations of ammonium acetate extractable Ca and Mg and Bray P extractable P were higher in the high pH (lime-amended) soils, while DTPA extractable Fe and Mn concentrations were higher in the low pH (iron sulfate-amended) soils (Table 2). An unavoidable confounding effect of these soil amendments was that pH changes were also associated with changes in soil elemental concentrations. These differences must be kept in mind when comparing the effects of pH on nutritional status, our first objective. However, for our second objective, comparisons of interest were primarily those within a pH regime.

Differences in aboveground dry weight were significant for population and pH regime, and the interaction effect was nonsignificant (Table 3). The variation among populations was significant for concentration and total content for each nutrient. Except for Fe concentration, the pH regime effects were also significant for all nutrients. Population \times pH regime interactions for nutrient concentration were significant ($P \leq 0.10$) for all elements except for P, while for total content, they were only significant for Mn. For aboveground dry weight and for all nutrients except Fe, the pH treatment had an overriding effect on nutrient concentration and total nutrient content, since the mean squares resulting from pH regime effects were much larger than mean squares for population effects or the population \times pH regime interaction (data not shown).

Although tissue Fe concentrations were similar at both pH

levels, they were high (Table 4), which suggests contamination of the samples with Fe from soil that may not have washed off during preparation. Average aluminum concentrations in aboveground tissues were also high ($>450 \text{ mg}\cdot\text{kg}^{-1}$), suggesting soil contamination (Jones et al., 1991). Although poor growth on high pH soils and chlorosis in blueberries is believed to be related to iron nutrition, tissue concentrations of Fe are not highly correlated with these symptoms (Cain, 1954; Gupton and Spiers, 1992; Korcak, 1989).

Despite significant differences in plant nutrient concentrations because of pH (Table 4), dry-weight accumulation was several fold higher at low pH and had an overriding effect on total nutrient content. Thus, plants grown under the low pH regime had a higher total content of all nutrients than those grown at high pH (Table 5).

Although Korcak (1988) found that stem and leaf nutrient concentrations differed, the aboveground tissue nutrient concentrations under the low pH regime (Table 4) were similar to leaf concentrations in blueberries with similar ancestry, grown on native soil in the same field (Rosen and Luby, 1987). The nutrient concentrations in aboveground tissue (stems and leaves combined) at low pH were within the same range as leaf concentrations of Mg, Mn, Cu, and B measured on plants grown on unamended soil at this site, but were lower for P and K, higher for Ca and Zn, and much higher for Fe (Rosen and Luby, 1987).

The large number of populations made it impractical to plot or tabulate all pH \times population interactions for all nutrients. Therefore, to address our objective on the relationship between *V. angustifolium* ancestry and pH tolerance, the populations were separated into groups based on percent lowbush ancestry. In addition, the correlations between the percent lowbush ancestry and either nutrient concentration or total content were calculated within each pH regime (Tables 4 and 5). The number of populations (or cultivars) within each percent lowbush classification were as follows: 25% to 33%, seven populations; 50% to 75%, seven populations; and 100%, 11 populations (Table 1).

At low pH, the concentration of P and Mn increased as the percent lowbush ancestry increased. However, Ca, Mg, and B concentrations decreased (Table 4). In contrast, at pH 5.0, Rosen and Luby (1987) found a highly significant positive correlation of

Table 4. Dry weight and nutrient concentrations in aboveground portion of blueberry plants grown at high (6.5) and low (5.0) pH.

Effect	Dry wt (g)		Nutrient concn																	
			(g·kg ⁻¹)								(mg·kg ⁻¹)									
			P	P	K	K	Ca	Ca	Mg	Mg	Fe	Fe	Mn	Mn	Zn	Zn	Cu	Cu	B	B
Overall	12.0	1.7	0.64	0.51	4.83	2.83	7.64	12.87	1.66	2.03	239	239	1149	248	20	36	2.8	2.0	46	21
pH regime ^z	*		#		*		*		*		NS		**		*		**		*	
Percent lowbush ^y																				
25-33	13.5	2.7	0.58	0.48	4.47	3.11	8.45	12.59	1.93	2.05	246	248	915	248	21	34	2.8	2.4	52	23
50-75	15.8	2.2	0.62	0.51	4.93	3.00	7.96	13.89	1.74	2.17	225	223	1135	298	21	42	3.1	2.0	50	22
100	9.8	1.1	0.68	0.52	4.99	2.59	7.01	12.51	1.47	1.93	243	241	1292	222	19	33	2.6	1.8	42	18
r ^x	NS	-0.52	0.67	NS	NS	-0.35	-0.72	NS	-0.71	NS	NS	NS	0.61	NS	NS	NS	NS	-0.46	-0.37	-0.43
Correlation of nutrient concentration with log ₁₀ dry weight ^t																				
	---	---	-0.40	0.29	0.50	0.72	0.03	-0.30	0.08	-0.15	-0.28	0.04	0.03	0.37	-0.05	0.20	0.01	0.46	0.40	0.28
			*	NS	**	**	NS	NS	NS	NS	NS	NS	NS	#	NS	NS	NS	*	*	NS

^z*, **, ***F value is >1 for pH regime effects ($P < 0.10$, 0.05, or 0.01, respectively) or r not equal to 0 for correlation. NS means not significantly different.

^yMeans for the population within each grouping. Population groups are based on populations percent lowbush ancestry, with seven, seven, and 11 populations within each grouping, respectively.

^xThe correlation between the percent lowbush ancestry and the nutrient concentration or dry weight. Only r values not equal to 0 ($P \leq 0.10$; $df = 23$) are listed.

Table 5. Mean total content of macro- and micronutrients for the aboveground portion of blueberry plants grown at high (6.5) and low (5.0) pH.

Effect	Nutrient content (mg/plant)																	
	P low	P high	K low	K high	Ca low	Ca high	Mg low	Mg high	Fe low	Fe high	Mn low	Mn high	Zn low	Zn high	Cu low	Cu high	B low	B high
Overall	7.5	0.8	56.2	4.4	89.1	19.5	19.5	3.2	2.8	0.4	12.9	0.3	0.22	0.05	0.032	0.003	0.5	0.03
pH regime ^z	*		*		#		#		*		*		#		*		*	
Percent lowbush ^y																		
25-33	7.8	1.3	58.9	8.1	109.6	31.6	25.1	5.2	3.2	0.6	11.2	0.5	0.25	0.09	0.037	0.006	0.6	0.06
50-75	9.5	1.1	74.1	6.2	123.0	29.5	26.9	4.6	3.5	0.5	17.0	0.4	0.32	0.09	0.047	0.004	0.7	0.04
100	6.6	0.5	46.8	2.6	67.6	12.9	14.1	2.0	2.3	0.3	12.3	0.3	0.17	0.33	0.025	0.002	0.4	0.02
r ^x	NS	-0.44	NS	-0.51	-0.37	-0.57	-0.41	-0.57	NS	-0.48	NS	-0.45	NS	-0.49	NS	-0.54	NS	-0.59

^z*F value > 1 for pH regime effects ($P \leq 0.10$ or 0.05 , respectively).

^yMeans for the populations within each grouping. Population groupings are based on populations percent lowbush ancestry, with seven, seven, and 11 populations within each grouping, respectively.

^xThe correlation between the percent lowbush ancestry and the nutrient concentration. Only r values not equal to 0 ($P \leq 0.10$, $df = 23$) are listed.

Ca, Mg, and B leaf concentrations and percent lowbush ancestry in similar blueberry germplasm. These differences may result from sampling whole plants in the present study rather than only leaves. Populations with a larger percentage lowbush ancestry concentrated P and Mn without a higher total content (Tables 4 and 5). Because total content of these elements was not affected, higher concentrations in lowbush germplasm were the result of similar uptake, but lower dry matter production. As the percentage of lowbush ancestry increased, total Ca and Mg content decreased at low pH (Tables 4 and 5).

At high pH, K, Cu, and B concentrations decreased as the percentage of lowbush ancestry increased (Table 4). The populations with a higher percentage of lowbush ancestry generally consisted of smaller plants and, thus, had a lower total content of all nutrients (Table 5). Calcium and Mg were the only nutrients exhibiting lower total content at both pH levels as the percent lowbush ancestry increased.

The average Mn concentration at low pH was $1149 \text{ mg}\cdot\text{kg}^{-1}$ (Table 3), which was higher than the average levels reported by Korcak et al. (1982) in populations derived largely from *V. corymbosum*, but within the range reported for the *V. corymbosum* cultivar 'Blueray' (Korcak, 1988) and for *V. angustifolium* (Hall et al., 1964; Townsend, 1969). Large variation in Mn concentration is not unusual in *Vaccinium* (Korcak, 1988). Korcak et al. (1986), Korcak (1988) and Rosen and Luby (1987) associated higher Mn concentration with *V. angustifolium* ancestry. These reports agree with the results from the present experiment at the low pH regime. However, at high soil pH, the populations had similar Mn concentrations regardless of ancestry and, when expressed as total content, Mn decreased with lowbush ancestry—a function of dry matter accumulation. Thus, mechanisms involving differential accumulation of Mn appear to be dependent on soil pH.

Another method of evaluating relationships between plant performance and nutrient status was to correlate dry matter accumulation and nutrient concentration over all populations within a pH regime. Although this relationship may have contributed to significant correlations between lowbush ancestry and nutrient status, as previously discussed, dry matter production and lowbush ancestry were only partially correlated at high pH and not correlated at low pH. Under the low pH regime, the correlation between nutrient concentration and dry weight was positive for K and B and negative for P (Table 4). The correlation between nutrient concentration and dry weight was positive ($P \leq 0.10$) for K, Mn, and Cu under the high pH regime. In previous studies, negative correlations between tissue K concentration and chlorosis or dry weight

accumulation were reported (Cain, 1954; Gupton and Spiers, 1992). Reasons for the positive correlation found in this study are not clear and may be related to the specific germplasm tested or soil type. It is questionable, therefore, whether selection for high tissue concentrations of K, Mn, or Cu would assist in the selection of populations with higher dry weight accumulation at higher pH. In addition, as pointed out by Gupton and Spiers (1992) and Finn et al. (1993), visual ratings and nondestructive plant volume measurements were highly correlated with shoot dry weight and may be the only selection criteria needed. Including the nutrient data, however, may help in understanding the response or tolerance mechanisms to higher pH.

For all nutrients, correlations between dry weight and nutrient content were high ($P \geq 0.91$, data not presented) because of the arithmetic relationship between these two traits and the large amount of variation for dry weight (Finn et al., 1993).

In conclusion, the effects of soil pH on the nutrient status in the plant depended on the populations examined. Therefore, generalizations about plant performance and nutrient concentration of the plant could only be made in the context of a given pH regime. Plant performance on higher pH soils appears to be related to concentrations of Mn, K, and Cu in the shoots, the significance of which needs further investigation. Although *V. angustifolium* has been proposed as a source of adaptation to upland soil conditions, which can include higher soil pH, the *V. angustifolium* germplasm examined in this study did not exhibit a particular tolerance to higher soil pH based on dry weight accumulation or nutrient status. Its adaptation to upland soils may result from other factors such as tolerance to drought, fine-textured soils, or low organic matter.

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